



CAL POLY

CPE 233 Hardware Assignment 3

Register File and Verification

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1 Project Description

In this project, a register file was created and tested using a testbench. The testbench was able to verify that the register file worked properly and passed all of the test cases. The register file was able to take in two different addresses and return the correct information as well as take in one address and write to a specific address.

2 Structural Design

2.1 Overall Elaborated Design

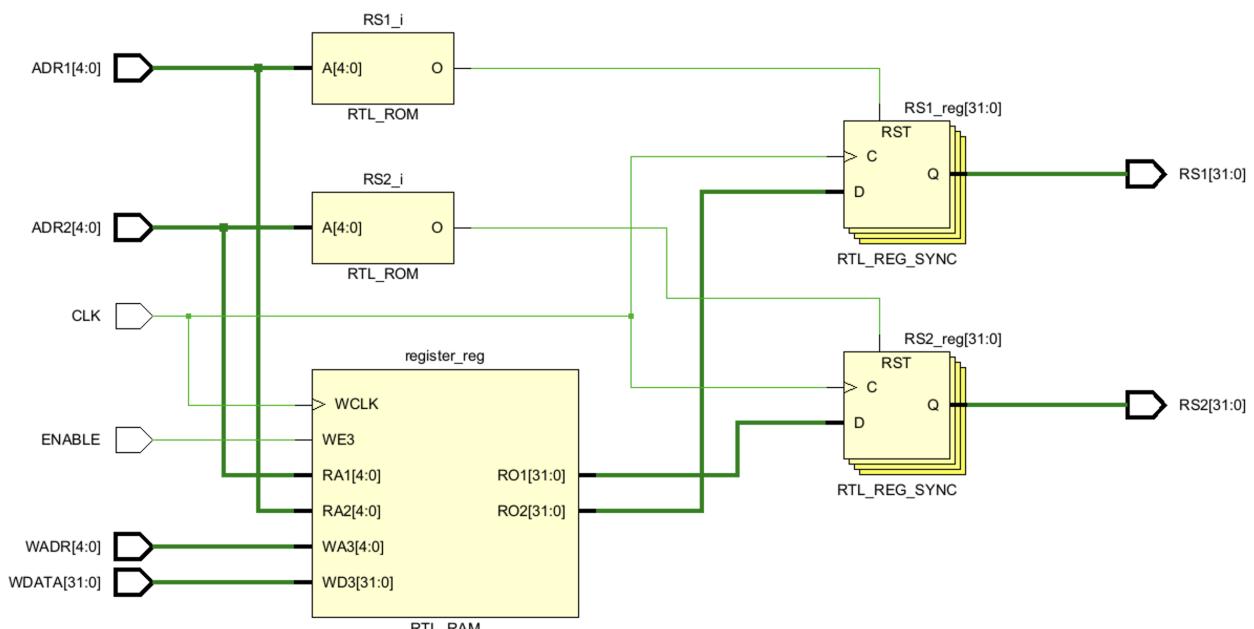


Figure 1: Program Counter Elaborated Design

3 Synthesis Warnings



Figure 2: Synthesis Warnings

4 Verification

4.1 Testbench Coverage

When testing this design, there were several test cases that were used to verify that the design was working properly. The test cases are listed below.

1. **Random Bits Test:** This test case was used to verify that the RegFile could store any random number in all of the registers and then provide that number through both of the register outputs.
2. **Zero Bits Test:** This test case was used to verify that the RegFile could store a zero in all of the registers and then provide that number through both of the register outputs.
3. **Enable Write Test:** This test case was used to verify that the enable write bit would allow the RegFile to write to the registers when it was high and not write to the registers when it was low.
4. **Min Bits Test:** This test case was used to verify that the RegFile could store the minimum number in all of the registers and then provide that number through both of the register outputs.
5. **Max Bits Test:** This test case was used to verify that the RegFile could store the maximum number in all of the registers and then provide that number through both of the register outputs.

4.2 Testbench Code

Listing 1: Verilog Testbench for Program Counter

```
1 'timescale 1ns / 1ps
2 ///////////////////////////////////////////////////////////////////
3 // Company: Cal Poly SLO
4 // Engineer: Ethan Vosburg
5 //
6 // Create Date: 01/26/2024 11:06:16 PM
7 // Module Name: RegFile_TB
8 // Project Name: RegFile
9 // Target Devices: Basys 3
10 // Description: This Testbench tests the RegFile module
11 //
12 // Revision:
13 // Revision 0.01 - File Created
14 //
15 ///////////////////////////////////////////////////////////////////
16
17
18 module RegFile_TB();
19
20    // Inputs
21    logic ENABLE_TB;           // 1-bit enable
22    logic CLK_TB = 0;          // 1-bit clock
23    logic [4:0] ADR1_TB;       // 5-bit address
24    logic [4:0] ADR2_TB;       // 5-bit address
25    logic [4:0] WADR_TB;       // 5-bit address
26    logic [31:0] WDATA_TB;     // 32-bit data
27
28    // Outputs
```

```

29 logic [31:0] RS1_TB;      // 32-bit data
30 logic [31:0] RS2_TB;      // 32-bit data
31
32 // Logic
33 logic passed = 1;         // 1 = pass, 0 = fail
34 logic simPage = 1;         // 1 = simPage, 0 = no simPage
35
36 // Define Clock
37 always #5 CLK_TB = ~CLK_TB;
38
39 // Define Clock
40 always #70 simPage = ~simPage;
41
42 // Instantiate the Unit Under Test (UUT)
43 RegFile uut (
44     .ENABLE(ENABLE_TB),
45     .CLK(CLK_TB),
46     .ADR1(ADR1_TB),
47     .ADR2(ADR2_TB),
48     .WADR(WADR_TB),
49     .WDATA(WDATA_TB),
50     .RS1(RS1_TB),
51     .RS2(RS2_TB)
52 );
53
54 // Begin simulation code
55 begin
56
57     $display("-----\n");
58     $display("RegFile Testbench\n");
59     $display("-----\n");
60
61     setup();           // Setup Task
62     randomBits();     // Random bits Task
63     zeroBits();       // Zero bits Task
64     enableWrite();    // Enable Write Task
65     minBits();        // Min bits Task
66     maxBits();        // Max bits Task
67
68     // Display overall pass/fail
69     $display("-----\n");
70     if (passed == 1) begin
71         $display("OVERALL PASS\n");
72     end else begin
73         $display("OVERALL FAIL\n");
74     end
75     $display("-----\n");
76     $finish;
77 end
78
79 task setup();
80     // Initialize Logic
81     ENABLE_TB = 0;      // Initialize ENABLE_TB
82     ADR1_TB = 0;        // Initialize ADR1_TB
83     ADR2_TB = 0;        // Initialize ADR2_TB
84     WADR_TB = 0;        // Initialize WADR_TB
85     WDATA_TB = 0;       // Initialize WDATA_TB
86     RS1_TB = 0;         // Initialize RS1_TB
87     RS2_TB = 0;         // Initialize RS2_TB
88
89     $display("Setup Complete");
90
91 endtask
92
93 task randomBits();
94     // Random bits
95     logic [31:0] testBits [0:31];
96
97     //enable write input

