Verilog HDL Assignment 5

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Question 1

ALSU

Verilog Code:

```verilog
module ALSU (A, B, opcode, cin, serial_in, direction, red_op_A, red_op_B, bypass_A, bypass_B, clk, rst, out, leds);
parameter INPUT_PRIORITY  =  "A";
parameter FULL_ADDER  =  "ON";
input clk, rst, cin, serial_in, red_op_A, red_op_B, bypass_A, bypass_B, direction;
input [2: 0] A, B, opcode;
output reg [15: 0] leds;
output reg [5: 0] out;
reg [2: 0] A_FF, B_FF, opcode_FF;
reg cin_FF, serial_in_FF, red_op_A_FF, red_op_B_FF, bypass_A_FF, bypass_B_FF, direction_FF;
always @(posedge clk or posedge rst) begin
  if (rst) begin
    A_FF  <=  0;  B_FF  <=  0;  opcode_FF  <=  0;  cin_FF  <=  0;  serial_in_FF  <=  0;  red_op_A_FF  <=  0;
    red_op_B_FF  <=  0;  bypass_A_FF  <=  0;  bypass_B_FF  <=  0;  direction_FF  <=  0;
  end begin
    A_FF  <=  A;  B_FF  <=  B;  opcode_FF  <=  opcode;  cin_FF  <=  cin;  serial_in_FF  <=  serial_in;  red_op_A_FF
            <=  red_op_A;
    red_op_B_FF  <=  red_op_B;  bypass_A_FF  <=  bypass_A;  bypass_B_FF  <=  bypass_B;  direction_FF  <
            =  direction;
  end
end
always @(posedge clk or posedge rst) begin
  if (rst) begin
    out  <=  0;
    leds  <=  0;
  end else begin
    if ((bypass_A_FF  ==  1) && (bypass_B_FF  ==  0)) begin
      out  <=  A_FF;  leds  <=  0;
    end
    else if ((bypass_B_FF  ==  1) && (bypass_A_FF  ==  0)) begin
      out  <=  B_FF;  leds  <=  0;
    end
    else if ((bypass_A_FF  ==  1) && (bypass_B_FF  ==  1)) begin
      leds  <=  0;
      case (INPUT_PRIORITY)
        "A" :  out  <=  A_FF;
        "B" :  out  <=  B_FF;
      endcase
    end
    else begin
```

```
case (opcode_FF)
  3'b000 :  begin
    if ((red_op_A_FF  ==  1) && (red_op_B_FF  ==  0)) begin
      out  <=  &A_FF; leds  <=  0;
    end
    else if ((red_op_B_FF  ==  1) && (red_op_A_FF  ==  0)) begin
      out  <=  &B_FF; leds  <=  0;
    end
    else if ((red_op_A_FF  ==  1) && (red_op_A_FF  ==  1)) begin
      leds  <=  0;
      case (INPUT_PRIORITY)
        "A" :  out  <=  &A_FF;
        "B" :  out  <=  &B_FF;
      endcase
    end
    else begin
      out  <=  A_FF & B_FF; leds  <=  0;
    end
  end
  3'b001 :  begin
    if ((red_op_A_FF  ==  1) && (red_op_B_FF  ==  0)) begin
      out  <=  ^A_FF; leds  <=  0;
    end
    else if ((red_op_B_FF  ==  1) && (red_op_A_FF  ==  0)) begin
      out  <=  ^B_FF; leds  <=  0;
    end
    else if ((red_op_A_FF  ==  1) && (red_op_A_FF  ==  1)) begin
      leds  <=  0;
      case (INPUT_PRIORITY)
        "A" :  out  <=  ^A_FF;
        "B" :  out  <=  ^B_FF;
      endcase
    end
    else begin
      out  <=  A_FF ^ B_FF; leds  <=  0;
    end
  end
  3'b010 :  begin
    case ({red_op_A_FF, red_op_B_FF})
      2'b01, 2'b10 :  begin
        out  <=  0; leds  <=  ~leds;
      end
      2'b00 :  begin
        case (FULL_ADDER)
          "ON" :  begin
                out  <=  A_FF  +  B_FF  +  cin_FF; leds  <=  0;
              end
          "OFF" :  begin
                out  <=  A_FF  +  B_FF; leds  <=  0;
              end
        endcase
        end
      endcase
    end
    3'b011 : begin
      case ({red_op_A_FF, red_op_B_FF})
        2'b01, 2'b10, 2'b11 : begin
          out <= 0; leds <= ~leds;
        end
        2'b00 : begin
          out <= A_FF * B_FF; leds <= 0;
        end
      endcase
    end
    3'b100 : begin
      case ({red_op_A_FF, red_op_B_FF})
        2'b01, 2'b10, 2'b11 : begin
          out <= 0; leds <= ~leds;
        end
        2'b00 : begin
          leds <= 0;
          if (direction_FF)
            out <= {out[4:0], serial_in_FF};
          else
            out <= {serial_in_FF, out[5:1]};
        end
      endcase
    end
    3'b101 : begin
      case ({red_op_A_FF, red_op_B_FF})
        2'b01, 2'b10, 2'b11 : begin
          out <= 0; leds <= ~leds;
        end
        2'b00 : begin
          leds <= 0;
          if (direction_FF)
            out <= {out[4:0], out[5]};
          else
            out <= {out[0], out[5:1]};
        end
      endcase
    end
    3'b110, 3'b111 : begin
      out <= 0; leds <= ~leds;
    end
   endcase
  end
 end
end
endmodule
```

```
/*
module ALSU (A, B, opcode, cin, serial_in, direction, red_op_A, red_op_B, bypass_A, bypass_B, clk, rst, out, leds);
parameter INPUT_PRIORITY = "A";
parameter FULL_ADDER = "ON";
input clk, rst, cin, serial_in, red_op_A, red_op_B, bypass_A, bypass_B, direction;
input [2: 0] A, B, opcode;
output reg [15: 0] leds;
output reg [5: 0] out;
reg [2: 0] A_FF, B_FF, opcode_FF;
reg cin_FF, serial_in_FF, red_op_A_FF, red_op_B_FF, bypass_A_FF, bypass_B_FF, direction_FF;
wire invalid_red_op, invalid_opcode, invalid;
assign invalid_red_op = (red_op_A_FF | red_op_B_FF) & (opcode_FF[1] | opcode_FF[2]);
assign invalid_opcode = opcode_FF[1] & opcode_FF[2];
assign invalid = invalid_red_op | invalid_opcode;
always @(posedge clk or posedge rst) begin
  if (rst) begin
    A_FF <= 0; B_FF <= 0; opcode_FF <= 0; cin_FF <= 0; serial_in_FF <= 0; red_op_A_FF <= 0;
    red_op_B_FF <= 0; bypass_A_FF <= 0; bypass_B_FF <= 0; direction_FF <= 0;
  end begin
    A_FF <= A; B_FF <= B; opcode_FF <= opcode; cin_FF <= cin; serial_in_FF <= serial_in; red_op_A_FF
                <= red_op_A;
    red_op_B_FF <= red_op_B; bypass_A_FF <= bypass_A; bypass_B_FF <= bypass_B; direction_FF <
                = direction;
  end
end
always @(posedge clk or posedge rst) begin
  if (rst) begin
    leds <= 0;
  end else begin
    if (invalid)
      leds = ~leds;
    leds <= 0;
  end
end
always @(posedge clk or posedge rst) begin
  if (rst) begin
    out <= 0;
  end
  else begin
    if (bypass_A_FF && bypass_B_FF)
      out <= (INPUT_PRIORITY == "A")? A_FF : B_FF;
    else if (bypass_A_FF)
      out <= A_FF;
    else if (bypass_B_FF)
      out <= B_FF;
    else begin
      if (invalid) begin
        out <= 0;
      end else begin
```

```
        case (opcode_FF)
          3'h0 :  begin
            if (red_op_A_FF && red_op_B_FF)
              out  <=  (INPUT_PRIORITY  ==  "A")? &A_FF :  &B_FF;
            else if (red_op_A_FF)
              out  <=  &A_FF;
            else if (red_op_B_FF)
              out  <=  &B_FF;
            else
              out  <=  A_FF & B_FF;
          end
          3'h1 :  begin
            if (red_op_A_FF && red_op_B_FF)
              out  <=  (INPUT_PRIORITY  ==  "A")? ^A_FF :  ^B_FF;
            else if (red_op_A_FF)
              out  <=  ^A_FF;
            else if (red_op_B_FF)
              out  <=  ^B_FF;
            else
              out  <=  A_FF ^ B_FF;
          end
          3'h2 :  begin
            if (FULL_ADDER  ==  "ON")
              out  <=  A_FF  +  B_FF  +  cin_FF;
            else
              out  <=  A_FF  +  B_FF;
          end
          3'h3 :  out  <=  A_FF  *  B_FF;
          3'h4 :  begin
            if (direction_FF)
              out  <=  {out[4: 0], serial_in_FF};
            else
              out  <=  {serial_in_FF, out[5: 1]};
          end
          3'h5 :  begin
            if (direction_FF)
              out  <=  {out[4: 0], out[5]};
            else
              out  <=  {out[0], out[5: 1]};
          end
        endcase
      end
    end
  end
end
endmodule  */
```

