

ELEC374 - Lab 3

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April 12, 2021

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1 Components

The purpose of this lab was to design, simulate, implement and verify a simple RISC computer (Mini SRC). Verilog was chosen over VHDL as it is better for more complex simulations. The verilog code for each of these components can be found in the Appendices.

1.1 Datapath

Select and Encode logic was used for load and store instruction as well as add, and, or instructions. The opcode that is read into Select and Encode is used to create the outputs for Ra, Rb, and Rc, in order to generate the GRa, GRb, GRc, which is the encoded to R0in-R15in and R0out-R15out registers. There is also support for a sign-extended C value in the lower 19 bits of the instruction address.

1.2 Control Unit

The control unit was used to compute all the necessary instructions using signal in order for there to be only one testbench needed. In order to define the control unit all datapath signals were passed from previous labs and new ones in the ALU. Additionally, the RAM's memory is accessed through the corresponding hex file, which contains the opcodes for all instructions. A detailed breakdown of the memory subsystem can be found at Appendix A.1.

1.3 ALU

The conff logic is created to ensure that conditional logic such as the branch instruction are able to be executed. The instructions associated with the conditional logic are stored in I-formatting, with the second register holding the branching condition. The components for the conff logic can be found at Appendix D.

2 Circuitry Demonstration

To demonstrate the success of the RAM and memory interface logic, multiple testbenches were created to simulate each operation. The testbenches all have their own control sequences unique to every operation and can be found in the appendices. The following subsections of the circuitry demonstration will detail the changes made in the test benches due to the control sequence changing as well as the waveforms generated by each simulation. Each instruction used to demonstrate the circuitry requires a specific OP Code. The following table shows the OP Code values stored in RAM initially, their address in RAM and also the instruction itself. For a full version of the initial RAM state, please see Appendix ???. Furthermore, in an effort to save paper, only the relevant signals were included for each instruction.

*Note that these instructions were tested before the rest, thus, the .hex file hadn't be completed. Thus, Appendix ?? and Appendix ?? have empty values in RAM where the OP Codes are for later tests.

2.1 Load Instructions

Two load instructions were tested to ensure that the values are able to load from the RAM onto its appropriate register. The control sequences for *ld R1, \$85*, *ld R0, \$35(R1)*, *ldi R1, \$85*, *ldi R0, \$35(R1)* can be found in Appendices F.3, F.4, F.5, and F.6 respectively. The value 85₁₆ and 35₁₆ was preloaded into the memory initialization file in slots 85₁₆ and 35₁₆ for these instructions respectively. The specific opcodes for these instructions can be found in Figure 2, and the relevant address was loaded into the PC register. The value of 0₁₆ was preloaded into register 1.

Address	Instruction	Op code (binary)	Op code (hex)
0	ldi R3, \$87	00001 0011 0000 000 0000 0000 1000 1000	09800087
1	ldi R3, 1(R3)	00001 0011 0011 000 0000 0000 0000 0001	09980001
2	ld R2, \$75	00000 0010 0000 000 0000 0000 0111 0101	01000075
3	ldi R2, -2(R2)	00001 0010 0010 111 1111 1111 1111 1110	0917FFFE
4	ld R1, 4(R2)	00000 0001 0010 000 0000 0000 0000 0100	00900004
5	ldi R0, 1	00001 0000 0000 000 0000 0000 0000 0001	08000001
6	ldi R3, \$73	00001 0011 0000 000 0000 0000 0111 0011	09800073
7	brmi R3, 3	10010 0011 0000 000 0000 0000 0000 0011	91800003
8	ldi R3, 5(R3)	00001 0011 0011 000 0000 0000 0000 0101	09980005
9	ld R7, -3(R3)	00000 0111 0011 111 1111 1111 1111 1101	039FFFFD
10	nop	11001 0000 0000 000 0000 0000 0000 0000	C8000000
11	brpl R7, 2	10010 0111 0010 000 0000 0000 0000 0010	93900002
12	ldi R4, 6(R1)	00001 0100 0001 000 0000 0000 0000 0110	0A080006
13	ldi R3, 2(R4)	00001 0011 0100 000 0000 0000 0000 0010	09A00002
14	add R3, R2, R3	00011 0011 0010 0011 000 0000 0000 0000	19918000
15	addi R7, R7, 3	01011 0111 0111 000 0000 0000 0000 0011	5BB80003
16	neg R7, R7	10000 0111 0111 000 0000 0000 0000 0000	83B80000
17	not R7, R7	10001 0111 0111 000 0000 0000 0000 0000	8BB80000
18	andi R7, R7, \$0F	01100 0111 0111 000 0000 0000 0000 1111	63B8000F
19	ori R7, R1, 3	01101 0111 0001 000 0000 0000 0000 0011	6B880003
20	shr R2, R3, R0	00101 0010 0011 0000 000 0000 0000 0000	29180000
21	st \$58, R2	00010 0010 0000 000 0000 0000 0101 1000	11000058
22	ror R1, R1, R0	00111 0001 0001 0000 000 0000 0000 0000	38880000
23	rol R2, R2, R0	01000 0010 0010 0000 000 0000 0000 0000	41100000
24	or R2, R3, R0	01010 0010 0011 0000 000 0000 0000 0000	51180000
25	and R1, R2, R1	01001 0001 0010 0001 000 0000 0000 0000	48908000
26	st \$67(R1), R2	00010 0010 0001 000 0000 0000 0110 0111	11080067
27	sub R3, R2, R3	00100 0011 0010 0011 000 0000 0000 0000	21918000
28	shl R1, R2, R0	00110 0001 0010 0000 000 0000 0000 0000	30900000
29	ldi R4, 5	00001 0100 0000 000 0000 0000 0000 0101	0A000005
30	ldi R5, \$1D	00001 0101 0000 000 0000 0000 0001 1101	0A80001D
31	mul R5, R4	01110 0101 0100 000 0000 0000 0000 0000	72A00000
32	mfhi R7	10111 0111 0000 000 0000 0000 0000 0000	BB800000
33	mflo R6	11000 0110 0000 000 0000 0000 0000 0000	C3000000
34	div R5, R4	01111 0101 0100 000 0000 0000 0000 0000	7AA00000
35	ldi R10, 0(R4)	00001 1010 0100 000 0000 0000 0000 0000	0D200000
36	ldi R11, 2(R5)	00001 1011 0101 000 0000 0000 0000 0010	0DA80002
37	ldi R12, 0(R6)	00001 1100 0110 000 0000 0000 0000 0000	0E300000
38	ldi R13, 0(R7)	00001 1101 0111 000 0000 0000 0000 0000	0EB80000
39	jal R12	10100 1100 0000 000 0000 0000 0000 0000	A6700000
40	halt	11010 0000 0000 000 0000 0000 0000 0000	D0000000
41	ORG \$91:	—	—
145	add R9, R10, R12	00011 1001 1010 1100 000 0000 0000 0000	1CD60000
146	sub R8, R11, R13	00100 1000 1011 1101 000 0000 0000 0000	245E8000
147	sub R9, R9, R8	00100 1001 1001 1000 000 0000 0000 0000	24CC0000
148	jr R14	10011 1110 1000 0000 000 0000 0000 0000	9F800000