```

```

99      ENABLE_TB = 32'h0000_0001;
100
101 // Load Random Bits
102 for (int i = 0; i < 31; i++) begin
103     testBits[i] = $random;
104     WADR_TB = i;
105     WDATA_TB = testBits[i];
106     #10;
107     // Display Case
108     // $display("WADR_TB[%0d] = %h", i, WADR_TB);
109 end
110
111 // Read random bits
112 // Check x0 returns 0
113 if (RS1_TB != 32'h0000_0000) begin
114     $display("Error: x0 test RS1_TB[%0d] = %h", 0, RS1_TB);
115     $display("Error: x0 test testBits[%0d] = %h", 0, testBits[0]);
116     passed = 0;
117 end
118 // Check x0 returns 0
119 if (RS2_TB != 32'h0000_0000) begin
120     $display("Error: x0 test RS2_TB[%0d] = %h", 0, RS2_TB);
121     $display("Error: x0 test testBits[%0d] = %h", 0, testBits[0]);
122     passed = 0;
123 end
124
125
126 for (int i = 1; i < 31; i++) begin
127     // Set ADR1 and ADR2 to i and allow for propagation
128     ADR1_TB = i;
129     ADR2_TB = i;
130     #1; // Less than 10ns to verify async read behavior
131
132     // Check RS1 returns expected value
133     if (RS1_TB != testBits[i]) begin
134         $display("Error: Random Read Test RS1_TB[%0d] = %h", i, RS1_TB);
135         $display("Error: Random Read Test testBits[%0d] = %h", i, testBits[i]);
136         passed = 0;
137     end
138
139     // Check RS2 returns expected value
140     if (RS2_TB != testBits[i]) begin
141         $display("Error: Random Read Test RS2_TB[%0d] = %h", i, RS2_TB);
142         $display("Error: Random Read Test testBits[%0d] = %h", i, testBits[i]);
143         passed = 0;
144     end
145     // #10;
146
147     // Display Case
148     // $display("ADR1_TB[%0d] = %h", i, ADR1_TB);
149     // $display("ADR2_TB[%0d] = %h", i, ADR2_TB);
150 end
151
152 if (passed == 1) begin
153     $display("Random Bits Test Passed");
154 end else begin
155     $display("Random Bits Test Failed");
156 end
157
158 endtask
159
160 // Task to test zero bits
161 task zeroBits();
162     //enable write input
163     ENABLE_TB = 32'h0000_0001;
164
165     WADR_TB = 0;
166     WDATA_TB = 32'h0000_0000;
167     ADR1_TB = 0;
168     ADR2_TB = 0;

```

```

169      #10;
170
171      // Load Zero Bits
172      // Check x0 returns 0
173      if (RS1_TB != 32'h0000_0000) begin
174          $display("Error: x0 Load All Zeros RS1");
175          passed = 0;
176      end
177      // Check x0 returns 0
178      if (RS2_TB != 32'h0000_0000) begin
179          $display("Error: x0 Load All Zeros RS2");
180          passed = 0;
181      end
182
183
184      WADR_TB = 0;
185      WDATA_TB = 32'hffff_ffff;
186      ADR1_TB = 0;
187      ADR2_TB = 0;
188      #10;
189
190      // Load Zero Bits
191      // Check x0 returns 0
192      if (RS1_TB != 32'h0000_0000) begin
193          $display("Error: x0 Load All F RS1");
194          passed = 0;
195      end
196      // Check x0 returns 0
197      if (RS2_TB != 32'h0000_0000) begin
198          $display("Error: x0 Load All F RS2");
199          passed = 0;
200      end
201
202      if (passed == 1) begin
203          $display("Zero Bits Test Passed");
204      end else begin
205          $display("Zero Bits Test Failed");
206      end
207
208  endtask
209
210  // Max Bits Task
211
212  task maxBits();
213      //enable write input
214      ENABLE_TB = 32'h0000_0001;
215
216      // Load Max Bits
217      for (int i = 0; i < 31; i++) begin
218          WADR_TB = i;
219          WDATA_TB = 32'hffff_ffff;
220          #10;
221          // Display Case
222          // $display("WADR_TB[%0d] = %h", i, WADR_TB);
223      end
224
225      // Read Max bits
226      for (int i = 1; i < 31; i++) begin
227          // Set ADR1 and ADR2 to i and allow for propagation
228          ADR1_TB = i;
229          ADR2_TB = i;
230          #10;
231
232          // Check RS1 returns expected value
233          if (RS1_TB != 32'hffff_ffff) begin
234              $display("Error: Max Read Test RS1_TB[%0d] = %h", i, RS1_TB);
235              passed = 0;
236          end
237
238          // Check RS2 returns expected value