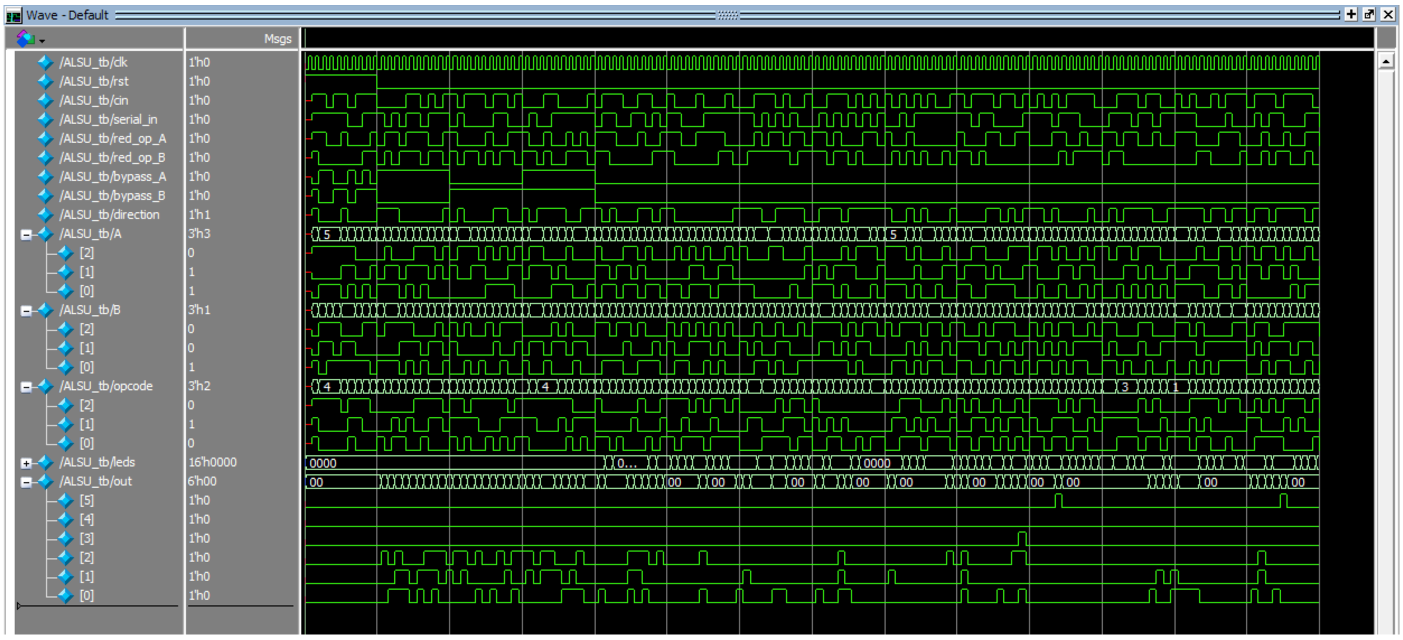
Testbench Code:

```
module ALSU_tb ();
parameter INPUT_PRIORITY = "A";
parameter FULL_ADDER = "ON";
reg clk, rst, cin, serial_in, red_op_A, red_op_B, bypass_A, bypass_B, direction;
reg [2:0] A, B, opcode;
wire [15:0] leds;
wire [5:0] out;
ALSU #(.INPUT_PRIORITY(INPUT_PRIORITY),.FULL_ADDER(FULL_ADDER))
DUT (A, B, opcode, cin, serial_in, direction, red_op_A, red_op_B, bypass_A, bypass_B, clk, rst, out, leds);
initial begin
  clk = 0;
  forever
    #1 clk = ~clk;
End
initial begin
  rst = 1;
  repeat (10) begin
    @(negedge clk);
    A = $random; B = $random; opcode = $urandom_range(0,7); cin = $random;
    serial_in = $random; direction = $random; red_op_A = $random;
    red_op_B = $random; bypass_A = $random; bypass_B = $random;
    if ((out != 0) && (leds != 0)) begin
      $display("The ALSU Design is Wrong! ");
      $stop;
    end
  end
  rst = 0;
  bypass_A = 1; bypass_B = 0;
  repeat (10) begin
    @(negedge clk);
    A = $random; B = $random; opcode = $urandom_range(0,7); cin = $random;
    serial_in = $random; direction = $random; red_op_A = $random;
    red_op_B = $random;
    if ((out != A) && (leds != 0)) begin
      $display("The ALSU Design is Wrong! ");
      $stop;
    end
  end
  bypass_A = 0; bypass_B = 1;
  repeat (10) begin
    @(negedge clk);
    A = $random; B = $random; opcode = $urandom_range(0,7); cin = $random;
    serial_in = $random; direction = $random; red_op_A = $random;
    red_op_B = $random;
    if ((out != B) && (leds != 0)) begin
      $display("The ALSU Design is Wrong! ");
      $stop;
    end
  end
  bypass_A = 1;
  repeat (10) begin
    @(negedge clk);
    A = $random; B = $random; opcode = $urandom_range(0,7); cin = $random;
    serial_in = $random; direction = $random; red_op_A = $random;
    red_op_B = $random;
    if ((out != A) && (leds != 0)) begin
      $display("The ALSU Design is Wrong! ");
      $stop;
    end
  end

  bypass_A = 0; bypass_B = 0;

  repeat (100) begin
    @(negedge clk);
    A = $random; B = $random; opcode = $urandom_range(0,7); cin = $random;
    serial_in = $random; direction = $random; red_op_A = $random;
    red_op_B = $random;
  end
  $stop;
end

initial
$monitor("time = %0t, A = %b, B = %b, opcode = %b, cin = %b, serial_in = %b, direction
                = %b, red_op_A = %b, red_op_B = %b, bypass_A = %b, bypass_B = %b, clk = %b, rst
                = %b, out = %b, leds = %b",
      $time, A, B, opcode, cin, serial_in, direction, red_op_A, red_op_B, bypass_A, bypass_B, clk, rst, out, leds);

endmodule
```