Figure 1: Table of relevant values in RAM initially

A General Components

A.1 Control Unit

```
1 module control_unit(
2
3   output reg Gra,Grb, Grc, Rin, Rout, BAout, Cout, Zloout, Zhighout// here,
4     you will define the inputs and outputs to your Control Unit
5   Yin, Zin,PCout, IncPC, MARin,Read, Write, Clear, ADD, AND, SHR,
6
7   input[31:0] IR,
8   input Clock, Reset, Stop, Con_FF);
9
10  parameter Initialize_Reset = -1 , Reset_state = 0 , fetch0 = 1 , fetch1 = 2
11    , fetch2 = 3 , // basic
12    // add
13    add3 = 4 , add4 = 5 , add5 = 6 ,
14    // sub
15    sub3 = 7 , sub4 = 8 , sub5 = 9 ,
16    // shr
17    shr3 = 10 , shr4 = 11 , shr5 = 12 ,
18    // shl
19    shl3 = 13 , shl4 = 14 , shl5 = 15 ,
20    // ror
21    ror3 = 16 , ror4 = 17 , ror5 = 18 ,
22    // rol
23    rol3 = 19 , rol4 = 20 , rol5 = 21 ,
24    // and
25    and3 = 22 , and4 = 23 , and5 = 24 ,
26    // or
27    or3 = 25 , or4 = 26 , or5 = 27 ,
28    // addi
29    addi3 = 28 , addi4 = 29 , addi5 = 30 ,
30    // andi
31    andi3 = 31 , andi4 = 32 , andi5 = 33 ,
32    // ori
33    ori3 = 34 , ori4 = 35 , ori5 = 36 ,
34    // mul
35    mul3 = 37 , mul4 = 38 , mul5 = 39 , mul6 = 40 ,
36    // div
37    div3 = 41 , div4 = 42 , div5 = 43 , div6 = 44 ,
38    // neg
39    neg3 = 45 , neg4 = 46 ,
40    // not
41    not3 = 47 , not4 = 48 ,
42    // ld
43    ld3 = 49 , ld4 = 50 , ld5 = 51 , ld6 = 52 , ld7 = 53 ,
44    // ldi
45    ldi3 = 54 , ldi4 = 55 , ldi5 = 56 ,
46    // st
47    st3 = 57 , st4 = 58 , st5 = 59 , st6 = 60 , st7 = 61 ,
48    // bracnh
49    branch3 = 62 , branch4 = 63 , branch5 = 64 , branch6 = 65 ,
50    // jr
51    jr3 = 76 ,
52    // jal
53    jal3 = 77 , jal4 = 78 ,
54    // in
55    in3 = 79 ,
```

```

54 // out
55 out3 = 80 ,
56 // mfhi
57 mfhi3 = 81 ,
58 // mflo
59 mflo3 = 82 ,
60 // nop
61 nop3 = 83 ,
62 // halt
63 halt3 = 84;
64
65 integer Present_state = Reset_state ;
66
67 always@ ( posedge Clock , posedge Reset , posedge Stop )
68 begin
69     if( Reset ) Present_state = #50 Initialize_Reset ;
70     if( Stop ) Present_state = halt3 ;
71     else case ( Present_state )
72         Initialize_Reset : #40 Present_state = Reset_state ;
73         Reset_state : #50 Present_state = fetch0 ;
74         fetch0 : #50 Present_state = fetch1 ;
75         fetch1 : #50 Present_state = fetch2 ;
76         fetch2 : #50 begin
77             case (IR [31:27])
78                 5 ' b00000 : Present_state = ld3;
79                 5 ' b00001 : Present_state = ldi3;
80                 5 ' b00010 : Present_state = st3;
81                 5 ' b00011 : Present_state = add3;
82                 5 ' b00100 : Present_state = sub3;
83                 5 ' b00101 : Present_state = shr3;
84                 5 ' b00110 : Present_state = shl3;
85                 5 ' b00111 : Present_state = ror3;
86                 5 ' b01000 : Present_state = rol3;
87                 5 ' b01001 : Present_state = and3;
88                 5 ' b01010 : Present_state = or3;
89                 5 ' b01011 : Present_state = addi3 ;
90                 5 ' b01100 : Present_state = andi3 ;
91                 5 ' b01101 : Present_state = ori3;
92                 5 ' b01110 : Present_state = mul3;
93                 5 ' b01111 : Present_state = div3;
94                 5 ' b10000 : Present_state = neg3;
95                 5 ' b10001 : Present_state = not3;
96                 5 ' b10010 : Present_state =branch3;
97                 5 ' b10011 : Present_state = jr3;
98                 5 ' b10100 : Present_state = jal3;
99                 5 ' b10101 : Present_state = in3;
100                5 ' b10110 : Present_state = out3;
101                5 ' b10111 : Present_state =mfhi3;
102                5 ' b11000 : Present_state =mflo3;
103                5 ' b11001 : Present_state = nop3;
104                5 ' b11010 : Present_state = halt3;
105                default : begin end
106            endcase
107        end
108        add3 : #50 Present_state = add4 ;
109        add4 : #50 Present_state = add5 ;
110        add5 : #50 Present_state = fetch0 ;
111        sub3 : #50 Present_state = sub4 ;
112        sub4 : #50 Present_state = sub5 ;

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113     sub5 : #50 Present_state = fetch0 ;
114     shr3 : #50 Present_state = shr4 ;
115     shr4 : #50 Present_state = shr5 ;
116     shr5 : #50 Present_state = fetch0 ;
117     shl3 : #50 Present_state = shl4 ;
118     shl4 : #50 Present_state = shl5 ;
119     shl5 : #50 Present_state = fetch0 ;
120     ror3 : #50 Present_state = ror4 ;
121     ror4 : #50 Present_state = ror5 ;
122     ror5 : #50 Present_state = fetch0 ;
123     rol3 : #50 Present_state = rol4 ;
124     rol4 : #50 Present_state = rol5 ;
125     rol5 : #50 Present_state = fetch0 ;
126     and3 : #50 Present_state = and4 ;
127     and4 : #50 Present_state = and5 ;
128     and5 : #50 Present_state = fetch0 ;
129     or3 : #50 Present_state = or4 ;
130     or4 : #50 Present_state = or5 ;
131     or5 : #50 Present_state = fetch0 ;
132     addi3 : #50 Present_state = addi4 ;
133     addi4 : #50 Present_state = addi5 ;
134     addi5 : #50 Present_state = fetch0 ;
135     andi3 : #50 Present_state = andi4 ;
136     andi4 : #50 Present_state = andi5 ;
137     andi5 : #50 Present_state = fetch0 ;
138     ori3 : #50 Present_state = ori4 ;
139     ori4 : #50 Present_state = ori5 ;
140     ori5 : #50 Present_state = fetch0 ;
141     mul3 : #50 Present_state = mul4 ;
142     mul4 : #50 Present_state = mul5 ;
143     mul5 : #50 Present_state = mul6 ;
144     mul6 : #50 Present_state = fetch0 ;
145     div3 : #50 Present_state = div4 ;
146     div4 : #50 Present_state = div5 ;
147     div5 : #50 Present_state = div6 ;
148     div6 : #50 Present_state = fetch0 ;
149     neg3 : #50 Present_state = neg4 ;
150     neg4 : #50 Present_state = fetch0 ;
151     not3 : #50 Present_state = not4 ;
152     not4 : #50 Present_state = fetch0 ;
153     ld3 : #50 Present_state = ld4 ;
154     ld4 : #50 Present_state = ld5 ;
155     ld5 : #50 Present_state = ld6 ;
156     ld6 : #50 Present_state = ld7 ;
157     ld7 : #50 Present_state = fetch0 ;
158     ldi3 : #50 Present_state = ldi4 ;
159     ldi4 : #50 Present_state = ldi5 ;
160     ldi5 : #50 Present_state = fetch0 ;
161     st3 : #50 Present_state = st4 ;
162     st4 : #50 Present_state = st5 ;
163     st5 : #50 Present_state = st6 ;
164     st6 : #50 Present_state = st7 ;
165     st7 : #50 Present_state = fetch0 ;
166     branch3 : #50 Present_state = branch4 ;
167     branch4 : #50 Present_state = branch5 ;
168     branch5 : #50 Present_state = branch6 ;
169     branch6 : #50 Present_state = fetch0 ;
170     jr3 : #50 Present_state = fetch0 ;
171     jal3 : #50 Present_state = jal4 ;

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172     jal4 : #50 Present_state = fetch0 ;
173     in3 : #50 Present_state = fetch0 ;
174     out3 : #50 Present_state = fetch0 ;
175     mfhi3 : #50 Present_state = fetch0 ;
176     mflo3 : #50 Present_state = fetch0 ;
177     nop3 : #50 Present_state = fetch0 ;
178     default : begin end
179 endcase
180 end
181
182 always@ ( Present_state )
183 begin
184     case ( Present_state )
185     Initialize_Reset : Clear <= 0;
186     Reset_state : begin
187         #10 Clear <= 0;
188         #15 Clear <= 1;
189         PCout <= 0; Zlowout <= 0; Zhighout <= 0;
190         MDRout <= 0; // initialize the signals
191         MARin <= 0; Zlowin <= 0; Zhighin <= 0;
192         PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
193         IncPC <= 0; Read <= 0; Write <= 0;
194         highin <= 0; lowin <= 0;
195         Cout <= 0; outPortIn <= 0; inPortOut <= 0;
196         con_in <= 0;
197         highout <= 0; lowout <= 0;
198         ADD <= 0; SUB <= 0; SHR <= 0; SHL <= 0; ROR
199         <= 0; ROL <= 0; AND <= 0; OR <= 0;
200         MUL <= 0; DIV <= 0; NEG <= 0; NOT <= 0;
201         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0;
202         Grb <= 0; Grc <= 0;
203         R15_enable <= 0; PC_enable <= 0;
204         Run <= 1;
205     end
206     fetch0 : begin
207         #10 PCout <= 1; MARin <= 1; IncPC <= 1;
208         Zlowin <= 1;
209         #15 PCout <= 0; MARin <= 0; IncPC <= 0;
210         Zlowin <= 0;
211     end
212     fetch1 : begin
213         #10 Zlowout <= 1; PCin <= 1; Read <= 1; MDRin <= 1;
214         #15 Zlowout <= 0; PCin <= 0; Read <= 0; MDRin <= 0;
215     end
216     fetch2 : begin
217         #10 MDRout <= 1; IRin <= 1;
218         #15 MDRout <= 0; IRin <= 0;
219     end
220     add3 : begin
221         #10 Grb <= 1; Rout <= 1; Yin <= 1;
222         #15 Grb <= 0; Rout <= 0; Yin <= 0;
223     end
224     add4 : begin
225         #10 Grc <= 1; Rout <= 1; Zlowin <= 1; ADD <= 1;
226         #15 Grc <= 0; Rout <= 0; Zlowin <= 0; ADD <= 0;
227     end
228     add5 : begin
229         #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
230         #15 Zlowout <= 0; Gra <= 0; Rin <= 0;

```



```

231     end
232 sub3 : begin
233     #10 Grb <= 1; Rout <= 1; Yin <= 1;
234     #15 Grb <= 0; Rout <= 0; Yin <= 0;
235     end
236 sub4 : begin
237     #10 Grc <= 1; Rout <= 1; Zlowin <= 1; SUB <=1;
238     #15 Grc <= 0; Rout <= 0; Zlowin <= 0; SUB <=0;
239     end
240 sub5 : begin
241     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
242     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
243     end
244 shr3 : begin
245     #10 Grb <= 1; Rout <= 1; Yin <= 1;
246     #15 Grb <= 0; Rout <= 0; Yin <= 0;
247     end
248 shr4 : begin
249     #10 Grc <= 1; Rout <= 1; Zlowin <= 1; SHR <=1;
250     #15 Grc <= 0; Rout <= 0; Zlowin <= 0; SHR <=0;
251     end
252 shr5 : begin
253     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
254     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
255     end
256 shl3 : begin
257     #10 Grb <= 1; Rout <= 1; Yin <= 1;
258     #15 Grb <= 0; Rout <= 0; Yin <= 0;
259     end
260 shl4 : begin
261     #10 Grc <= 1; Rout <= 1; Zlowin <= 1; SHL <=1;
262     #15 Grc <= 0; Rout <= 0; Zlowin <= 0; SHL <=0;
263     end
264 shl5 : begin
265     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
266     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
267     end
268 ror3 : begin
269     #10 Grb <= 1; Rout <= 1; Yin <= 1;
270     #15 Grb <= 0; Rout <= 0; Yin <= 0;
271     end
272 ror4 : begin
273     #10 Grc <= 1; Rout <= 1; ROR <= 1; Zlowin <=1;
274     #15 Grc <= 0; Rout <= 0; ROR <= 0; Zlowin <=0;
275     end
276 ror5 : begin
277     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
278     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
279     end
280 rol3 : begin
281     #10 Grb <= 1; Rout <= 1; Yin <= 1;
282     #15 Grb <= 0; Rout <= 0; Yin <= 0;
283     end
284 rol4 : begin
285     #10 Grc <= 1; Rout <= 1; ROL <= 1; Zlowin <=1;
286     #15 Grc <= 0; Rout <= 0; ROL <= 0; Zlowin <=0;
287     end
288 rol5 : begin
289     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;

```

```

290     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
291     end
292 and3 : begin
293     #10 Grb <= 1; Rout <= 1; Yin <= 1;
294     #15 Grb <= 0; Rout <= 0; Yin <= 0;
295     end
296 and4 : begin
297     #10 Grc <= 1; Rout <= 1; AND <= 1; Zlowin <=1;
298     #15 Grc <= 0; Rout <= 0; AND <= 0; Zlowin <=0;
299     end
300 and5 : begin
301     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
302     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
303     end
304 or3 : begin
305     #10 Grb <= 1; Rout <= 1; Yin <= 1;
306     #15 Grb <= 0; Rout <= 0; Yin <= 0;
307     end
308 or4 : begin
309     #10 Grc <= 1; Rout <= 1; OR <= 1; Zlowin <=1;
310     #15 Grc <= 0; Rout <= 0; OR <= 0; Zlowin <=0;
311     end
312 or5 : begin
313     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
314     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
315     end
316 addi3 : begin
317     #10 Grb <= 1; Rout <= 1; Yin <= 1;
318     #15 Grb <= 0; Rout <= 0; Yin <= 0;
319     end
320 addi4 : begin
321     #10 Cout <= 1; Zlowin <= 1; ADD <= 1;
322     #15 Cout <= 0; Zlowin <= 0; ADD <= 0;
323     end
324 addi5 : begin
325     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
326     #20 Zlowout <= 0; Gra <= 0; Rin <= 0;
327     end
328 andi3 : begin
329     #10 Grb <= 1; Rout <= 1; Yin <= 1;
330     #15 Grb <= 0; Rout <= 0; Yin <= 0;
331     end
332 andi4 : begin
333     #10 Cout <= 1; Zlowin <= 1; AND <= 1;
334     #15 Cout <= 0; Zlowin <= 0; AND <= 0;
335     end
336 andi5 : begin
337     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
338     #20 Zlowout <= 0; Gra <= 0; Rin <= 0;
339     end
340 ori3 : begin
341     #10 Grb <= 1; Rout <= 1; Yin <= 1;
342     #15 Grb <= 0; Rout <= 0; Yin <= 0;
343     end
344 ori4 : begin
345     #10 Cout <= 1; Zlowin <= 1; OR <= 1;
346     #15 Cout <= 0; Zlowin <= 0; OR <= 0;
347     end
348 ori5 : begin