```

```

239     if (RS2_TB != 32'hffff_ffff) begin
240         $display("Error: Max Read Test RS2_TB[%0d] = %h", i, RS2_TB);
241         passed = 0;
242     end
243     #10;
244
245     // Display Case
246     // $display("ADR1_TB[%0d] = %h", i, ADR1_TB);
247     // $display("ADR2_TB[%0d] = %h", i, ADR2_TB);
248 end
249
250 if (passed == 1) begin
251     $display("Max Bits Test Passed");
252 end else begin
253     $display("Max Bits Test Failed");
254 end
255
256 endtask
257
258 task minBits();
259     //enable write input
260     ENABLE_TB = 32'h0000_0001;
261
262     // Load Min Bits
263     for (int i = 0; i < 31; i++) begin
264         WADR_TB = i;
265         WDATA_TB = 32'h0000_0000; // Write minimum value
266         #10;
267         // Display Case
268         // $display("WADR_TB[%0d] = %h", i, WADR_TB);
269     end
270
271     // Read Min bits
272     for (int i = 1; i < 31; i++) begin
273         // Set ADR1 and ADR2 to i and allow for propagation
274         ADR1_TB = i;
275         ADR2_TB = i;
276         #10;
277
278         // Check RS1 returns expected value
279         if (RS1_TB != 32'h0000_0000) begin // Check for minimum value
280             $display("Error: Min Read Test RS1_TB[%0d] = %h", i, RS1_TB);
281             passed = 0;
282         end
283
284         // Check RS2 returns expected value
285         if (RS2_TB != 32'h0000_0000) begin // Check for minimum value
286             $display("Error: Min Read Test RS2_TB[%0d] = %h", i, RS2_TB);
287             passed = 0;
288         end
289         #10;
290
291         // Display Case
292         // $display("ADR1_TB[%0d] = %h", i, ADR1_TB);
293         // $display("ADR2_TB[%0d] = %h", i, ADR2_TB);
294     end
295
296     if (passed == 1) begin
297         $display("Min Bits Test Passed");
298     end else begin
299         $display("Min Bits Test Failed");
300     end
301
302 endtask
303
304 //Enable Write Task
305 task enableWrite();
306     // Random bits
307     logic [31:0] testBits [0:31];
308

```

```

309     //enable write input
310     ENABLE_TB = 32'h0000_0001;
311
312     // Load Random Bits
313     for (int i = 0; i < 31; i++) begin
314         testBits[i] = $random;
315         WADR_TB = i;
316         WDATA_TB = testBits[i];
317         #10;
318         // Display Case
319         // $display("WADR_TB[%0d] = %h", i, WADR_TB);
320     end
321
322     // Disable write input
323     ENABLE_TB = 32'h0000_0000;
324     #10
325
326     // Attempt to zero out registers
327     for (int i = 0; i < 31; i++) begin
328         WADR_TB = i;
329         WDATA_TB = 32'h0000_0000; // Write minimum value
330         #10;
331         // Display Case
332         // $display("WADR_TB[%0d] = %h", i, WADR_TB);
333     end
334
335     for (int i = 1; i < 31; i++) begin
336         // Set ADR1 and ADR2 to i and allow for propagation
337         ADR1_TB = i;
338         ADR2_TB = i;
339         #10;
340
341         // Check RS1 returns expected value
342         if (RS1_TB != testBits[i]) begin
343             $display("Error: Enable Bits Test RS1_TB[%0d] = %h", i, RS1_TB);
344             $display("Error: Enable Bits Test testBits[%0d] = %h", i, testBits[i]);
345             passed = 0;
346         end
347
348         // Check RS2 returns expected value
349         if (RS2_TB != testBits[i]) begin
350             $display("Error: Enable Bits Test RS2_TB[%0d] = %h", i, RS2_TB);
351             $display("Error: Enable Bits Test testBits[%0d] = %h", i, testBits[i]);
352             passed = 0;
353         end
354         #10;
355
356         // Display Case
357         // $display("ADR1_TB[%0d] = %h", i, ADR1_TB);
358         // $display("ADR2_TB[%0d] = %h", i, ADR2_TB);
359     end
360
361     if (passed == 1) begin
362         $display("Enable Write Test Passed");
363     end else begin
364         $display("Enable Write Test Failed");
365     end
366
367 endtask
368
369
370 endmodule

```

4.3 Testbench Output

Running this testbench produced the following output in the TCL code console:

Listing 2: TCL Output from ProgramCounterEnv_TB

```
1 -----
2 RegFile Testbench
3 -----
4 -----
5 -----
6 -----
7 Setup Complete
8 Random Bits Test Passed
9 Zero Bits Test Passed
10 Enable Write Test Passed
11 Min Bits Test Passed
12 Max Bits Test Passed
13 -----
14 -----
15 OVERALL PASS
16 -----
17 -----
18 -----
19 $finish called at time : 3980 ns
```