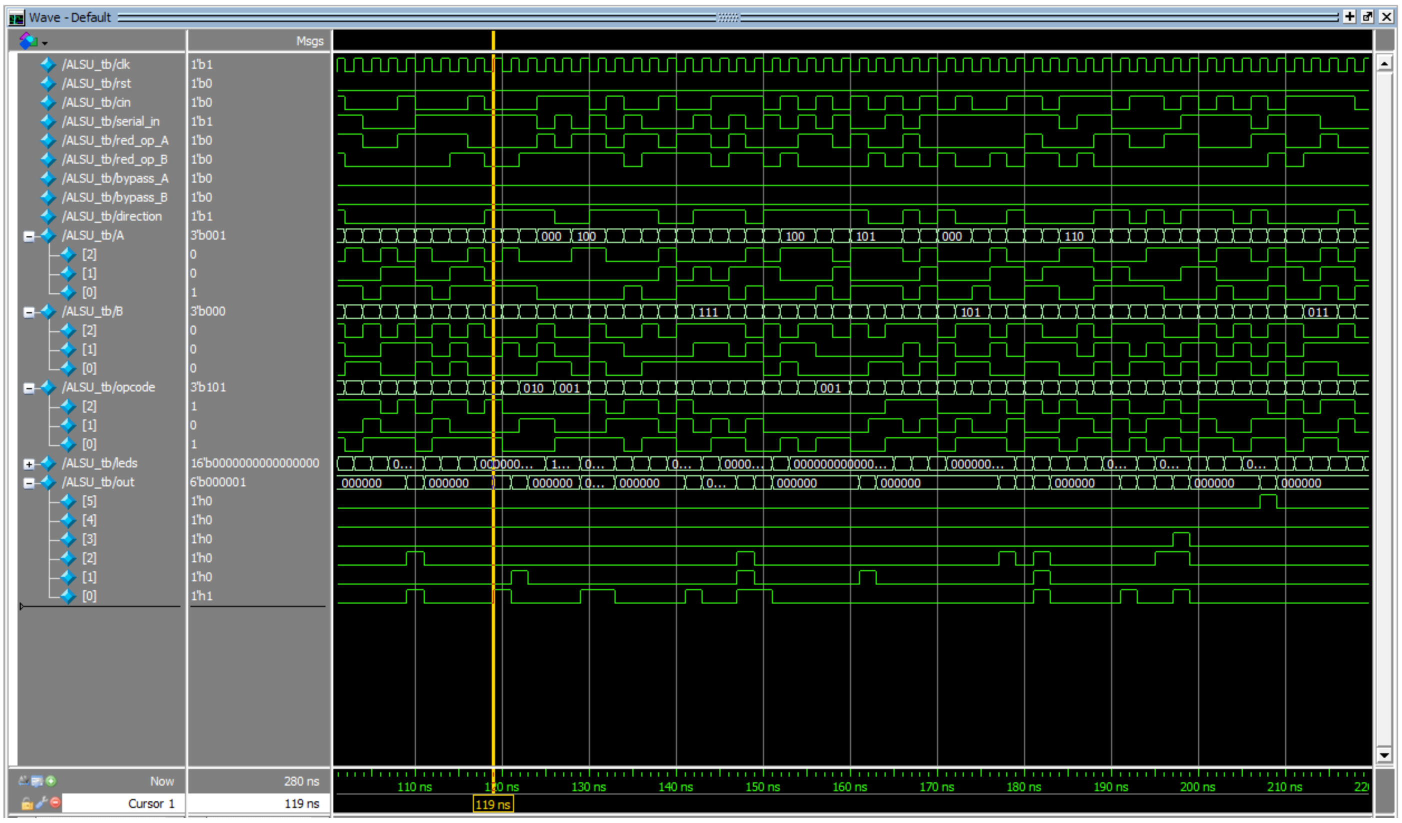
Do File for (ALSU) Question 1

```
vlib work
vlog ALSU.v ALSU_tb.v
vsim -voptargs=+acc work.ALSU_tb
add wave *
run -all
```