```

```

349     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
350     #20 Zlowout <= 0; Gra <= 0; Rin <= 0;
351     end
352 mul3 : begin
353     #10 Grb <= 1; Rout <= 1; Yin <= 1;
354     #15 Grb <= 0; Rout <= 0; Yin <= 0;
355     end
356 mul4 : begin
357     #10 Gra <= 1; Rout <= 1; MUL <= 1; Zlowin <=1; Zhighin <= 1;
358     #35 Gra <= 0; Rout <= 0; MUL <= 0; Zlowin <=0; Zhighin <= 0;
359     end
360 mul5 : begin
361     #10 Zlowout <= 1; lowin <= 1;
362     #15 Zlowout <= 0; lowin <= 0;
363     end
364 mul6 : begin
365     #10 Zhighout <= 1; highin <= 1;
366     #15 Zhighout <= 0; highin <= 0;
367     end
368 div3 : begin
369     #10 Gra <= 1; Rout <= 1; Yin <= 1;
370     #15 Gra <= 0; Rout <= 0; Yin <= 0;
371     end
372 div4 : begin
373     #10 Grb <= 1; Rout <= 1; DIV <= 1; Zlowin <=1; Zhighin <= 1;
374     #35 Grb <= 0; Rout <= 0; DIV <= 0; Zlowin <=0; Zhighin <= 0;
375     end
376 div5 : begin
377     #10 Zlowout <= 1; lowin <= 1;
378     #15 Zlowout <= 0; lowin <= 0;
379     end
380 div6 : begin
381     #10 Zhighout <= 1; highin <= 1;
382     #15 Zhighout <= 0; highin <= 0;
383     end
384 neg3 : begin
385     #10 Grb <= 1; Rout <= 1; Zlowin <= 1; NEG <=1;
386     #15 Grb <= 0; Rout <= 0; Zlowin <= 0; NEG <=0;
387     end
388 neg4 : begin
389     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
390     #20 Zlowout <= 0; Gra <= 0; Rin <= 0;
391     end
392 not3 : begin
393     #10 Grb <= 1; Rout <= 1; Zlowin <= 1; NOT <=1;
394     #15 Grb <= 0; Rout <= 0; Zlowin <= 0; NOT <=0;
395     end
396 not4 : begin
397     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
398     #20 Zlowout <= 0; Gra <= 0; Rin <= 0;
399     end
400 ld3 : begin
401     #10 Grb <= 1; BAout <= 1; Yin <= 1;
402     #15 Grb <= 0; BAout <= 0; Yin <= 0;
403     end
404 ld4 : begin
405     #10 Cout <= 1; Zlowin <= 1; ADD <= 1;
406     #15 Cout <= 0; Zlowin <= 0; ADD <= 0;
407     end

```

```

408 ld5 : begin
409     #10 Zlowout <= 1; MARin <= 1;
410     #15 Zlowout <= 0; MARin <= 0;
411 end
412 ld6 : begin
413     #10 Read <= 1; MDRin <= 1;
414     #15 Read <= 0; MDRin <= 0;
415 end
416 ld7 : begin
417     #10 MDRout <= 1; Gra <= 1; Rin <= 1;
418     #15 MDRout <= 0; Gra <= 0; Rin <= 0;
419 end
420 ldi3 : begin
421     #10 Grb <= 1; BAout <= 1; Yin <= 1;
422     #15 Grb <= 0; BAout <= 0; Yin <= 0;
423 end
424 ldi4 : begin
425     #10 Cout <= 1; Zlowin <= 1; ADD <= 1;
426     #15 Cout <= 0; Zlowin <= 0; ADD <= 0;
427 end
428 ldi5 : begin
429     #10 Zlowout <= 1; Gra <= 1; Rin <= 1;
430     #15 Zlowout <= 0; Gra <= 0; Rin <= 0;
431 end
432 st3 : begin
433     #10 Grb <= 1; Rout <= 1; Yin <= 1; BAout <=1;
434     #15 Grb <= 0; Rout <= 0; Yin <= 0; BAout <=0;
435 end
436 st4 : begin
437     #10 Cout <= 1; Zlowin <= 1; ADD <= 1;
438     #15 Cout <= 0; Zlowin <= 0; ADD <= 0;
439 end
440 st5 : begin
441     #10 Zlowout <= 1; MARin <= 1;
442     #15 Zlowout <= 0; MARin <= 0;
443 end
444 st6 : begin
445     #10 Gra <= 1; Rout <= 1; MDRin <= 1;
446     #15 Gra <= 0; Rout <= 0; MDRin <= 0;
447 end
448 st7 : begin
449     #10 MDRout <= 1; Write <= 1;
450     #15 MDRout <= 0; Write <= 0;
451 end
452 branch3 : begin
453     #10 Gra <= 1; Rout <= 1; con_in <= 1;
454     #15 Gra <= 0; Rout <= 0; con_in <= 0;
455 end
456 branch4 : begin
457     #10 PCout <= 1; Yin <= 1;
458     #10 PCout <= 0; Yin <= 0;
459 end
460 branch5 : begin
461     #10 Cout <= 1; Zlowin <= 1; ADD <= 1;
462     #15 Cout <= 0; Zlowin <= 0; ADD <= 0;
463 end
464 branch6 : begin
465     if ( Con_FF ) begin
466         #10 Zlowout <= 1; PC_enable <= 1;

```

```

467         #15 Zlowout <= 0; PC_enable <= 0;
468     end
469 end
470 jr3 : begin
471     #10 Gra <= 1; Rout <= 1; PCin <= 1;
472     #15 Gra <= 0; Rout <= 0; PCin <= 0;
473 end
474 jal3 : begin
475     #10 R15_enable <= 1; PCout <= 1;
476     #15 R15_enable <= 0; PCout <= 0;
477 end
478 jal4 : begin
479     #10 Gra <= 1; Rout <= 1; PCin <= 1;
480     #15 Gra <= 0; Rout <= 0; PCin <= 0;
481 end
482 in3 : begin
483     #10 Gra <= 1; Rin <= 1; inPortOut <= 1;
484     #15 Gra <= 0; Rin <= 0; inPortOut <= 0;
485 end
486 out3 : begin
487     #10 Gra <= 1; Rout <= 1; outPortIn <= 1;
488     #15 Gra <= 0; Rout <= 0; outPortIn <= 0;
489 end
490 mfhi3 : begin
491     #10 Gra <= 1; Rin <= 1; highout <= 1;
492     #15 Gra <= 0; Rin <= 0; highout <= 0;
493 end
494 mflo3 : begin
495     #10 Gra <= 1; Rin <= 1; lowout <= 1;
496     #15 Gra <= 0; Rin <= 0; lowout <= 0;
497 end
498 nop3 : begin end // nothing
499 halt3 : Run <= 0; // no Run
500     default : begin end
501 endcase
502 end
503 endmodule

```

A.2 Datapath

```

1
2 module datapath (input Clock, Reset, Stop );
3
4     wire Rin , Rout , BAout , Cout , Gra , Grb , Grc;
5     wire PCOut , MDRout , Zhighout , Zlowout , Zhighin , Zlowin , highin ,
        lowin ,
6     highout , lowout ;
7     wire MARin , PCin , MDRin , IRin , Yin , con_in , IncPC ;
8     wire outPortIn , inPortOut , inPortIn ;
9     wire Read , Write , Clear , Run , PC_enable , R15_enable ;
10    wire ADD , SUB , SHR , SHL , ROR , ROL , AND , OR , MUL , DIV , NEG , NOT;
11    wire [11:0] CONTROL ;
12    assign CONTROL [0] = AND;
13    assign CONTROL [1] = OR;
14    assign CONTROL [2] = ADD;
15    assign CONTROL [3] = SUB;
16    assign CONTROL [4] = NEG;
17    assign CONTROL [5] = NOT;
18    assign CONTROL [6] = SHL;

```

```

19 assign CONTROL [7] = SHR;
20 assign CONTROL [8] = ROL;
21 assign CONTROL [9] = ROR;
22 assign CONTROL [10] = MUL;
23 assign CONTROL [11] = DIV;
24
25 wire [31:0] Bus_Mux_Out ; // output of bus
26 wire [31:0] BusMuxIn_R0 , BusMuxIn_R1 , BusMuxIn_R2 , BusMuxIn_R3 ,
27     BusMuxIn_R4 , BusMuxIn_R5 , BusMuxIn_R6 , BusMuxIn_R7 , BusMuxIn_R8
28     ,
29     BusMuxIn_R9 , BusMuxIn_R10 , BusMuxIn_R11 , BusMuxIn_R12 ,
30     BusMuxIn_R13 ,
31     BusMuxIn_R14 , BusMuxIn_R15 , BusMuxIn_Z_HI , BusMuxIn_Z_LO ,
32     BusMuxIn_HI ,
33     BusMuxIn_LO , BusMuxIn_PC , BusMuxIn_IR , BusMuxIn_IN_PORT ,
34     BusMuxIn_OUT_PORT , BusMuxIn_MDR ; // register " storage "
35
36 wire [31:0] ZOut_HI , ZOut_LO ; // ALU output
37
38 wire [31:0] Y_contents ;
39
40 wire [31:0] CSignExtended ;
41
42 wire [8:0] mar_out ;
43
44 wire R15in ;
45 assign R15in = R15_enable | RXin [15];
46
47 wire PCin_or_enable ;
48 assign PCin_or_enable = PCin | PC_enable ;
49
50 wire [31:0] R0_out ;
51 assign R0_out = BAout ? 0 : BusMuxIn_R0 ;
52
53 // 15 Registers
54 register_zero #(0) R0 (Clock , Clear , BAout , Bus_Mux_Out , RXin [0] ,
55     BusMuxIn_R0 );
56 Register #(0) R1 (Clock , Clear , Bus_Mux_Out , RXin [1] , BusMuxIn_R1 );
57 //preloads 133 into R1 (hex 85)
58 Register #(0) R2 (Clock , Clear , Bus_Mux_Out , RXin [2] , BusMuxIn_R2 );
59 //preloads 1 into R2
60 Register #(0) R3 (Clock , Clear , Bus_Mux_Out , RXin [3] , BusMuxIn_R3 );
61 Register #(0) R4 (Clock , Clear , Bus_Mux_Out , RXin [4] , BusMuxIn_R4 );
62 Register #(0) R5 (Clock , Clear , Bus_Mux_Out , RXin [5] , BusMuxIn_R5 );
63 Register #(0) R6 (Clock , Clear , Bus_Mux_Out , RXin [6] , BusMuxIn_R6 );
64 Register #(0) R7 (Clock , Clear , Bus_Mux_Out , RXin [7] , BusMuxIn_R7 );
65 Register #(0) R8 (Clock , Clear , Bus_Mux_Out , RXin [8] , BusMuxIn_R8 );
66 Register #(0) R9 (Clock , Clear , Bus_Mux_Out , RXin [9] , BusMuxIn_R9 );
67 Register #(0) R10 (Clock , Clear , Bus_Mux_Out , RXin [10] , BusMuxIn_R10 )
68     ;
69 Register #(0) R11 (Clock , Clear , Bus_Mux_Out , RXin [11] , BusMuxIn_R11 )
70     ;
71 Register #(0) R12 (Clock , Clear , Bus_Mux_Out , RXin [12] , BusMuxIn_R12 )
72     ;
73 Register #(0) R13 (Clock , Clear , Bus_Mux_Out , RXin [13] , BusMuxIn_R13 )
74     ;
75 Register #(0) R14 (Clock , Clear , Bus_Mux_Out , RXin [14] , BusMuxIn_R14 )
76     ;