4.4 Simulation Results

Running this testbench produced the following simulation results:

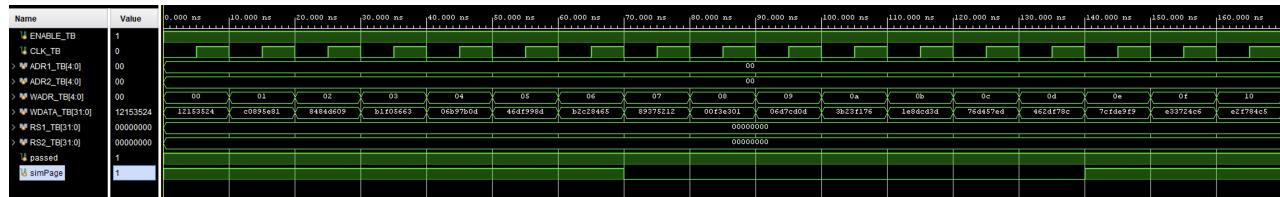


Figure 3: RegFile Simulation Ons - 140ns

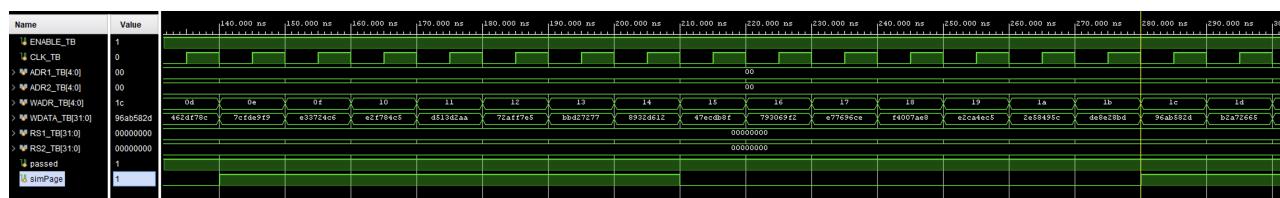


Figure 4: RegFile Simulation 140ns - 280ns

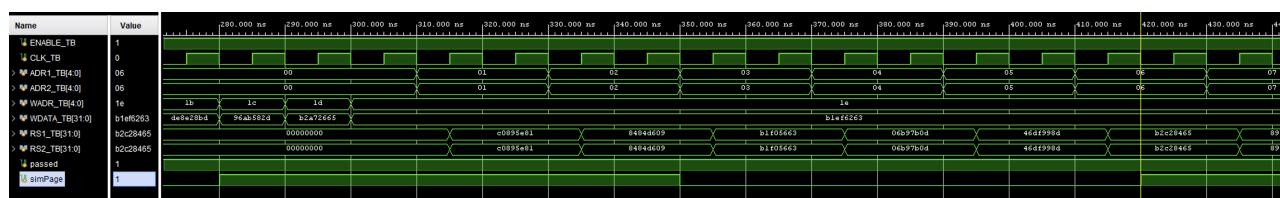


Figure 5: RegFile Simulation 280ns - 420ns

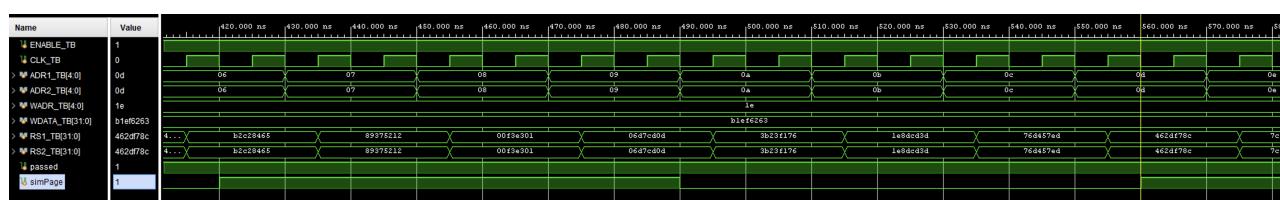


Figure 6: RegFile Simulation 420ns - 560ns

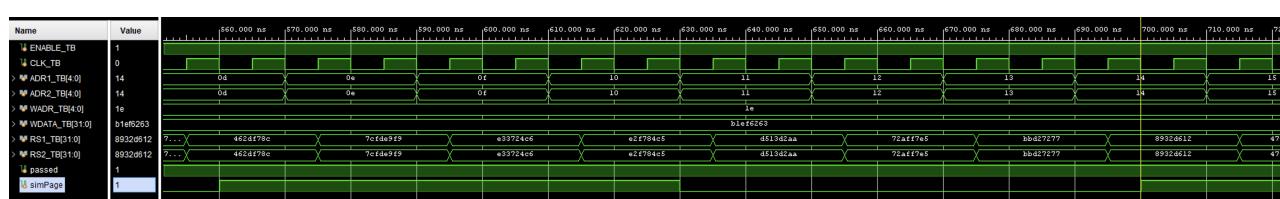


Figure 7: RegFile Simulation 560ns - 700ns

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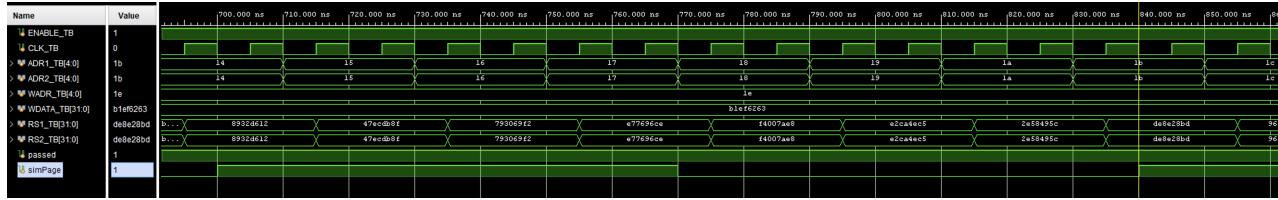