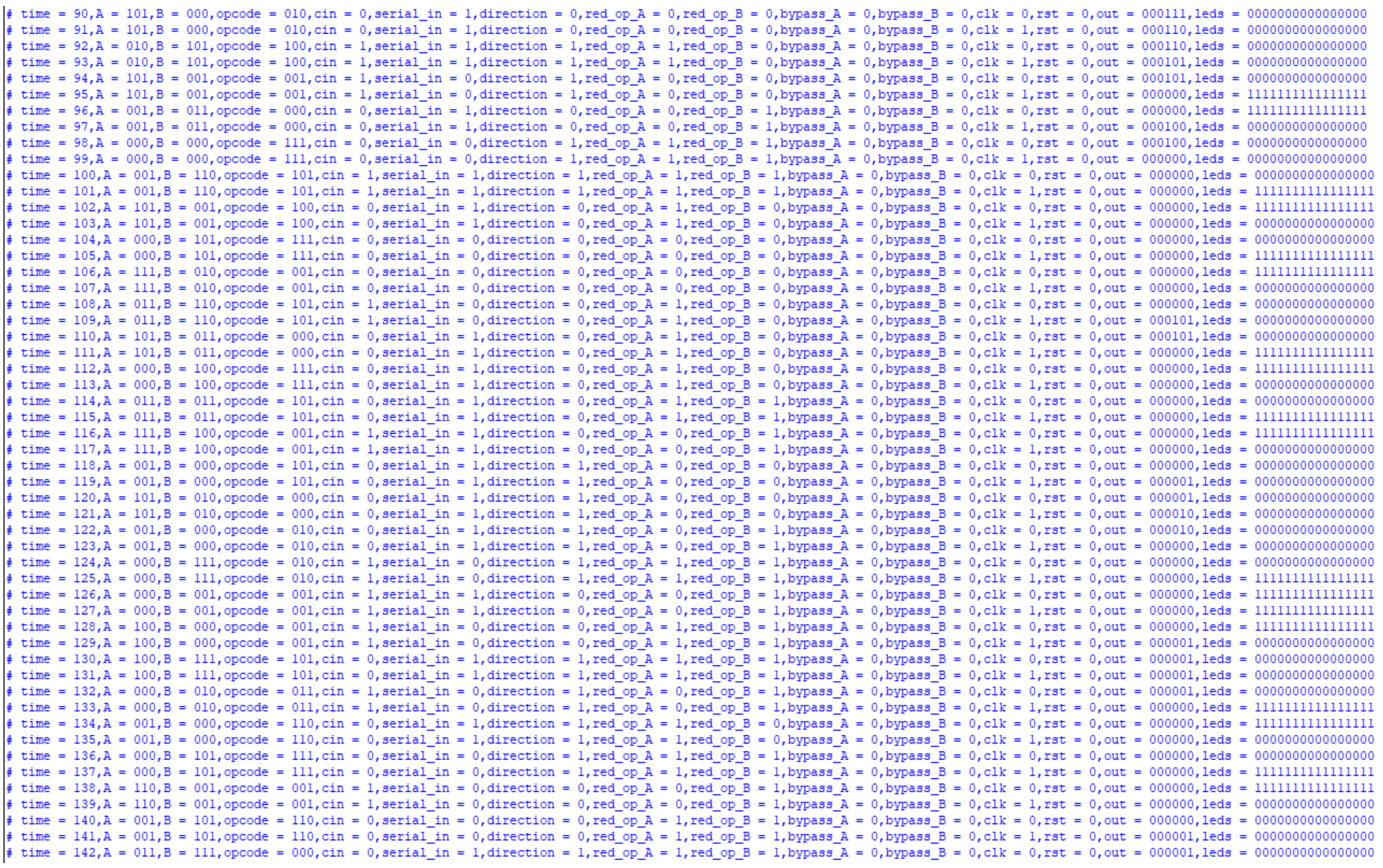
Waveform:



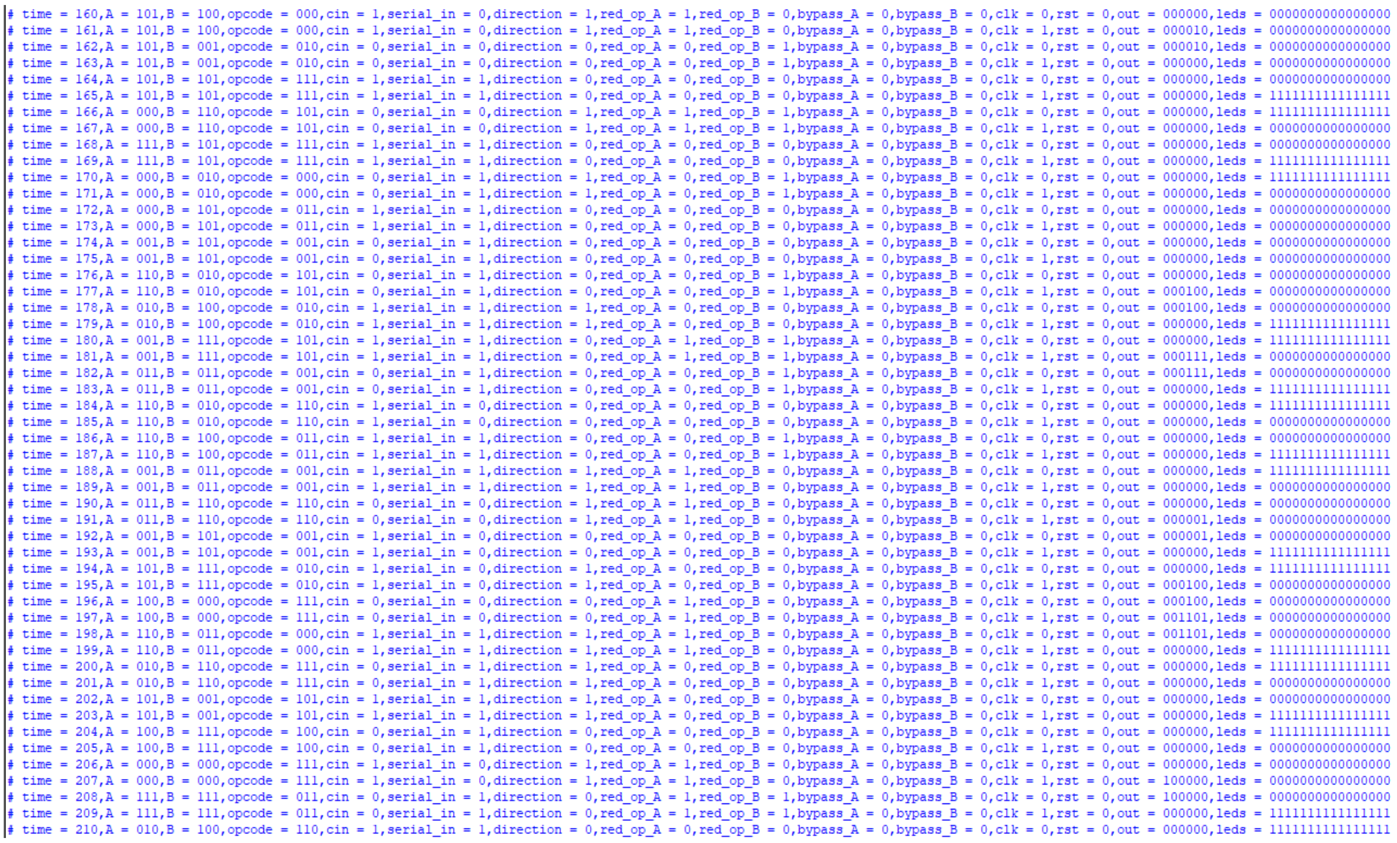
Wave - Default	Msgs
/ALSU_tb/clk	1'h0
/ALSU_tb/rst	1'h0
/ALSU_tb/cin	1'h0
/ALSU_tb/serial_in	1'h0
/ALSU_tb/red_op_A	1'h0
/ALSU_tb/red_op_B	1'h0
/ALSU_tb/bypass_A	1'h0
/ALSU_tb/bypass_B	1'h0
/ALSU_tb/direction	1'h1
/ALSU_tb/A	3'h3
[2]	0
[1]	1
[0]	1
/ALSU_tb/B	3'h1
[2]	0
[1]	0
[0]	1
/ALSU_tb/opcode	3'h2
[2]	0
[1]	1
[0]	0
/ALSU_tb/leds	16'h0000
/ALSU_tb/out	6'h00
[5]	1'h0
[4]	1'h0
[3]	1'h0
[2]	1'h0
[1]	1'h0
[0]	1'h0