```

```

67 Register #(0) R15 (Clock , Clear , Bus_Mux_Out , R15in , BusMuxIn_R15 );
68
69 // High and Low Register Used in Multiplication and Division
70 Register HI (Clock , Clear , Bus_Mux_Out , highin , BusMuxIn_HI );
71 Register LO (Clock , Clear , Bus_Mux_Out , lowin , BusMuxIn_LO );
72
73 Register Z_HI (Clock , Clear , ZOut_HI , Zhighin , BusMuxIn_Z_HI );
74 Register Z_LO (Clock , Clear , ZOut_LO , Zlowin , BusMuxIn_Z_LO );
75
76 /* PC IR Y */
77 Register #(0) PC (Clock , Clear , Bus_Mux_Out , PCin_or_enable ,
    BusMuxIn_PC ); //preload address 1 in PC
78 Register #(0) IR (Clock , Clear , Bus_Mux_Out , IRin , BusMuxIn_IR );
79 Register #(0) Y (Clock , Clear , Bus_Mux_Out , Yin , Y_contents );
80
81 /* I/O */
82 inputPort #(0) IN_PORT (Clock , Clear , inPortIn , from_input_unit,
    BusMuxIn_IN_PORT );
83 outputPort OUT_PORT (Clock , Clear , outPortIn , Bus_Mux_Out ,
    to_output_unit )
84
85
86 Bus bus (.R0_out(RXout[0]), .R1_out(RXout [1]), .R2_out(RXout [2]) , .
    R3_out(RXout [3]), .R4_out(RXout[4]), .R5_out(RXout [5]), .R6_out(
    RXout[6]),
87 .R7_out(RXout[7]), .R8_out(RXout [8]), .R9_out(RXout[9]) , .R10_out(RXout
    [10]), .R11_out(RXout[11]), .R12_out(RXout [12]), .R13_out(RXout[13]),
88 .R14_out ( RXout [14]) , .R15_out(RXout[15]), .HI_out(highout), .LO_out(
    lowout), .Z_high_out(Zhighout), . Z_low_out(Zlowout), .PC_out(PCOut),
89 .MDR_out(MDRout), .In_Portout ( inPortOut ), .C_out(Cout), .BusMuxIn_R0(
    R0_out), .BusMuxIn_R1(BusMuxIn_R1), .BusMuxIn_R2(BusMuxIn_R2), .
    BusMuxIn_R3(BusMuxIn_R3),
90 .BusMuxIn_R4(BusMuxIn_R4), .BusMuxIn_R5(BusMuxIn_R5), .BusMuxIn_R6(
    BusMuxIn_R6), .BusMuxIn_R7(BusMuxIn_R7), .BusMuxIn_R8(BusMuxIn_R8), .
    BusMuxIn_R9(BusMuxIn_R9),
91 .BusMuxIn_R10(BusMuxIn_R10), . BusMuxIn_R11(BusMuxIn_R11), .BusMuxIn_R12(
    BusMuxIn_R12), .BusMuxIn_R13(BusMuxIn_R13), .BusMuxIn_R14(BusMuxIn_R14
    ), .BusMuxIn_R15(BusMuxIn_R15),
92 .BusMuxIn_HI(BusMuxIn_HI), .BusMuxIn_LO(BusMuxIn_LO), .BusMuxIn_Z_HI(
    BusMuxIn_Z_HI), .BusMuxIn_Z_LO(BusMuxIn_Z_LO), .BusMuxIn_PC(
    BusMuxIn_PC), .BusMuxIn_MDR(BusMuxIn_MDR),
93 .BusMuxIn_IN_PORT(BusMuxIn_IN_PORT), .C_Sign_Extended(CSignExtended ) , .
    BusMuxOut(Bus_Mux_Out));
94
95 ALU alu (.A( Y_contents ), .B( Bus_Mux_Out ), . C_LO ( ZOut_LO ), . C_HI (
    ZOut_HI ), .cntrl(CONTROL), .IncPC(IncPC));
96
97 MDR mdr (. Read ( Read ), .clk ( Clock ), .clr ( Clear ), . MDRin ( MDRin ),
    . BusMuxOut(Bus_Mux_Out ), . Mdatain ( mdr_data_in ), . MDRout (
    BusMuxIn_MDR ));
98
99
100 select_and_encode IR_select (Gra , Grb , Grc , Rin , Rout , BAout ,
    BusMuxIn_IR , RXin , RXout , CSignExtended );
101
102 con_ff con_logic (con_in , BusMuxIn_IR [22:19] , Bus_Mux_Out , toControlUnit
    );
103
104 MAR mar ( Bus_Mux_Out , MARin , Clock , Clear , mar_out );

```

```

105
106 ram ram_inst (. address ( mar_out ), . clock ( Clock ), . data (
    BusMuxIn_MDR ), .wren ( Write ), .q( mdr_data_in ));
107
108 ControlUnit CPU (. Read ( Read ), . Write ( Write ), .Run(Run), . Clear (
    Clear ), .PC_enable ( PC_enable ), . R15_enable ( R15_enable ), .Gra(Gra
    ), .Grb(Grb), .Grc(Grc), .Rin(Rin), .Rout(Rout), .PCout(PCOut), .MDRout(
    MDRout), .Zhighout(Zhighout), .Zlowout(Zlowout), .highout(highout), .
    lowout(lowout), .Zhighin(Zhighin), . Zlowin ( Zlowin ), . highin (
    highin ), . lowin (
109 lowin ), . PCin ( PCin ), . IRin ( IRin ), .Yin(Yin), . MDRin ( MDRin ), .
    MARin (
110 MARin ), . outPortIn ( outPortIn ), . inPortOut ( inPortOut ), . Cout ( Cout
    ), .
111 BAout ( BAout ), . con_in ( con_in ), . IncPC ( IncPC ),
112 .ADD(ADD), .SUB(SUB), .SHR(SHR), .SHL(SHL), .ROR(ROR), .ROL(ROL), .AND(AND
113 ), .OR(OR), .MUL(MUL), .DIV(DIV), .NEG(NEG), .NOT(NOT),
114 .IR( BusMuxIn_IR ), . Clock ( Clock ), . Reset ( Reset ), . Stop ( Stop ), .
    Con_FF (
115 toControlUnit ));

```

A.3 Bus

```

1 module Bus (R0_out, R1_out, R2_out, R3_out, R4_out, R5_out, R6_out, R7_out,
    R8_out, R9_out, R10_out, R11_out, R12_out, R13_out, R14_out, R15_out,
    HI_out, LO_out, Z_high_out, Z_low_out, PC_out, MDR_out, In_Portout,
    C_out, BusMuxIn_R0, BusMuxIn_R1, BusMuxIn_R2, BusMuxIn_R3, BusMuxIn_R4,
    BusMuxIn_R5, BusMuxIn_R6, BusMuxIn_R7, BusMuxIn_R8, BusMuxIn_R9,
    BusMuxIn_R10, BusMuxIn_R11, BusMuxIn_R12, BusMuxIn_R13, BusMuxIn_R14,
    BusMuxIn_R15, BusMuxIn_HI, BusMuxIn_LO, BusMuxIn_Z_HI, BusMuxIn_Z_LO,
    BusMuxIn_PC, BusMuxIn_MDR, BusMuxIn_IN_PORT, C_Sign_Extended, BusMuxOut
    );
2
3 input wire R0_out, R1_out, R2_out, R3_out, R4_out, R5_out, R6_out,
    R7_out, R8_out, R9_out, R10_out, R11_out, R12_out, R13_out, R14_out,
    R15_out, HI_out, LO_out, Z_high_out, Z_low_out, PC_out, MDR_out,
    In_Portout, C_out;
4
5 input [31:0] BusMuxIn_R0, BusMuxIn_R1, BusMuxIn_R2, BusMuxIn_R3,
    BusMuxIn_R4, BusMuxIn_R5, BusMuxIn_R6, BusMuxIn_R7, BusMuxIn_R8,
    BusMuxIn_R9, BusMuxIn_R10, BusMuxIn_R11, BusMuxIn_R12, BusMuxIn_R13,
    BusMuxIn_R14, BusMuxIn_R15, BusMuxIn_HI, BusMuxIn_LO, BusMuxIn_Z_HI
    , BusMuxIn_Z_LO, BusMuxIn_PC, BusMuxIn_MDR, BusMuxIn_IN_PORT,
    C_Sign_Extended;
6
7 output reg [31:0] BusMuxOut;
8
9 reg [4:0] encoderOut;
10
11 always @ (*)
12 begin
13     if (C_out) BusMuxOut = C_Sign_Extended; else
14     if (In_Portout) BusMuxOut = BusMuxIn_IN_PORT; else
15     if (MDR_out) BusMuxOut = BusMuxIn_MDR; else
16     if (PC_out) BusMuxOut = BusMuxIn_PC; else
17     if (Z_low_out) BusMuxOut = BusMuxIn_Z_LO; else
18     if (Z_high_out) BusMuxOut = BusMuxIn_Z_HI; else
19     if (LO_out) BusMuxOut = BusMuxIn_LO; else
20     if (HI_out) BusMuxOut = BusMuxIn_HI; else

```



```

21         if (R15_out)      BusMuxOut = BusMuxIn_R15; else
22         if (R14_out)      BusMuxOut = BusMuxIn_R14; else
23         if (R13_out)      BusMuxOut = BusMuxIn_R13; else
24         if (R12_out)      BusMuxOut = BusMuxIn_R12; else
25         if (R11_out)      BusMuxOut = BusMuxIn_R11; else
26         if (R10_out)      BusMuxOut = BusMuxIn_R10; else
27         if (R9_out)       BusMuxOut = BusMuxIn_R9; else
28         if (R8_out)       BusMuxOut = BusMuxIn_R8; else
29         if (R7_out)       BusMuxOut = BusMuxIn_R7; else
30         if (R6_out)       BusMuxOut = BusMuxIn_R6; else
31         if (R5_out)       BusMuxOut = BusMuxIn_R5; else
32         if (R4_out)       BusMuxOut = BusMuxIn_R4; else
33         if (R3_out)       BusMuxOut = BusMuxIn_R3; else
34         if (R2_out)       BusMuxOut = BusMuxIn_R2; else
35         if (R1_out)       BusMuxOut = BusMuxIn_R1; else
36         if (R0_out)       BusMuxOut = BusMuxIn_R0; else
37         BusMuxOut = C_Sign_Extended;
38     end
39
40 endmodule

```

A.4 Register Zero

```

1  module register_zero #(parameter VAL = 0)(input clk, clr, BAout, input
   [31:0] BusMuxOut, input R0in, output reg [31:0] BusMuxIn_R0);
2      always@(posedge clk or negedge clr)
3      begin
4          if(clr == 0) BusMuxIn_R0 = 0;
5          else if (BAout == 0) BusMuxIn_R0 = 0;
6          else if(R0in) BusMuxIn_R0 <= BusMuxOut;
7      end
8      initial BusMuxIn_R0 = VAL; // assigns initial value
9  endmodule

```

A.5 Arithmetic Logic Unit

```

1  module ALU (input [31:0] A, B, output reg [31:0] C_LO, C_HI, input wire [3:0]
   cntrl, input IncPC);
2
3      wire [63:0] div_quotient;
4
5      wire [63:0] booth_result;
6
7      div restoring_div(.quotient_and_remainder(div_quotient), .dividend(A), .
   divisor(B));
8
9      mul booth (booth_result, A, B);
10
11     always @(*) begin
12         C_LO = 0;
13         C_HI = 0;
14         if (IncPC) C_LO = B + 1; // increases program counter
15         else begin
16             case(cntrl)
17                 11 : begin // division
18                     C_LO = div_quotient [31:0];
19                     C_HI = div_quotient [63:32];
20                 end
21                 10 : begin // multiplication

```

```

22         C_LO = booth_result[31:0];
23         C_HI = booth_result [63:32];
24     end
25     9 : C_LO = A >> B | A << (32 - B); // rotate right
26     8 : C_LO = A << B | A >> (32 - B); // rotate left
27     7 : C_LO = A >>> B; // right arithmetic shift - A = how many
        shifts, B = the number you want to shift
28     6 : C_LO = A <<< B; // left arithtmatic shift - A = how many
        shifts, B = the number you want to shift
29     5 : C_LO = ~B; // logical not
30     4 : C_LO = -B; //negation function
31     3 : C_LO = A - B;
32     2 : C_LO = A + B;
33     1 : C_LO = A | B;
34     0 : C_LO = A & B;
35     default : begin end
36 endcase
37 end
38 end
39 endmodule

```

B Select and Encode

```

1 module select_and_encode (Gra, Grb, Grc, Rin, Rout, BAout, IR, RXin, RXout,
    CSigExtended);
2
3     input Gra, Grb, Grc, Rin, Rout, BAout; // from CPU
4     input [31:0] IR;
5     output reg [15:0] RXin, RXout; // Registers 0 - 15 in/out
6     output [31:0] CSigExtended;
7
8     reg [3:0] selected_register;
9
10    always @(Gra, Grb, Grc, IR, BAout, Rin, Rout) // are these the right
        thingsin the sensitivity list
11    begin
12        RXout = 0;
13        RXin = 0;
14        selected_register = 0;
15
16        // Select
17        if (Gra == 1) selected_register = IR[26:23]; else
18        if (Grb == 1) selected_register = IR[22:19]; else
19        if (Grc == 1) selected_register = IR[18:15];
20
21        if (BAout == 1 || Rout == 1) begin
22            RXout[selected_register] = 1;
23        end else
24        if (Rin) begin
25            RXin[selected_register] = 1;
26        end
27
28    end
29
30    assign CSigExtended = $signed(IR[18:0]);
31 endmodule