Figure 8: RegFile Simulation 700ns - 840ns

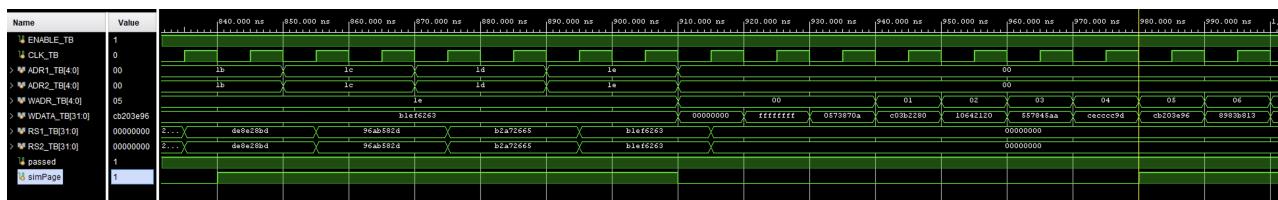


Figure 9: RegFile Simulation 840ns - 980ns

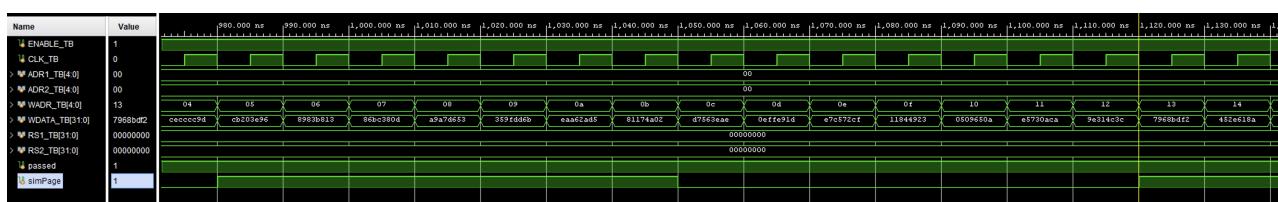


Figure 10: RegFile Simulation 980ns - 1120ns

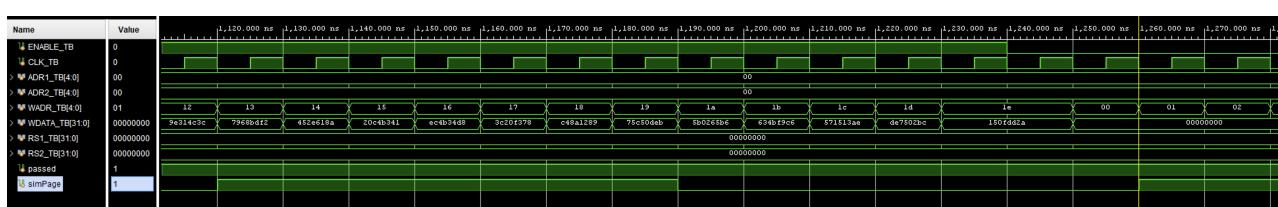


Figure 11: RegFile Simulation 1120ns - 1260ns

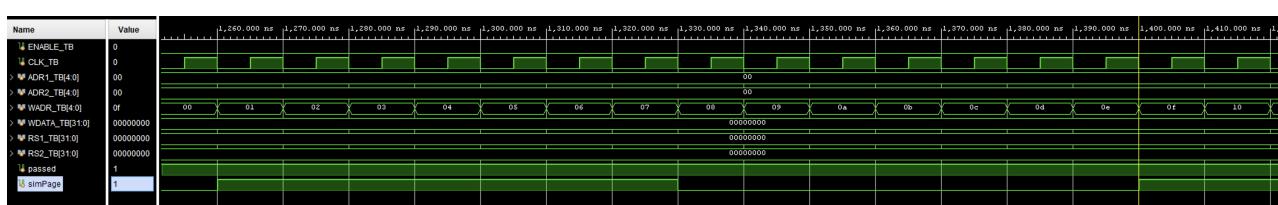


Figure 12: RegFile Simulation 1260ns - 1400ns

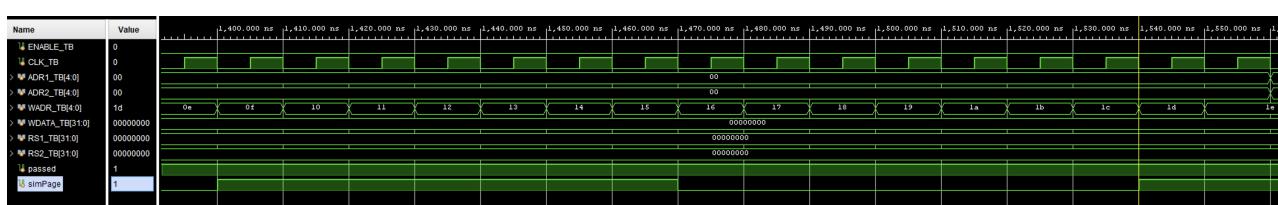


Figure 13: RegFile Simulation 1400ns - 1540ns

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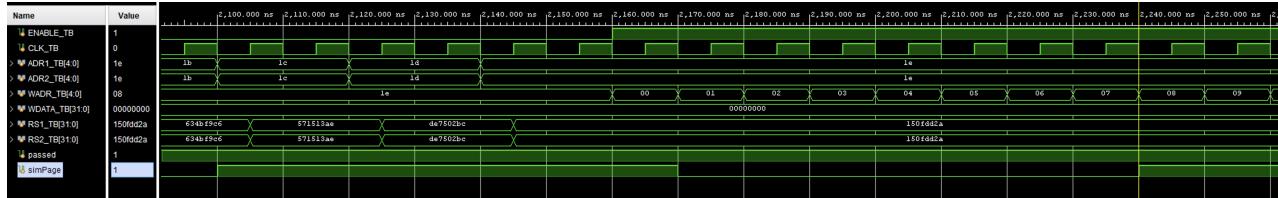