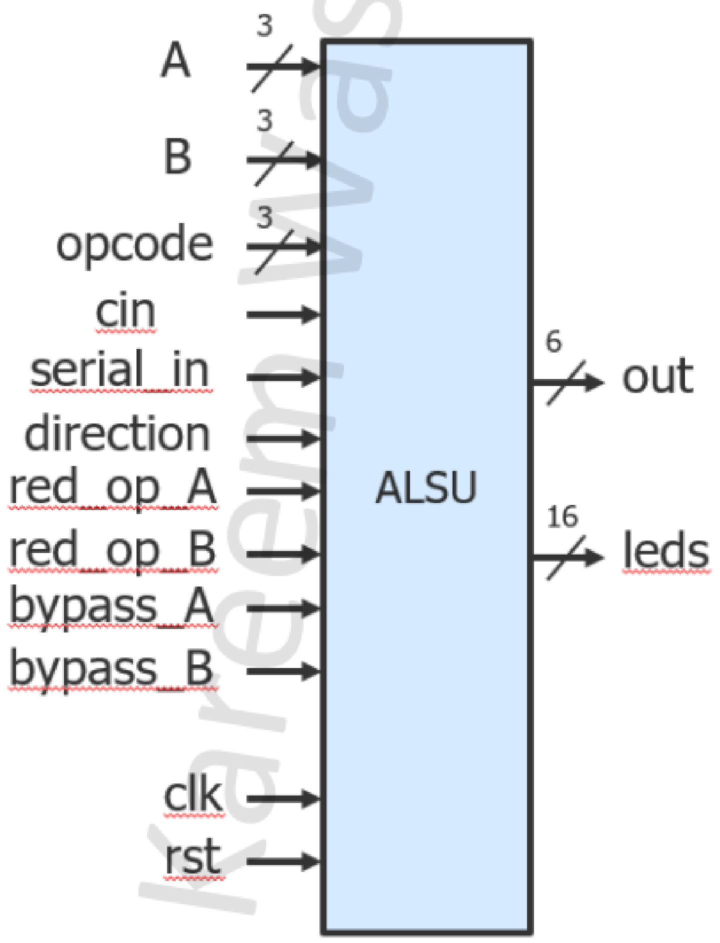
Wave - Default	Msgs
/ALSU_tb/clk	1'b1
/ALSU_tb/rst	1'b0
/ALSU_tb/cin	1'b0
/ALSU_tb/serial_in	1'b1
/ALSU_tb/red_op_A	1'b0
/ALSU_tb/red_op_B	1'b0
/ALSU_tb/bypass_A	1'b0
/ALSU_tb/bypass_B	1'b0
/ALSU_tb/direction	1'b1
/ALSU_tb/A	3'b001
[2]	0
[1]	0
[0]	1
/ALSU_tb/B	3'b000
[2]	0
[1]	0
[0]	0
/ALSU_tb/opcode	3'b101
[2]	1
[1]	0
[0]	1
/ALSU_tb/leds	16'b0000000000000000
/ALSU_tb/out	6'b000001
[5]	1'h0
[4]	1'h0
[3]	1'h0
[2]	1'h0
[1]	1'h0
[0]	1'h1
Now	280 ns
Cursor 1	119 ns



```
# time = 90,A = 101,B = 000,opcode = 010,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000111,leds = 0000000000000000
# time = 91,A = 101,B = 000,opcode = 010,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000110,leds = 0000000000000000
# time = 92,A = 010,B = 101,opcode = 100,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000110,leds = 0000000000000000
# time = 93,A = 010,B = 101,opcode = 100,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000101,leds = 0000000000000000
# time = 94,A = 101,B = 001,opcode = 001,cin = 1,serial_in = 0,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000101,leds = 0000000000000000
# time = 95,A = 101,B = 001,opcode = 001,cin = 1,serial_in = 0,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 96,A = 001,B = 011,opcode = 000,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 97,A = 001,B = 011,opcode = 000,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000100,leds = 0000000000000000
# time = 98,A = 000,B = 000,opcode = 111,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000100,leds = 0000000000000000
# time = 99,A = 000,B = 000,opcode = 111,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 100,A = 001,B = 110,opcode = 101,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 101,A = 001,B = 110,opcode = 101,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 102,A = 101,B = 001,opcode = 100,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 103,A = 101,B = 001,opcode = 100,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 104,A = 000,B = 101,opcode = 111,cin = 0,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 105,A = 000,B = 101,opcode = 111,cin = 0,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 106,A = 111,B = 010,opcode = 001,cin = 0,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 107,A = 111,B = 010,opcode = 001,cin = 0,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 108,A = 011,B = 110,opcode = 101,cin = 1,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 109,A = 011,B = 110,opcode = 101,cin = 1,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000101,leds = 0000000000000000
# time = 110,A = 101,B = 011,opcode = 000,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000101,leds = 0000000000000000
# time = 111,A = 101,B = 011,opcode = 000,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 112,A = 000,B = 100,opcode = 111,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 113,A = 000,B = 100,opcode = 111,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 114,A = 011,B = 011,opcode = 101,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 115,A = 011,B = 011,opcode = 101,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 116,A = 111,B = 100,opcode = 001,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 117,A = 111,B = 100,opcode = 001,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 118,A = 001,B = 000,opcode = 101,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 119,A = 001,B = 000,opcode = 101,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000001,leds = 0000000000000000
# time = 120,A = 101,B = 010,opcode = 000,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000001,leds = 0000000000000000
# time = 121,A = 101,B = 010,opcode = 000,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000010,leds = 0000000000000000
# time = 122,A = 001,B = 000,opcode = 010,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000010,leds = 0000000000000000
# time = 123,A = 001,B = 000,opcode = 010,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 124,A = 000,B = 111,opcode = 010,cin = 1,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 125,A = 000,B = 111,opcode = 010,cin = 1,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 126,A = 000,B = 001,opcode = 001,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 127,A = 000,B = 001,opcode = 001,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 128,A = 100,B = 000,opcode = 001,cin = 1,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 129,A = 100,B = 000,opcode = 001,cin = 1,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000001,leds = 0000000000000000
# time = 130,A = 100,B = 111,opcode = 101,cin = 0,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000001,leds = 0000000000000000
# time = 131,A = 100,B = 111,opcode = 101,cin = 0,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000001,leds = 0000000000000000
# time = 132,A = 000,B = 010,opcode = 011,cin = 1,serial_in = 0,direction = 1,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000001,leds = 0000000000000000
# time = 133,A = 000,B = 010,opcode = 011,cin = 1,serial_in = 0,direction = 1,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 134,A = 001,B = 000,opcode = 110,cin = 0,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 135,A = 001,B = 000,opcode = 110,cin = 0,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 136,A = 000,B = 101,opcode = 111,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 137,A = 000,B = 101,opcode = 111,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 138,A = 110,B = 001,opcode = 001,cin = 1,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 139,A = 110,B = 001,opcode = 001,cin = 1,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 140,A = 001,B = 101,opcode = 110,cin = 0,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 141,A = 001,B = 101,opcode = 110,cin = 0,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000001,leds = 0000000000000000
# time = 142,A = 011,B = 111,opcode = 000,cin = 0,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000001,leds = 0000000000000000
```