```

C Memory Subsystem

C.1 RAM

```
1 // megafunction wizard: %RAM: 1-PORT%
2 // GENERATION: STANDARD
3 // VERSION: WM1.0
4 // MODULE: altsyncram
5
6 // =====
7 // File Name: ram.v
8 // Megafunction Name(s):
9 //     altsyncram
10 //
11 // Simulation Library Files(s):
12 //     altera_mf
13 // =====
14 // *****
15 // THIS IS A WIZARD-GENERATED FILE. DO NOT EDIT THIS FILE!
16 //
17 // 13.0.1 Build 232 06/12/2013 SP 1 SJ Full Version
18 // *****
19
20
21 //Copyright (C) 1991-2013 Altera Corporation
22 //Your use of Altera Corporation's design tools, logic functions
23 //and other software and tools, and its AMPP partner logic
24 //functions, and any output files from any of the foregoing
25 //(including device programming or simulation files), and any
26 //associated documentation or information are expressly subject
27 //to the terms and conditions of the Altera Program License
28 //Subscription Agreement, Altera MegaCore Function License
29 //Agreement, or other applicable license agreement, including,
30 //without limitation, that your use is for the sole purpose of
31 //programming logic devices manufactured by Altera and sold by
32 //Altera or its authorized distributors. Please refer to the
33 //applicable agreement for further details.
34
35
36 // synopsys translate_off
37 `timescale 1 ps / 1 ps
38 // synopsys translate_on
39 module ram (
40     address,
41     clock,
42     data,
43     wren,
44     q);
45
46     input [8:0] address;
47     input clock;
48     input [31:0] data;
49     input wren;
50     output [31:0] q;
51 `ifndef ALTERA_RESERVED_QIS
52 // synopsys translate_off
53 `endif
54     tri1 clock;
55 `ifndef ALTERA_RESERVED_QIS
```

```

56 // synopsys translate_on
57 `endif
58
59 wire [31:0] sub_wire0;
60 wire [31:0] q = sub_wire0[31:0];
61
62 altsyncram altsyncram_component (
63     .address_a (address),
64     .clock0 (clock),
65     .data_a (data),
66     .wren_a (wren),
67     .q_a (sub_wire0),
68     .aclr0 (1'b0),
69     .aclr1 (1'b0),
70     .address_b (1'b1),
71     .addressstall_a (1'b0),
72     .addressstall_b (1'b0),
73     .byteena_a (1'b1),
74     .byteena_b (1'b1),
75     .clock1 (1'b1),
76     .clocken0 (1'b1),
77     .clocken1 (1'b1),
78     .clocken2 (1'b1),
79     .clocken3 (1'b1),
80     .data_b (1'b1),
81     .eccstatus (),
82     .q_b (),
83     .rden_a (1'b1),
84     .rden_b (1'b1),
85     .wren_b (1'b0));
86
87 defparam
88     altsyncram_component.clock_enable_input_a = "BYPASS",
89     altsyncram_component.clock_enable_output_a = "BYPASS",
90 `ifdef NO_PLI
91     altsyncram_component.init_file = "ram.rif"
92 `else
93     altsyncram_component.init_file = "ram.hex"
94 `endif
95 ,
96     altsyncram_component.intended_device_family = "Cyclone_III",
97     altsyncram_component.lpm_hint = "ENABLE_RUNTIME_MOD=NO",
98     altsyncram_component.lpm_type = "altsyncram",
99     altsyncram_component.numwords_a = 512,
100     altsyncram_component.operation_mode = "SINGLE_PORT",
101     altsyncram_component.outdata_aclr_a = "NONE",
102     altsyncram_component.outdata_reg_a = "UNREGISTERED",
103     altsyncram_component.power_up_uninitialized = "FALSE",
104     altsyncram_component.read_during_write_mode_port_a = "DONT_CARE",
105     altsyncram_component.widthad_a = 9,
106     altsyncram_component.width_a = 32,
107     altsyncram_component.width_byteena_a = 1;
108
109 endmodule
110
111 // =====
112 // CNX file retrieval info
113 // =====
114 // Retrieval info: PRIVATE: ADDRESSSTALL_A NUMERIC "0"

```

```

115 // Retrieval info: PRIVATE: AclrAddr NUMERIC "0"
116 // Retrieval info: PRIVATE: AclrByte NUMERIC "0"
117 // Retrieval info: PRIVATE: AclrData NUMERIC "0"
118 // Retrieval info: PRIVATE: AclrOutput NUMERIC "0"
119 // Retrieval info: PRIVATE: BYTE_ENABLE NUMERIC "0"
120 // Retrieval info: PRIVATE: BYTE_SIZE NUMERIC "8"
121 // Retrieval info: PRIVATE: BlankMemory NUMERIC "0"
122 // Retrieval info: PRIVATE: CLOCK_ENABLE_INPUT_A NUMERIC "0"
123 // Retrieval info: PRIVATE: CLOCK_ENABLE_OUTPUT_A NUMERIC "0"
124 // Retrieval info: PRIVATE: Clken NUMERIC "0"
125 // Retrieval info: PRIVATE: DataBusSeparated NUMERIC "1"
126 // Retrieval info: PRIVATE: IMPLEMENT_IN_LES NUMERIC "0"
127 // Retrieval info: PRIVATE: INIT_FILE_LAYOUT STRING "PORT_A"
128 // Retrieval info: PRIVATE: INIT_TO_SIM_X NUMERIC "0"
129 // Retrieval info: PRIVATE: INTENDED_DEVICE_FAMILY STRING "Cyclone III"
130 // Retrieval info: PRIVATE: JTAG_ENABLED NUMERIC "0"
131 // Retrieval info: PRIVATE: JTAG_ID STRING "NONE"
132 // Retrieval info: PRIVATE: MAXIMUM_DEPTH NUMERIC "0"
133 // Retrieval info: PRIVATE: MIFfilename STRING "ram.hex"
134 // Retrieval info: PRIVATE: NUMWORDS_A NUMERIC "512"
135 // Retrieval info: PRIVATE: RAM_BLOCK_TYPE NUMERIC "0"
136 // Retrieval info: PRIVATE: READ_DURING_WRITE_MODE_PORT_A NUMERIC "2"
137 // Retrieval info: PRIVATE: RegAddr NUMERIC "1"
138 // Retrieval info: PRIVATE: RegData NUMERIC "1"
139 // Retrieval info: PRIVATE: RegOutput NUMERIC "0"
140 // Retrieval info: PRIVATE: SYNTH_WRAPPER_GEN_POSTFIX STRING "0"
141 // Retrieval info: PRIVATE: SingleClock NUMERIC "1"
142 // Retrieval info: PRIVATE: UseDQRAM NUMERIC "1"
143 // Retrieval info: PRIVATE: WRCONTROL_ACLR_A NUMERIC "0"
144 // Retrieval info: PRIVATE: WidthAddr NUMERIC "9"
145 // Retrieval info: PRIVATE: WidthData NUMERIC "32"
146 // Retrieval info: PRIVATE: rden NUMERIC "0"
147 // Retrieval info: LIBRARY: altera_mf altera_mf.altera_mf_components.all
148 // Retrieval info: CONSTANT: CLOCK_ENABLE_INPUT_A STRING "BYPASS"
149 // Retrieval info: CONSTANT: CLOCK_ENABLE_OUTPUT_A STRING "BYPASS"
150 // Retrieval info: CONSTANT: INIT_FILE STRING "ram.hex"
151 // Retrieval info: CONSTANT: INTENDED_DEVICE_FAMILY STRING "Cyclone III"
152 // Retrieval info: CONSTANT: LPM_HINT STRING "ENABLE_RUNTIME_MOD=NO"
153 // Retrieval info: CONSTANT: LPM_TYPE STRING "altsyncram"
154 // Retrieval info: CONSTANT: NUMWORDS_A NUMERIC "512"
155 // Retrieval info: CONSTANT: OPERATION_MODE STRING "SINGLE_PORT"
156 // Retrieval info: CONSTANT: OUTDATA_ACLR_A STRING "NONE"
157 // Retrieval info: CONSTANT: OUTDATA_REG_A STRING "UNREGISTERED"
158 // Retrieval info: CONSTANT: POWER_UP_UNINITIALIZED STRING "FALSE"
159 // Retrieval info: CONSTANT: READ_DURING_WRITE_MODE_PORT_A STRING "DONT_CARE"
160 // Retrieval info: CONSTANT: WIDTHAD_A NUMERIC "9"
161 // Retrieval info: CONSTANT: WIDTH_A NUMERIC "32"
162 // Retrieval info: CONSTANT: WIDTH_BYTEENA_A NUMERIC "1"
163 // Retrieval info: USED_PORT: address 0 0 9 0 INPUT NODEFVAL "address[8..0]"
164 // Retrieval info: USED_PORT: clock 0 0 0 0 INPUT VCC "clock"
165 // Retrieval info: USED_PORT: data 0 0 32 0 INPUT NODEFVAL "data[31..0]"
166 // Retrieval info: USED_PORT: q 0 0 32 0 OUTPUT NODEFVAL "q[31..0]"
167 // Retrieval info: USED_PORT: wren 0 0 0 0 INPUT NODEFVAL "wren"
168 // Retrieval info: CONNECT: @address_a 0 0 9 0 address 0 0 9 0
169 // Retrieval info: CONNECT: @clock0 0 0 0 0 clock 0 0 0 0
170 // Retrieval info: CONNECT: @data_a 0 0 32 0 data 0 0 32 0
171 // Retrieval info: CONNECT: @wren_a 0 0 0 0 wren 0 0 0 0
172 // Retrieval info: CONNECT: q 0 0 32 0 @q_a 0 0 32 0

```

```

173 // Retrieval info: GEN_FILE: TYPE_NORMAL ram.v TRUE
174 // Retrieval info: GEN_FILE: TYPE_NORMAL ram.inc FALSE
175 // Retrieval info: GEN_FILE: TYPE_NORMAL ram.cmp FALSE
176 // Retrieval info: GEN_FILE: TYPE_NORMAL ram.bsf FALSE
177 // Retrieval info: GEN_FILE: TYPE_NORMAL ram_inst.v TRUE
178 // Retrieval info: GEN_FILE: TYPE_NORMAL ram_bb.v FALSE
179 // Retrieval info: LIB_FILE: altera_mf

```

C.2 Memory Address Register

```

1 module MAR(input [31:0] BusMuxOut, input MARin, clk, clr, output reg [8:0]
  Address);
2   always@(posedge clk or negedge clr)
3   begin
4       if(clr == 0) Address <= 0;
5       else if(MARin) Address <= BusMuxOut[8:0];
6   end
7 endmodule

```

C.3 Memory Data Register

```

1 module MDR (input Read, clr, clk, MDRin, input [31:0] BusMuxOut, Mdatain,
  output reg [31:0] MDRout);
2
3   always@(posedge clk or negedge clr)
4   begin
5       if(clr == 0) MDRout <= 0; // 32'h0000_0000 zero also works
6       else if(MDRin) MDRout <= Read ? Mdatain : BusMuxOut;
7   end
8
9 endmodule