Figure 18: RegFile Simulation 2100ns - 2240ns

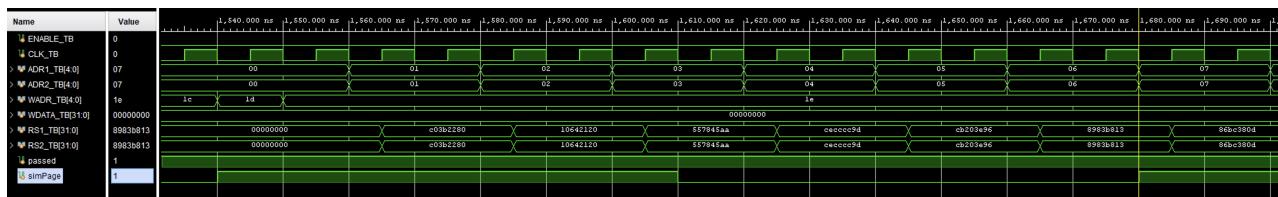


Figure 14: RegFile Simulation 1540ns - 1680ns

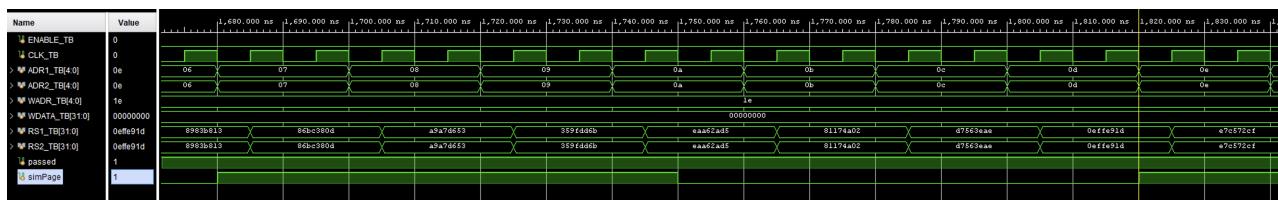


Figure 15: RegFile Simulation 1680ns - 1820ns

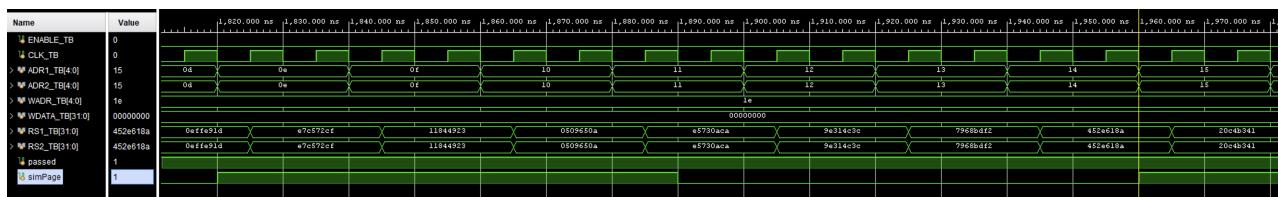


Figure 16: RegFile Simulation 1820ns - 1960ns

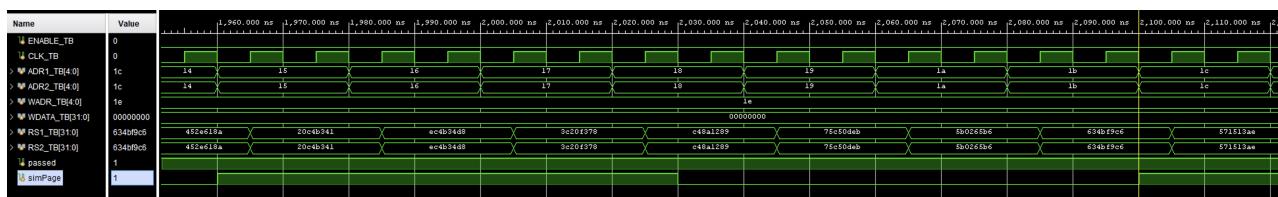


Figure 17: RegFile Simulation 1960ns - 2100ns

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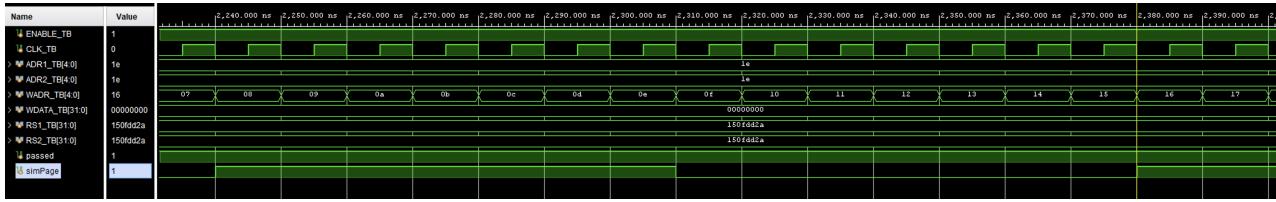