```
# time = 160,A = 101,B = 100,opcode = 000,cin = 1,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 161,A = 101,B = 100,opcode = 000,cin = 1,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000010,leds = 0000000000000000
# time = 162,A = 101,B = 001,opcode = 010,cin = 0,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000010,leds = 0000000000000000
# time = 163,A = 101,B = 001,opcode = 010,cin = 0,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 164,A = 101,B = 101,opcode = 111,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 165,A = 101,B = 101,opcode = 111,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 166,A = 000,B = 110,opcode = 101,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 167,A = 000,B = 110,opcode = 101,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 168,A = 111,B = 101,opcode = 111,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 169,A = 111,B = 101,opcode = 111,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 170,A = 000,B = 010,opcode = 000,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 171,A = 000,B = 010,opcode = 000,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 172,A = 000,B = 101,opcode = 011,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 173,A = 000,B = 101,opcode = 011,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 174,A = 001,B = 101,opcode = 001,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 175,A = 001,B = 101,opcode = 001,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 176,A = 110,B = 010,opcode = 101,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 177,A = 110,B = 010,opcode = 101,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000100,leds = 0000000000000000
# time = 178,A = 010,B = 100,opcode = 010,cin = 1,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000100,leds = 0000000000000000
# time = 179,A = 010,B = 100,opcode = 010,cin = 1,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 180,A = 001,B = 111,opcode = 101,cin = 1,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 181,A = 001,B = 111,opcode = 101,cin = 1,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000111,leds = 0000000000000000
# time = 182,A = 011,B = 011,opcode = 001,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000111,leds = 0000000000000000
# time = 183,A = 011,B = 011,opcode = 001,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 184,A = 110,B = 010,opcode = 110,cin = 1,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 185,A = 110,B = 010,opcode = 110,cin = 1,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 186,A = 110,B = 100,opcode = 011,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 187,A = 110,B = 100,opcode = 011,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 188,A = 001,B = 011,opcode = 001,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 189,A = 001,B = 011,opcode = 001,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 190,A = 011,B = 110,opcode = 110,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 191,A = 011,B = 110,opcode = 110,cin = 0,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000001,leds = 0000000000000000
# time = 192,A = 001,B = 101,opcode = 001,cin = 1,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000001,leds = 0000000000000000
# time = 193,A = 001,B = 101,opcode = 001,cin = 1,serial_in = 0,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 194,A = 101,B = 111,opcode = 010,cin = 1,serial_in = 0,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 195,A = 101,B = 111,opcode = 010,cin = 1,serial_in = 0,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000100,leds = 0000000000000000
# time = 196,A = 100,B = 000,opcode = 111,cin = 0,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000100,leds = 0000000000000000
# time = 197,A = 100,B = 000,opcode = 111,cin = 0,serial_in = 0,direction = 0,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 001101,leds = 0000000000000000
# time = 198,A = 110,B = 011,opcode = 000,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 001101,leds = 0000000000000000
# time = 199,A = 110,B = 011,opcode = 000,cin = 1,serial_in = 1,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 200,A = 010,B = 110,opcode = 111,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 201,A = 010,B = 110,opcode = 111,cin = 0,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 202,A = 101,B = 001,opcode = 101,cin = 1,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 203,A = 101,B = 001,opcode = 101,cin = 1,serial_in = 1,direction = 1,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 204,A = 100,B = 111,opcode = 100,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
# time = 205,A = 100,B = 111,opcode = 100,cin = 0,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 0000000000000000
# time = 206,A = 000,B = 000,opcode = 111,cin = 1,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 0000000000000000
# time = 207,A = 000,B = 000,opcode = 111,cin = 1,serial_in = 0,direction = 1,red_op_A = 1,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 100000,leds = 0000000000000000
# time = 208,A = 111,B = 111,opcode = 011,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 100000,leds = 0000000000000000
# time = 209,A = 111,B = 111,opcode = 011,cin = 0,serial_in = 1,direction = 0,red_op_A = 1,red_op_B = 1,bypass_A = 0,bypass_B = 0,clk = 1,rst = 0,out = 000000,leds = 1111111111111111
# time = 210,A = 010,B = 100,opcode = 110,cin = 1,serial_in = 1,direction = 0,red_op_A = 0,red_op_B = 0,bypass_A = 0,bypass_B = 0,clk = 0,rst = 0,out = 000000,leds = 1111111111111111
```