```

D CON FF

```

1 module con_ff (con_in, IR, BusMuxOut, toControlUnit);
2
3   input con_in; // enable
4   input [3:0] IR;
5   input [31:0] BusMuxOut;
6   output reg toControlUnit; // this is PC + 1 + C (signExtended)
7
8   function triple_nor(input [31:0] BusMuxOut);
9       // as long as 1 bit is 1, return true. Since this is then put
10      // through a NOT gate, it means
11      // as long as 1 bit is 1, return false
12      // that is, if zero, return true
13      triple_nor = (BusMuxOut == 0) ? 1 : 0;
14   endfunction
15
16   always @(posedge con_in) begin
17
18       // Note: Nor with same input is a not. Negated again, it is the original
19
20       if (con_in) begin
21           case (IR[3:2])
22               0: toControlUnit = triple_nor(BusMuxOut); // branch if zero
23               1: toControlUnit = !triple_nor(BusMuxOut); // branch if non
24                   zero

```

```

22         2: toControlUnit = !BusMuxOut[31]; // branch if greater than
           zero
23         3: toControlUnit = BusMuxOut[31]; // branch if less than
           zero
24         default: begin end // otherwise do nothing
25     endcase
26     end else toControlUnit <= 0; // set 0
27 end
28
29 endmodule

```

E Input/Output Ports

E.1 Input Port

```

1 module inputPort #(parameter VAL = 0)(input clk, clr, strobe, input [31:0]
  inputUnit, output reg [31:0] busMuxIn_In_PortIn);
2     always@(posedge clk or negedge clr)
3     begin
4         if(clr == 0) busMuxIn_In_PortIn <= 0;
5         else if(strobe) busMuxIn_In_PortIn <= inputUnit;
6     end
7     initial busMuxIn_In_PortIn = VAL; // assigns initial value
8 endmodule

```

E.2 Output Port

```

1 module outputPort #(parameter VAL = 0) (input clk, clr, outPortIn, input
  [31:0] BusMuxOut, output reg [31:0] outputUnit);
2     always@(posedge clk or negedge clr)
3     begin
4         if(clr == 0) outputUnit <= 0;
5         else if(outPortIn) outputUnit <= BusMuxOut;
6     end
7     initial outputUnit = VAL; // assigns initial value
8 endmodule

```

F Control Sequences

F.1 st \$90, R1

```

1 always @(Present_state)// do the required job ineach state
2 begin
3     case (Present_state) //assert the required signals in each clock cycle
4         Default: begin //initialize the signals
5             PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
              initialize the signals
6             MARin <= 0; Zlowin <= 0; Zhighin <= 0;
7             PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
8             IncPC <= 0; Read <= 0; CONTROL <= 0;
9             Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
10            Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
              <= 0;
11            Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
12            BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
              ram_enable <= 0;
13            R15_enable <= 0; PC_enable <= 0;
14        end
15    T0: begin

```

```

16         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; // Mdatain
           <= 32'h10080090; // opcode for st 90 r1
17         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin <= 0;
18     end
19     T1: begin
20         #10 Zlowout <= 1; PCin <= 1; Read <= 1; MDRin <= 1;
21         #15 Zlowout <= 0; PCin <= 0; Read <= 0; MDRin <= 0;
22     end
23     T2: begin
24         #10 MDRout <= 1; IRin <= 1;
25         #15 MDRout <= 0; IRin <= 0;
26     end
27     T3: begin
28         #10 Cout <= 1; MARin <= 1;
29         #10 Cout <= 0; MARin <= 0;
30     end
31     T4: begin
32         #10 Grb <= 1; BAout <= 1; Rout <= 1; MDRin <= 1;
33         #15 Grb <= 0; BAout <= 0; Rout <= 0; MDRin <= 0;
34     end
35     T5: begin
36         #10 MDRout <= 1; ram_enable <= 1; // output of RDR written to
           RAM
37         #15 MDRout <= 0; ram_enable <= 0;
38     end
39 endcase
40 end

```

F.2 st \$90(R1), R1

```

1  always @(Present_state) // do the required job in each state
2  begin
3      case (Present_state) // assert the required signals in each clock cycle
4      Default: begin // initialize the signals
5          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout <= 0; //
           initialize the signals
6          MARin <= 0; Zlowin <= 0; Zhighin <= 0;
7          PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
8          IncPC <= 0; Read <= 0; CONTROL <= 0;
9          Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
10         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn <= 0; con_in
           <= 0;
11         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
12         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
           ram_enable <= 0;
13         R15_enable <= 0; PC_enable <= 0;
14     end
15     T0: begin
16         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; // Mdatain
           <= 32'h590FFFFB; opcode for ADDI R2, R1, -5 01011 0010 0001
           111 1111 1111 1111 1011 in init file
17         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin <= 0;
18     end
19     T1: begin
20         #10 Zlowout <= 1; PCin <= 1; Read <= 1; MDRin <= 1;
21         #15 Zlowout <= 0; PCin <= 0; Read <= 0; MDRin <= 0;
22     end
23     T2: begin
24         #10 MDRout <= 1; IRin <= 1;

```



```

25         #15 MDRout<= 0; IRin <= 0;
26     end
27     T3: begin
28         #10 Grb <= 1; Rout<= 1; Yin <= 1;
29         #15 Grb <= 0; Rout<= 0; Yin <= 0;
30     end
31     T4: begin
32         #10 Zlowin <= 1; CONTROL <= 2; // add, result is stored in ZL0
33         #15 Zlowin <= 0;
34     end
35     T5: begin
36         #10 Zlowout <= 1; MARin <= 1; // store in MAR
37         #15 Zlowout <= 0; MARin <= 0;
38     end
39     T6: begin
40         #10 Cout<= 1; Read <= 0; MDRin <= 1; // read from CSignExtended,
41             store in MDR
42         #20 Cout<= 0; MDRin <= 0;
43     end
44     T7: begin // output of MDR written to RAM
45         #10 MDRout <= 1; ram_enable <= 1;
46         #15 MDRout <= 0; ram_enable <= 0;
47     end
48 endcase
49 end
50
51
52 always @(Present_state)// do the required job ineach state
53 begin
54     case (Present_state) //assert the required signals in each clock cycle
55     Default: begin //initialize the signals
56         PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
57             initialize the signals
58         MARin <= 0; Zlowin <= 0; Zhighin <= 0;
59         PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
60         IncPC <= 0; Read <= 0; CONTROL <= 0;
61         Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
62         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
63             <= 0;
64         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
65         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
66         ram_enable <= 0;
67     end
68     T0: begin
69         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; // Mdatain
70             <= 32'h190FFFFB; opcode for // opcode for st 90 r1
71         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
72     end
73     T1: begin
74         #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1;
75         #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
76     end
77     T2: begin
78         #10 MDRout<= 1; IRin <= 1;
79         #15 MDRout<= 0; IRin <= 0;
80     end
81     T3: begin // read from R1, store in Z_L0
82         #10 Grb <= 1; Rout <= 1; Zlowin <= 1;

```

```

79         #15 Grb <= 0; Rout <= 0; Zlowin <= 0;
80     end
81     T4: begin // write address from instruction to Y register
82         #10 Cout <= 1; Yin <= 1;
83         #15 Cout <= 0; Yin <= 0;
84     end
85     T5: begin // Add Y and Z_L0, send to MAR
86         #10 Zlowout <= 1; MARin <= 1; CONTROL <= 2;
87         #15 Zlowout <= 0; MARin <= 0;
88     end
89     T6: begin // read from Z_L0, write to MDR
90         #10 Zlowout <= 1; MDRin <= 1;
91         #15 Zlowout <= 0; MDRin <= 0;
92     end
93     T7: begin // output of MDR written to RAM
94         #10 MDRout <= 1; ram_enable <= 1;
95         #15 MDRout <= 0; ram_enable <= 0;
96     end
97 endcase
98 end

```

F.3 ld R1, \$85), R1

```

1  always @(Present_state) // do the required job in each state
2  begin
3      case (Present_state) // assert the required signals in each clock cycle
4      Default: begin // initialize the signals
5          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout <= 0; //
6              initialize the signals
7          MARin <= 0; Zlowin <= 0; Zhighin <= 0;
8          PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
9          IncPC <= 0; Read <= 0; CONTROL <= 0;
10         Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
11         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn <= 0; con_in
12             <= 0;
13         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
14         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
15             ram_enable <= 0;
16         R15_enable <= 0; PC_enable <= 0;
17     end
18     T0: begin
19         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; //
20             initialize the signals
21         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin <= 0;
22     end
23     T1: begin
24         #10 Zlowout <= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
25             32'h00800085; // opcode for ld 90 r1
26         #15 Zlowout <= 0; PCin <= 0; Read <= 0; MDRin <= 0;
27     end
28     T2: begin
29         #10 MDRout <= 1; IRin <= 1;
30         #15 MDRout <= 0; IRin <= 0;
31     end
32     T3: begin
33         #10 Grb <= 1; BAout <= 1; Yin <= 1;
34         #15 Grb <= 0; BAout <= 0; Yin <= 0;
35     end
36     T4: begin

```

```

32         #10 Cout<= 1;  CONTROL<= 2; Zlowin <= 1;
33         #15 Cout<= 0;  Zlowin <= 0;
34     end
35     T5: begin
36         #10 Zlowout<= 1; MARin <= 1;
37         #15 Zlowout<= 0; MARin <= 0;
38     end
39     T6: begin
40         #10 Read <= 1; MDRin <= 1;
41         #15 Read <= 0; MDRin <= 0;
42     end
43     T7: begin
44         #10 MDRout <= 1; Gra <= 1; Rin <= 1;
45         #15 MDRout <= 0; Gra <= 0; Rin <= 0;
46     end
47 endcase
48 end

```

F.4 ld R0, \$35(R1)

```

1  always @(Present_state)// do the required job ineach state
2  begin
3      case (Present_state) //assert the required signals in each clock cycle
4          Default: begin //initialize the signals
5              PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0;  //
6                  initialize the signals
7              MARin <= 0; Zlowin <= 0; Zhighin <= 0;
8              PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
9              IncPC <= 0; Read <= 0; CONTROL <= 0;
10             Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
11             Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
12                 <= 0;
13             Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
14             BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
15             ram_enable <= 0;
16             R15_enable <= 0; PC_enable <= 0;
17         end
18         T0: begin
19             #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1;  //
20                 initialize the signals
21             #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
22         end
23         T1: begin
24             #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
25                 32'h00800023; //opcode for ld 90 r1
26             #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
27         end
28         T2: begin
29             #10 MDRout<= 1; IRin <= 1;
30             #15 MDRout<= 0; IRin <= 0;
31         end
32         T3: begin
33             #10 Grb <= 1; BAout<= 1; Yin <= 1;
34             #15 Grb <= 0; BAout<= 0; Yin <= 0;
35         end
36         T4: begin
37             #10 Cout<= 1;  CONTROL<= 2; Zlowin <= 1;
38             #15 Cout<= 0; Zlowin <= 0;
39         end
40     end

```

```

35     T5: begin
36         #10 Zlowout<= 1; MARin <= 1;
37         #15 Zlowout<= 0; MARin <= 0;
38     end
39     T6: begin
40         #10 Read <= 1; MDRin <= 1;
41         #15 Read <= 0; MDRin <= 0;
42     end
43     T7: begin
44         #10 MDRout <= 1; Gra <= 1; Rin <= 1;
45         #15 MDRout <= 0; Gra <= 0; Rin <= 0;
46     end
47 endcase
48 end

```

F.5 ldi R1, \$85

```

1  always @(Present_state)// do the required job ineach state
2  begin
3      case (Present_state) //assert the required signals in each clock cycle
4          Default: begin //initialize the signals
5              PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
6                  initialize the signals
7              MARin <= 0; Zlowin <= 0; Zhighin <= 0;
8              PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
9              IncPC <= 0; Read <= 0; CONTROL <= 0;
10             Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
11             Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
12                 <= 0;
13             Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
14             BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
15             ram_enable <= 0;
16             R15_enable <= 0; PC_enable <= 0;
17         end
18         T0: begin
19             #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1; //
20                 initialize the signals
21             #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
22         end
23         T1: begin
24             #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
25                 32'h08800085; //Reading from RAM 0000101000000
26                 xxxxxxxxxxxxxxxxxxxx
27             #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
28         end
29         T2: begin
30             #10 MDRout<= 1; IRin <= 1;
31             #15 MDRout<= 0; IRin <= 0;
32         end
33         T3: begin
34             #10 Grb <= 1; BAout<= 1; Yin <= 1;
35             #15 Grb <= 0; BAout<= 0; Yin <= 0;
36         end
37         T4: begin
38             #10 Cout<= 1; Zlowin <= 1; CONTROL <= 2;
39             #15 Cout<= 0; Zlowin <= 0;
40         end
41         T5: begin
42             #10 Zlowout<= 1; Gra <= 1; Rin <= 1;