Figure 19: RegFile Simulation 2240ns - 2380ns

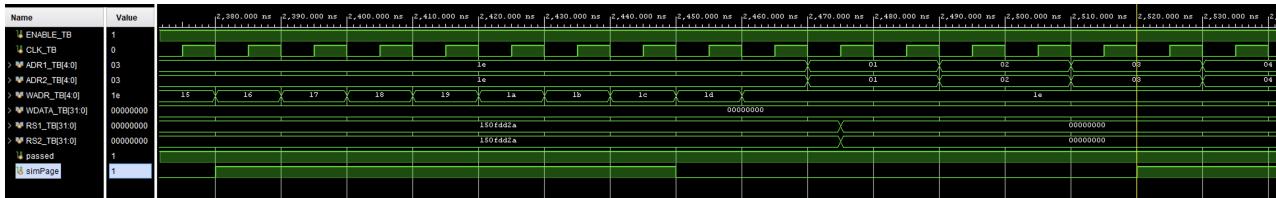


Figure 20: RegFile Simulation 2380ns - 2520ns

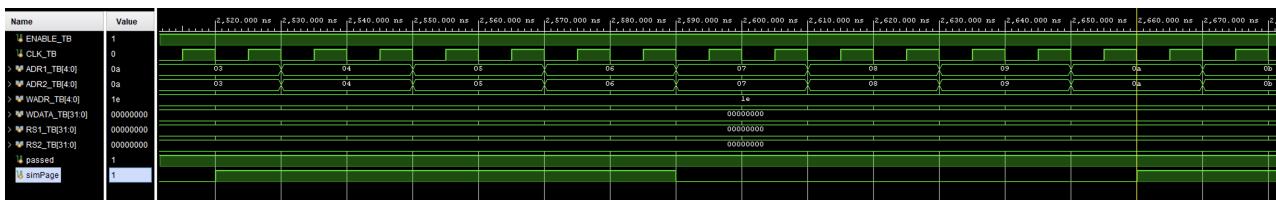


Figure 21: RegFile Simulation 2520ns - 2660ns

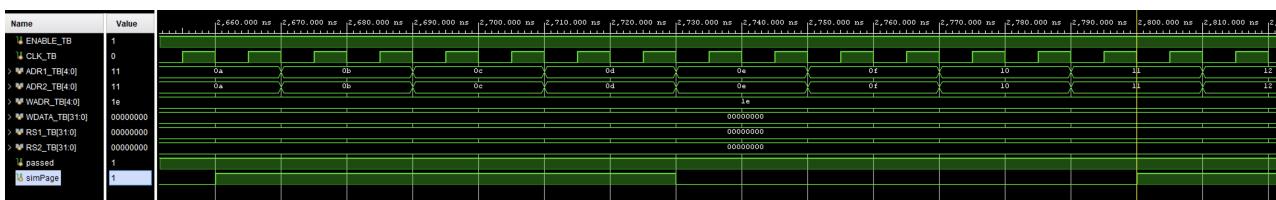


Figure 22: RegFile Simulation 2660ns - 2800ns

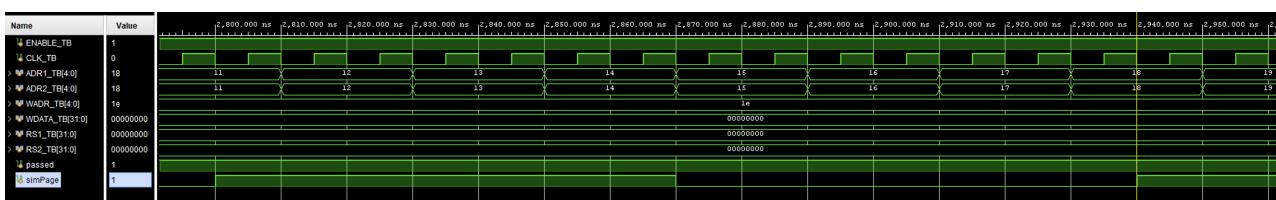


Figure 23: RegFile Simulation 2800ns - 2940ns

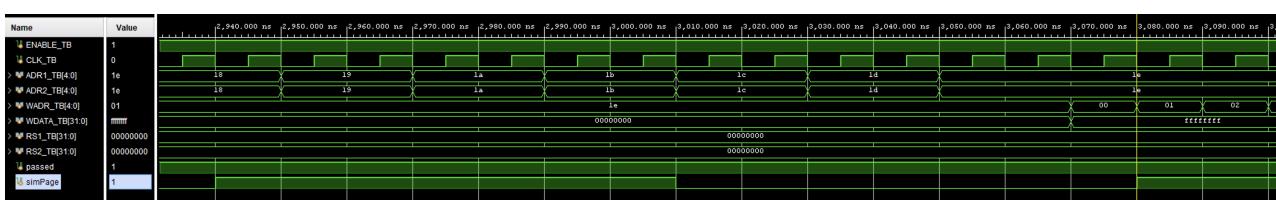


Figure 24: RegFile Simulation 2940ns - 3080ns

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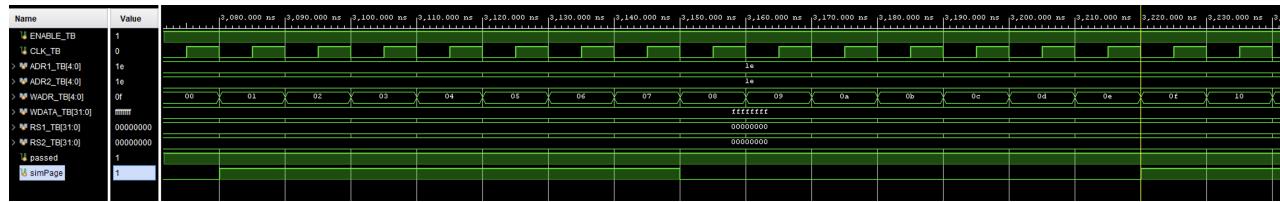