Opcode	Operation
000	AND
001	XOR
010	Addition
011	Multiplication
100	Shift output by 1 bit
101	Rotate output by 1 bit
110	Invalid opcode
111	Invalid opcode

Input	Width	Description
clk	1	Input clock
rst	1	Active high asynchronous reset
A	3	Input port A
B	3	Input port B
cin	1	Carry in bit, only valid to be used if the parameter FULL_ADDER is "ON"
serial_in	1	Serial in bit, used in shift operations only
red_op_A	1	When set to high, this indicates that reduction operation would be executed on A rather than bitwise operations on A and B when the opcode indicates AND and XOR operations
red_op_B	1	When set to high, this indicates that reduction operation would be executed on B rather than bitwise operations on A and B when the opcode indicates AND and XOR operations
opcode	3	Opcode has a separate table to describe the different operations executed
bypass_A	1	When set to high, this indicates that port A will be registered to the output ignoring the opcode operation
bypass_B	1	When set to high, this indicates that port B will be registered to the output ignoring the opcode operation
direction	1	The direction of the shift or rotation operation is left when this input is set to high; otherwise, it is right.

Output	Width	Description
leds	16	When an invalid operation occurs, all bits blink (bits turn on and then off with each clock cycle). Blinking serves as a warning; otherwise, if a valid operation occurs, it is set to low.
out	6	Output of the ALSU

Parameter	Default value	Description
INPUT_PRIORITY	A	Priority is given to the port set by this parameter whenever there is a conflict. Conflicts can occur in two scenarios, red_op_A and red_op_B are both set to high or bypass_A and bypass_B are both set to high. Legal values for this parameter are A and B
FULL_ADDER	ON	When this parameter has value "ON" then cin input must be considered in the addition operation between A and B. Legal values for this parameter are ON and OFF

Question 2

DSP48A1 Xilinx Spartan - 6 FPGA

Verilog Code:

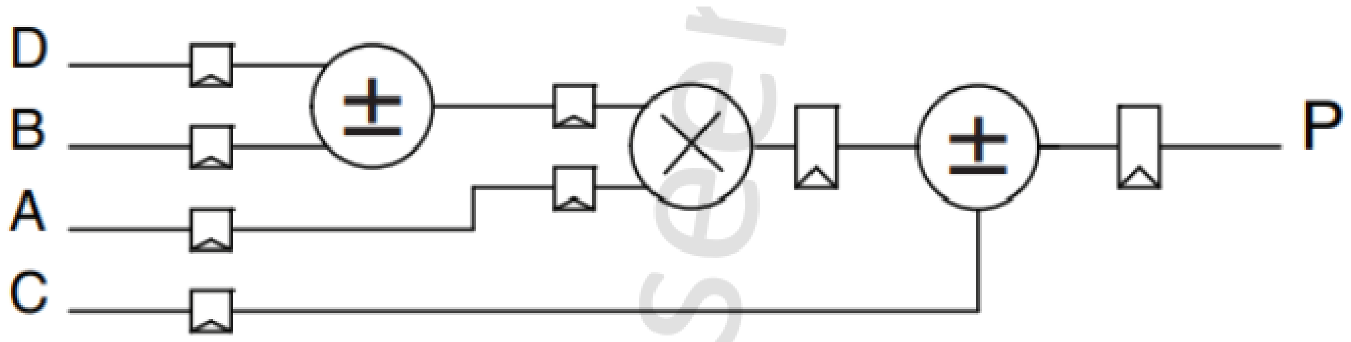
```
module DSP (A, B, C, D, clk, rst_n, P);

parameter OPERATION = "ADD";

input [17:0] A, B, D;
input [47:0] C;
input clk, rst_n;
output reg [47:0] P;
reg [17:0] A_FF_1, A_FF_2, B_FF, D_FF, adder_out1;
reg [47:0] C_FF, adder_out2, multiplier_out;

always @(posedge clk or negedge rst_n) begin
   if (~rst_n) begin
      A_FF_1 <= 0; A_FF_2 <= 0; B_FF <= 0; D_FF <= 0; adder_out1 <= 0;
      C_FF <= 0; adder_out2 <= 0; multiplier_out <= 0;
   end
   else begin
      A_FF_1 <= A; A_FF_2 <= A_FF_1; B_FF <= B; D_FF <= D; C_FF <= 0;
      if (OPERATION == "ADD") begin
         adder_out1 <= D_FF + B_FF;
         adder_out2 <= multiplier_out + C_FF;
      end else if (OPERATION == "SUBTRACT") begin
         adder_out1 <= D_FF - B_FF;
         adder_out2 <= multiplier_out - C_FF;
      end
      multiplier_out <= A_FF_2 * adder_out1;
      P <= adder_out2;
   end
end


endmodule
```

Testbench Code:

```
module DSP_tb ();

parameter OPERATION = "ADD";

reg [17:0] A, B, D;
reg [47:0] C;
reg clk, rst_n;

wire [47:0] P;

DSP #(.OPERATION(OPERATION)) DUT (A, B, C, D, clk, rst_n, P);

initial begin
   clk = 0;
   forever
      #25 clk = ~clk;
end

initial begin
   rst_n = 0;
   repeat (10) begin
      A = $random; B = $random;
      C = $random; D = $random;
      @(negedge clk);
      if (P != 0) begin
         $display("The DSP Design is Wrong! ");
         $stop;
      end
   end
   rst_n = 1;
   repeat (100) begin
      A = $urandom_range(0,500); B = $urandom_range(0,500);
      C = $urandom_range(0,500); D = $urandom_range(0,500);
      @(negedge clk);
   end
   $stop;
end
initial
$monitor("time = %0t, A = %b, B = %b, C = %b, D = %b, CLK = %b,
                                             RST_N = %b, P = %b", $time, A, B, C, D, clk, rst_n, P);

endmodule
```