```

```

37         #15 Zlowout<= 0; Gra <= 0; Rin <= 0;
38     end
39 endcase
40 end

```

F.6 ldi R0, \$35(R1)

```

1  always @(Present_state)// do the required job ineach state
2  begin
3      case (Present_state) //assert the required signals in each clock cycle
4          Default: begin //initialize the signals
5              PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
                    initialize the signals
6              MARin <= 0; Zlowin <= 0; Zhighin <= 0;
7              PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
8              IncPC <= 0; Read <= 0; CONTROL <= 0;
9              Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
10             Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
                    <= 0;
11             Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
12             BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
                    ram_enable <= 0;
13             R15_enable <= 0; PC_enable <= 0;
14         end
15         T0: begin
16             #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1; //
                    initialize the signals
17             #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
18         end
19         T1: begin
20             #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; //Mdatain <=
                    32'h08800023; //Reading from RAM 0000101000000
                    xxxxxxxxxxxxxxxxxxxx
21             #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
22         end
23         T2: begin
24             #10 MDRout<= 1; IRin <= 1;
25             #15 MDRout<= 0; IRin <= 0;
26         end
27         T3: begin
28             #10 Grb <= 1; BAout<= 1; Yin <= 1;
29             #15 Grb <= 0; BAout<= 0; Yin <= 0;
30         end
31         T4: begin
32             #10 Cout<= 1; Zlowin <= 1; CONTROL <= 2;
33             #15 Cout<= 0; Zlowin <= 0;
34         end
35         T5: begin
36             #10 Zlowout<= 1; Gra <= 1; Rin <= 1;
37             #15 Zlowout<= 0; Gra <= 0; Rin <= 0;
38         end
39     endcase
40 end

```

F.7 brzr R2, 35

```

1  //uses ConFF to determine what branch instruction to use op code is
    different however
2  // opcode for brnr PC <- PC + 1 + C (10010xxxx-00xxxxxxxxxxxxxx)//

```

```

3
4 always @(Present_state)// do the required job ineach state
5 begin
6     case (Present_state) //assert the required signals in each clock cycle
7     Default: begin //initialize the signals
8         PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
            initialize the signals
9         MARin <= 0; Zlowin <= 0; Zhighin <= 0;
10        PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
11        IncPC <= 0; Read <= 0; CONTROL <= 0;
12        Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
13        Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
            <= 0;
14        Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
15        BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
            ram_enable <= 0;
16        R15_enable <= 0; PC_enable <= 0;
17    end
18    T0: begin
19        #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1;
20        #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
21    end
22    T1: begin
23        #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
            32'h91000023; // opcode for brzr R2, 35 (10010 0010 0000
            0000 000 0000 0010 0011)//
24        #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
25    end
26    T2: begin
27        #10 MDRout<= 1; IRin <= 1;
28        #15 MDRout<= 0; IRin <= 0;
29    end
30    T3: begin
31        #10 Gra <= 1; Rout <= 1; con_in <= 1;
32        #15 Gra <= 0; Rout <= 0; con_in <= 0;
33    end
34    T4: begin
35        #10 PCout<= 1; Yin <= 1; // put PC in Y register
36        #10 PCout<= 0; Yin <= 0;
37    end
38    T5: begin
39        #10 Cout<= 1; CONTROL <= 2; Zlowin <= 1; // add PC with branch,
            store in Z_L0
40        #15 Cout<= 0; Zlowin <= 0;
41    end
42    T6: begin // enable the PC
43        #10 Zlowout <= 1; PC_enable <= 1; //Reading from PCin
44        #15 Zlowout <= 0; PC_enable <= 0;
45    end
46 endcase
47 end

```

F.8 brnz R2, 35

```

1 //uses ConFF to determine what branch instruction to use op code is
    different however
2 // opcode for brnr PC <- PC + 1 + C (10010xxxx-01xxxxxxxxxxxxxxxx)//
3
4 always @(Present_state)// do the required job ineach state

```

```

5  begin
6      case (Present_state) //assert the required signals in each clock cycle
7          Default: begin //initialize the signals
8              PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
                initialize the signals
9              MARin <= 0; Zlowin <= 0; Zhighin <= 0;
10             PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
11             IncPC <= 0; Read <= 0; CONTROL <= 0;
12             Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
13             Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
                <= 0;
14             Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
15             BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
                ram_enable <= 0;
16             R15_enable <= 0; PC_enable <= 0;
17         end
18         T0: begin
19             #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1;
20             #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
21         end
22         T1: begin
23             #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; //Mdatain <=
                32'h91200023; // opcode for brnz R2, 35 (10010 0010 0100
                0000 000 0000 0010 0011)//
24             #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
25         end
26         T2: begin
27             #10 MDRout<= 1; IRin <= 1;
28             #15 MDRout<= 0; IRin <= 0;
29         end
30         T3: begin
31             #10 Gra <= 1; Rout <= 1; con_in <= 1;
32             #15 Gra <= 0; Rout <= 0; con_in <= 0;
33         end
34         T4: begin
35             #10 PCout<= 1; Yin <= 1; // put PC in Y register
36             #10 PCout<= 0; Yin <= 0;
37         end
38         T5: begin
39             #10 Cout<= 1; CONTROL <= 2; Zlowin <= 1; // add PC with branch,
                store in Z_L0
40             #15 Cout<= 0; Zlowin <= 0;
41         end
42         T6: begin // enable the PC
43             #10 Zlowout <= 1; PC_enable <= 1; //Reading from PCin
44             #15 Zlowout <= 0; PC_enable <= 0;
45         end
46     endcase
47 end

```

F.9 brpl R2, 35

```

1  //uses ConFF to determine what branch instruction to use op code is
    different however
2  // opcode for brpl PC <- PC + 1 + C (10010xxxx-10xxxxxxxxxxxxxxxx)//
3
4  always @(Present_state)// do the required job ineach state
5  begin
6      case (Present_state) //assert the required signals in each clock cycle

```

```

7      Default: begin //initialize the signals
8          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
              initialize the signals
9          MARin <= 0; Zlowin <= 0; Zhighin <= 0;
10         PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
11         IncPC <= 0; Read <= 0; CONTROL <= 0;
12         Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
13         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
              <= 0;
14         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
15         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
              ram_enable <= 0;
16         R15_enable <= 0; PC_enable <= 0;
17     end
18     T0: begin
19         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1;
20         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
21     end
22     T1: begin
23         #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
              32'h91400023; // opcode for brpl R2, 35 (10010 0010 1000
              0000 000 0000 0010 0011)//
24         #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
25     end
26     T2: begin
27         #10 MDRout<= 1; IRin <= 1;
28         #15 MDRout<= 0; IRin <= 0;
29     end
30     T3: begin
31         #10 Gra <= 1; Rout <= 1; con_in <= 1;
32         #15 Gra <= 0; Rout <= 0; con_in <= 0;
33     end
34     T4: begin
35         #10 PCout<= 1; Yin <= 1; // put PC in Y register
36         #10 PCout<= 0; Yin <= 0;
37     end
38     T5: begin
39         #10 Cout<= 1; CONTROL <= 2; Zlowin <= 1; // add PC with branch,
              store in Z_L0
40         #15 Cout<= 0; Zlowin <= 0;
41     end
42     T6: begin // enable the PC
43         #10 Zlowout <= 1; PC_enable <= 1; //Reading from PCin
44         #15 Zlowout <= 0; PC_enable <= 0;
45     end
46 endcase
47 end

```

F.10 brmi R2, 35

```

1 //uses ConFF to determine what branch instruction to use op code is
  different however
2 // opcode for brmi PC <- PC + 1 + C (10010xxxx-11xxxxxxxxxxxxxxxx)//
3
4 always @(Present_state)// do the required job ineach state
5 begin
6     case (Present_state) //assert the required signals in each clock cycle
7     Default: begin //initialize the signals
8         PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //

```



```

        initialize the signals
9      MARin <= 0; Zlowin <= 0; Zhighin <= 0;
10     PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
11     IncPC <= 0; Read <= 0; CONTROL <= 0;
12     Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
13     Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn <= 0; con_in
        <= 0;
14     Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
15     BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
        ram_enable <= 0;
16     R15_enable <= 0; PC_enable <= 0;
17   end
18   T0: begin
19     #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1;
20     #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin <= 0;
21   end
22   T1: begin
23     #10 Zlowout <= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
        32'h91600023; // opcode for brmi R2, 35 (10010 0010 1100
        0000 000 0000 0010 0011)//
24     #15 Zlowout <= 0; PCin <= 0; Read <= 0; MDRin <= 0;
25   end
26   T2: begin
27     #10 MDRout <= 1; IRin <= 1;
28     #15 MDRout <= 0; IRin <= 0;
29   end
30   T3: begin
31     #10 Gra <= 1; Rout <= 1; con_in <= 1;
32     #15 Gra <= 0; Rout <= 0; con_in <= 0;
33   end
34   T4: begin
35     #10 PCout <= 1; Yin <= 1; // put PC in Y register
36     #10 PCout <= 0; Yin <= 0;
37   end
38   T5: begin
39     #10 Cout <= 1; CONTROL <= 2; Zlowin <= 1; // add PC with branch,
        store in Z_L0
40     #15 Cout <= 0; Zlowin <= 0;
41   end
42   T6: begin // enable the PC
43     #10 Zlowout <= 1; PC_enable <= 1; //Reading from PCin
44     #15 Zlowout <= 0; PC_enable <= 0;
45   end
46   endcase
47 end

```

F.11 jal R1

```

1 //uses ConFF to determine what branch instruction to use op code is
  different however
2 // opcode for jal R1 (10100xxxx-----)// if R15 it is
  for precedence return
3
4 always @(Present_state) // do the required job in each state
5 begin
6   case (Present_state) //assert the required signals in each clock cycle
7     Default: begin //initialize the signals
8       PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout <= 0; //
        initialize the signals

```

```

9      MARin <= 0; Zlowin <= 0; Zhighin <= 0;
10     PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
11     IncPC <= 0; Read <= 0; CONTROL <= 0;
12     Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
13     Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
        <= 0;
14     Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
15     BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
        ram_enable <= 0;
16     R15_enable <= 0; PC_enable <= 0;
17 end
18 T0: begin
19     #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; //
        initialize the signals
20     #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin <= 0;
21 end
22 T1: begin
23     #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; //Mdatain <=
        32'hA0800000; // opcode for jal R1
        (10100000100000000000000000) 000//
24     #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
25 end
26 T2: begin
27     #10 MDRout<= 1; IRin <= 1;
28     #15 MDRout<= 0; IRin <= 0;
29 end
30 T3: begin
31     #10 R15_enable <= 1; PCout <= 1;
32     #15 R15_enable <= 0; PCout <= 0;
33 end
34 T4: begin
35     #10 Gra <= 1; Rout <= 1; PCin <= 1;
36     #15 Gra <= 0; Rout <= 0; PCin <= 0;
37 end
38 endcase
39 end

```

F.12 jr R1

```

1  //uses ConFF to determine what branch instruction to use op code is
    different however
2  // opcode for jr R1 (10011xxxx-----)// if R15 it is for
    procedure return
3
4  always @(Present_state)// do the required job ineach state
5  begin
6      case (Present_state) //assert the required signals in each clock cycle
7      Default: begin //initialize the signals
8          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
            initialize the signals
9          MARin <= 0; Zlowin <= 0; Zhighin <= 0;
10         PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
11         IncPC <= 0; Read <= 0; CONTROL <= 0;
12         Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
13         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
            <= 0;
14         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
15         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
            ram_enable <= 0;