Figure 25: RegFile Simulation 3080ns - 3220ns

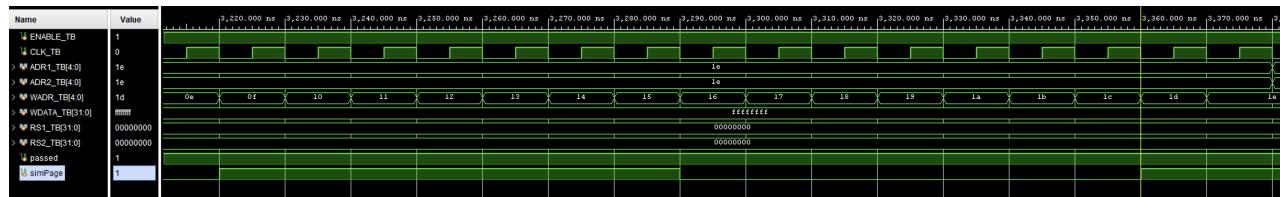


Figure 26: RegFile Simulation 3220ns - 3360ns



Figure 27: RegFile Simulation 3360ns - 3500ns

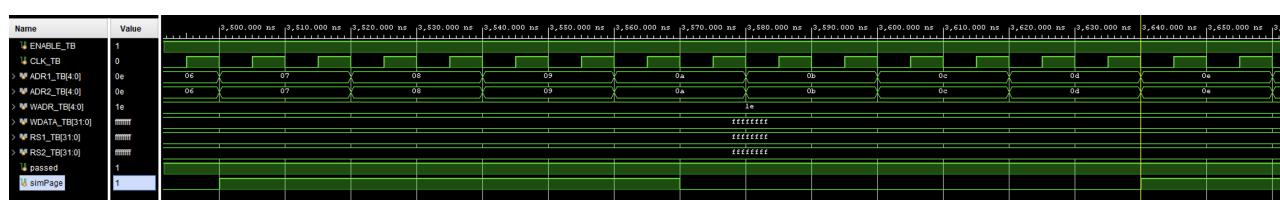


Figure 28: RegFile Simulation 3500ns - 3640ns



Figure 29: RegFile Simulation 3640ns - 3780ns

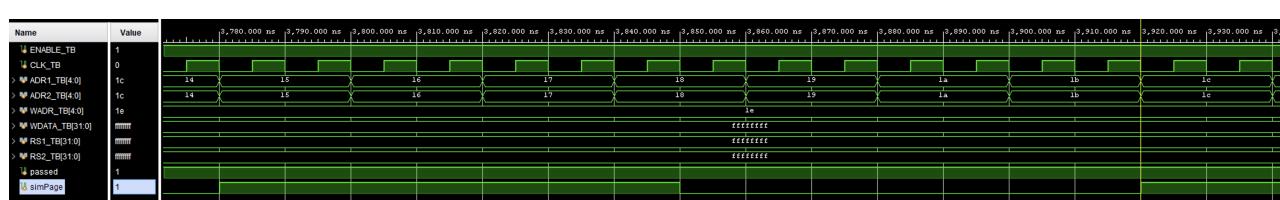


Figure 30: RegFile Simulation 3780ns - 3920ns

5 Source Code

5.1 Register File

Listing 3: Verilog Code for Register File

```
1 'timescale 1ns / 1ps
2 ///////////////////////////////////////////////////////////////////
3 // Company: Cal Poly SLO
4 // Engineer: Ethan Vosburg
5 //
6 // Create Date: 01/26/2024 06:24:51 PM
7 // Module Name: RegFile
8 // Project Name: RegFile
9 // Target Devices: Basys 3
10 // Description: Create a Register for the ALU
11 //
12 // Revision:
13 // Revision 0.01 - File Created
14 //
15 ///////////////////////////////////////////////////////////////////
16
17
18 module RegFile(
19     // Inputs
20     input ENABLE,
21     input CLK,
22     input [4:0] ADR1,
23     input [4:0] ADR2,
24     input [4:0] WADR,
25     input [31:0] WDATA,
26
27     // Outputs
28     output logic [31:0] RS1,
29     output logic [31:0] RS2
30 );
31
32 // Declare register array
33 logic [31:0] register [0:31];
34
35 always_ff @(posedge CLK) begin
36     if (ENABLE == 1) begin
37         // Write data to register
38         register[WADR] <= WDATA;
39     end
40
41 end
42
43
44 always_comb begin
45     // Add logic for zero register
46     if (ADR1 == 0) RS1 = 32'h0000_0000;
47     else RS1 = register[ADR1];
48
49     if (ADR2 == 0) RS2 = 32'h0000_0000;
50     else RS2 = register[ADR2];
51
52     // Present data from 2 desire
53
54
55 end
56 endmodule
```

6 Conclusion

The program counter is a very important module and will be used heavily in the Otter processor. This counter keeps track of which line of machine code to feed the rest of the processor and it makes allows branching and many other capabilities. In this project, a program counter was created and tested using a testbench. The testbench was able to verify that the program counter and the mux associated with it worked properly and passed all of the test cases. All code for this assignment can be found [here](#).