```

```

16         R15_enable <= 0; PC_enable <= 0;
17     end
18     T0: begin
19         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1; //
                initialize the signals
20         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
21     end
22     T1: begin
23         #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; //Mdatain <=
                32'h98800000; // opcode for jr R1
                (100110001000000000000000) 000//
24         #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
25     end
26     T2: begin
27         #10 MDRout<= 1; IRin <= 1;
28         #15 MDRout<= 0; IRin <= 0;
29     end
30     T3: begin
31         #10 Gra <= 1; Rout <= 1; PCin <= 1;
32         #15 Gra <= 0; Rout <= 0; PCin <= 0;
33     end
34 endcase
35 end

```

F.13 in R1

```

1 // Input Port
2 always @(Present_state)// do the required job ineach state
3 begin
4     case (Present_state) //assert the required signals in each clock cycle
5     Default: begin //initialize the signals
6         PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
                initialize the signals
7         MARin <= 0; Zlowin <= 0; Zhighin <= 0;
8         PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
9         IncPC <= 0; Read <= 0; CONTROL <= 0;
10        Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
11        Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
                <= 0;
12        Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
13        BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
                ram_enable <= 0;
14        R15_enable <= 0; PC_enable <= 0;
15    end
16    T0: begin
17        #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1; //
                initialize the signals
18        #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
19    end
20    T1: begin
21        #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
                32'h00000151; // opcode for in r1 101010001// put Mdatain
                onto inputport
22        #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
23    end
24    T2: begin
25        #10 MDRout<= 1; IRin <= 1; // read MDR into IR
26        #15 MDRout<= 0; IRin <= 0;
27    end

```

```

28         T3: begin
29             #10 Gra <= 1; Rin <= 1; inPortOut <= 1;
30             #15 Gra <= 0; Rin <= 0; inPortOut <= 0;
31         end
32     endcase
33 end

```

F.14 out R1

```

1  // Output Port
2  always @(Present_state)// do the required job ineach state
3  begin
4      case (Present_state) //assert the required signals in each clock cycle
5          Default: begin //initialize the signals
6              PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
                initialize the signals
7              MARin <= 0; Zlowin <= 0; Zhighin <= 0;
8              PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
9              IncPC <= 0; Read <= 0; CONTROL <= 0;
10             Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
11             Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
                <= 0;
12             Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
13             BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
                ram_enable <= 0;
14             R15_enable <= 0; PC_enable <= 0;
15         end
16         T0: begin
17             #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1; //
                initialize the signals
18             #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
19         end
20         T1: begin
21             #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
                32'h00000161; // opcode for out r1 101100001// put Mdatain
                onto outputport
22             #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
23         end
24         T2: begin
25             #10 MDRout<= 1; IRin <= 1; // read MDR into IR
26             #15 MDRout<= 0; IRin <= 0;
27         end
28         T3: begin
29             #10 Gra <= 1; Rout <= 1; outPortIn <= 1;
30             #15 Gra <= 0; Rout <= 0; outPortIn <= 0;
31         end
32     endcase
33 end

```

F.15 addi R2, R1, -5

```

1  always @(Present_state)// do the required job ineach state
2  begin
3      case (Present_state) //assert the required signals in each clock cycle
4          Default: begin //initialize the signals
5              PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
                initialize the signals
6              MARin <= 0; Zlowin <= 0; Zhighin <= 0;
7              PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;

```

```

8      IncPC <= 0; Read <= 0; CONTROL <= 0;
9      Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
10     Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
        <= 0;
11     Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
12     BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
        ram_enable <= 0;
13     R15_enable <= 0; PC_enable <= 0;
14 end
15 T0: begin
16     #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; // Mdatain
        <= 32'h590FFFFB; opcode for ADDI R2, R1, -5 01011 0010 0001
        111 1111 1111 1111 1011 in init file
17     #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
18 end
19 T1: begin
20     #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1;
21     #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
22 end
23 T2: begin
24     #10 MDRout<= 1; IRin <= 1;
25     #15 MDRout<= 0; IRin <= 0;
26 end
27 T3: begin
28     #10 Grb <= 1; Rout<= 1; Yin <= 1;
29     #15 Grb <= 0; Rout<= 0; Yin <= 0;
30 end
31 T4: begin
32     #10 Cout<= 1; Zlowin <= 1; CONTROL <= 2; // add, result is
        stored in Z_L0
33     #15 Cout<= 0; Zlowin <= 0;
34 end
35 T5: begin
36     #10 Zlowout<= 1; Gra <= 1; Rin <= 1; // read from Z_L0, store in
        R2
37     #20 Zlowout<= 0; Gra <= 0; Rin <= 0;
38 end
39 endcase
40 end

```

F.16 andi R2, R1 \$26

```

1  always @(Present_state)// do the required job ineach state
2  begin
3      case (Present_state) //assert the required signals in each clock cycle
4      Default: begin //initialize the signals
5          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
            initialize the signals
6          MARin <= 0; Zlowin <= 0; Zhighin <= 0;
7          PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
8          IncPC <= 0; Read <= 0; CONTROL <= 0;
9          Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
10         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
            <= 0;
11         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
12         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
            ram_enable <= 0;
13         R15_enable <= 0; PC_enable <= 0;
14     end

```

```

15     T0: begin
16         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; // Mdatain
            <= 32'h61080026; opcode for ANDI R2, R1, $26 : 01100 0010
            0001 000 0000 0000 0010 0110 in init file
17         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin <= 0;
18     end
19     T1: begin
20         #10 Zlowout <= 1; PCin <= 1; Read <= 1; MDRin <= 1;
21         #15 Zlowout <= 0; PCin <= 0; Read <= 0; MDRin <= 0;
22     end
23     T2: begin
24         #10 MDRout <= 1; IRin <= 1;
25         #15 MDRout <= 0; IRin <= 0;
26     end
27     T3: begin
28         #10 Grb <= 1; Rout <= 1; Yin <= 1;
29         #15 Grb <= 0; Rout <= 0; Yin <= 0;
30     end
31     T4: begin
32         #10 Cout <= 1; Zlowin <= 1; CONTROL <= 0; // and, result is
            stored in Z_L0
33         #15 Cout <= 0; Zlowin <= 0;
34     end
35     T5: begin
36         #10 Zlowout <= 1; Gra <= 1; Rin <= 1; // read from Z_L0, store in
            R2
37         #20 Zlowout <= 0; Gra <= 0; Rin <= 0;
38     end
39 endcase
40 end

```

F.17 ori R2, R1 \$26

```

1  always @(Present_state) // do the required job in each state
2  begin
3      case (Present_state) // assert the required signals in each clock cycle
4      Default: begin // initialize the signals
5          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout <= 0; //
            initialize the signals
6          MARin <= 0; Zlowin <= 0; Zhighin <= 0;
7          PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
8          IncPC <= 0; Read <= 0; CONTROL <= 0;
9          Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
10         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn <= 0; con_in
            <= 0;
11         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
12         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
            ram_enable <= 0; R15_enable <= 0;
13     end
14     T0: begin
15         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin <= 1; // Mdatain
            <= 32'h59080026; opcode for ORI R2, R1, 26 01011 0010 0001
            000 0000 0000 0010 0110 in init file
16         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin <= 0;
17     end
18     T1: begin
19         #10 Zlowout <= 1; PCin <= 1; Read <= 1; MDRin <= 1;
20         #15 Zlowout <= 0; PCin <= 0; Read <= 0; MDRin <= 0;
21     end

```

```

22     T2: begin
23         #10 MDRout<= 1; IRin <= 1;
24         #15 MDRout<= 0; IRin <= 0;
25     end
26     T3: begin
27         #10 Grb <= 1; Rout<= 1; Yin <= 1;
28         #15 Grb <= 0; Rout<= 0; Yin <= 0;
29     end
30     T4: begin
31         #10 Cout<= 1; Zlowin <= 1; CONTROL <= 1; // or, result is stored
32             in Z_L0
33         #15 Cout<= 0; Zlowin <= 0;
34     end
35     T5: begin
36         #10 Zlowout<= 1; Gra <= 1; Rin <= 1; // read from Z_L0, store in
37             R2
38         #20 Zlowout<= 0; Gra <= 0; Rin <= 0;
39     end
40 endcase
41 end

```

F.18 mfhi R2

```

1  //uses ConFF to determine what branch instruction to use op code is
   different however
2  // opcode for mfhi R2 (10100xxxx-----)// if R15 it is
   for procedure return
3
4  always @(Present_state)// do the required job ineach state
5  begin
6      case (Present_state) //assert the required signals in each clock cycle
7      Default: begin //initialize the signals
8          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
9              initialize the signals
10         MARin <= 0; Zlowin <= 0; Zhighin <= 0;
11         PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
12         IncPC <= 0; Read <= 0; CONTROL <= 0;
13         Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
14         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
15             <= 0;
16         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
17         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
18             ram_enable <= 0;
19         R15_enable <= 0; PC_enable <= 0;
20     end
21     T0: begin
22         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1; //
23             initialize the signals
24         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
25     end
26     T1: begin
27         #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; //Mdatain <=
28             32'hB9000000; // opcode for mfhi R2
29             (101110010000000000000000) 000//
30         #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
31     end
32     T2: begin
33         #10 MDRout<= 1; IRin <= 1;
34         #15 MDRout<= 0; IRin <= 0;
35     end

```

```

29     end
30     T3: begin // enable write to register by reading from HI
31         #10 Gra <= 1; Rin <= 1; highout <= 1;
32         #15 Gra <= 0; Rin <= 0; highout <= 0;
33     end
34
35 endcase
36 end

```

F.19 mflo R2

```

1  //uses ConFF to determine what branch instruction to use op code is
   different however
2  // opcode for mflo R2 (10100xxxx-----)// if R15 it is
   for procedure return
3
4  always @(Present_state)// do the required job ineach state
5  begin
6      case (Present_state) //assert the required signals in each clock cycle
7      Default: begin //initialize the signals
8          PCout <= 0; Zlowout <= 0; Zhighout <= 0; MDRout<= 0; //
               initialize the signals
9          MARin <= 0; Zlowin <= 0; Zhighin <= 0;
10         PCin <= 0; MDRin <= 0; IRin <= 0; Yin <= 0;
11         IncPC <= 0; Read <= 0; CONTROL <= 0;
12         Clear <= 1; Yout <= 0; highin <= 0; lowin <= 0;
13         Cout <= 0; outPortIn <= 0; inPortOut <= 0; inPortIn<= 0; con_in
               <= 0;
14         Mdatain <= 32'h00000000; highout <= 0; lowout <= 0;
15         BAout <= 0; Rin <= 0; Rout <= 0; Gra <= 0; Grb <= 0; Grc <= 0;
               ram_enable <= 0;
16         R15_enable <= 0; PC_enable <= 0;
17     end
18     T0: begin
19         #10 PCout <= 1; MARin <= 1; IncPC <= 1; Zlowin<= 1; //
               initialize the signals
20         #15 PCout <= 0; MARin <= 0; IncPC <= 0; Zlowin<= 0;
21     end
22     T1: begin
23         #10 Zlowout<= 1; PCin <= 1; Read <= 1; MDRin <= 1; // Mdatain <=
               32'hC1000000; // opcode for mflo R2
               (11000001000000000000000000) 000//
24         #15 Zlowout<= 0; PCin <= 0; Read <= 0; MDRin <= 0;
25     end
26     T2: begin
27         #10 MDRout<= 1; IRin <= 1;
28         #15 MDRout<= 0; IRin <= 0;
29     end
30     T3: begin
31         #10 Gra <= 1; Rin <= 1; lowout <= 1;
32         #15 Gra <= 0; Rin <= 0; lowout <= 0;
33     end
34 endcase
35 end

```