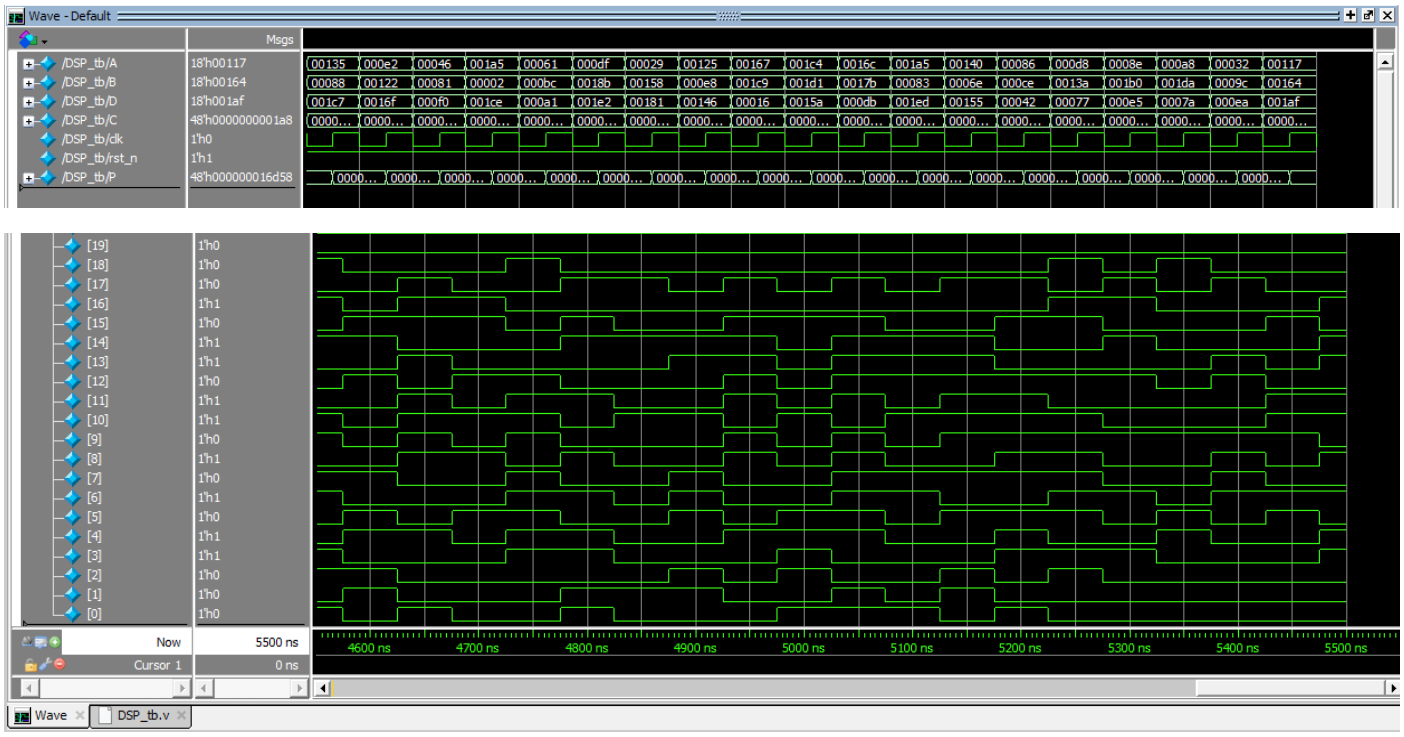
Do File for (DSP) Question 2

```
vlib work
vlog DSP.v DSP_tb.v
vsim −voptargs=+acc work.DSP_tb
add wave *
run −all
```

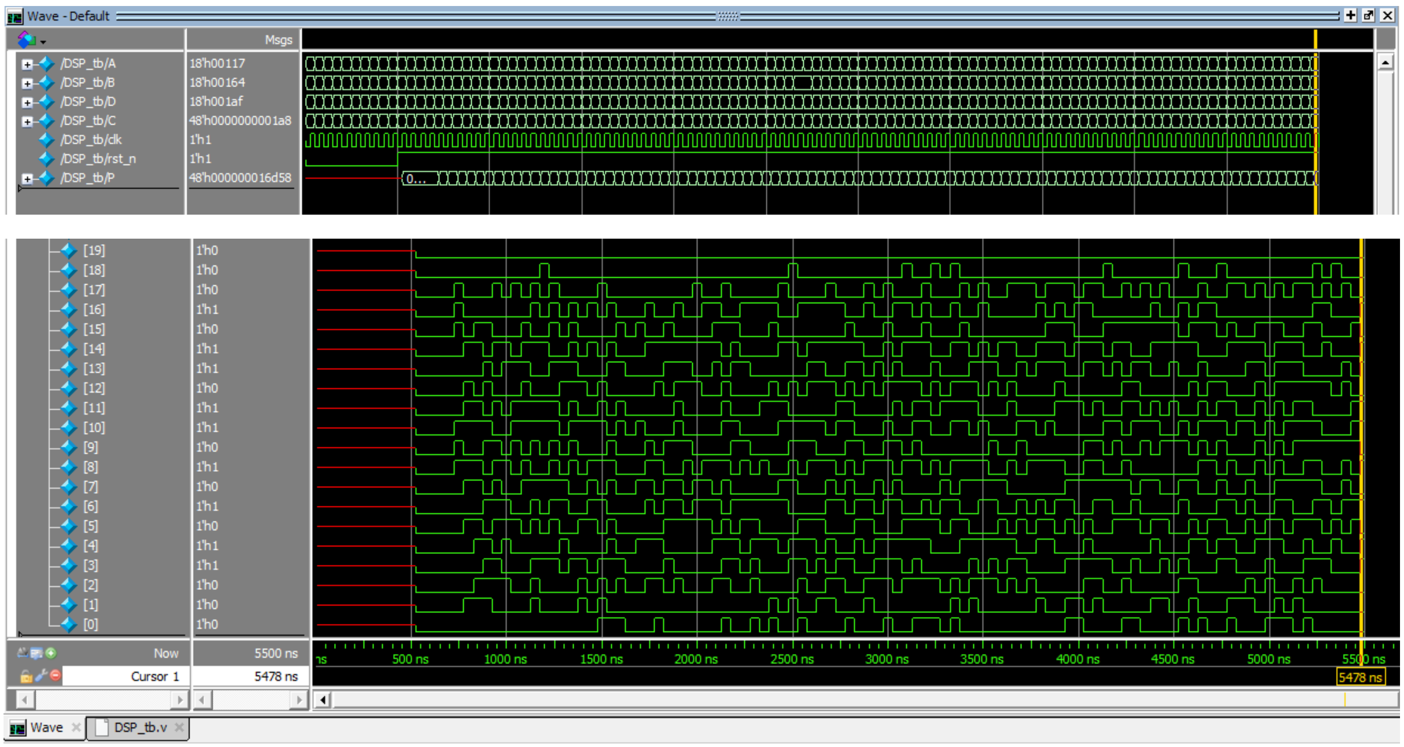


Port	Type	Width
A	Input	18
B	Input	18
C	Input	48
D	Input	18
clk	Input	1
rst_n (sync active low)	Input	1
P	Output	48

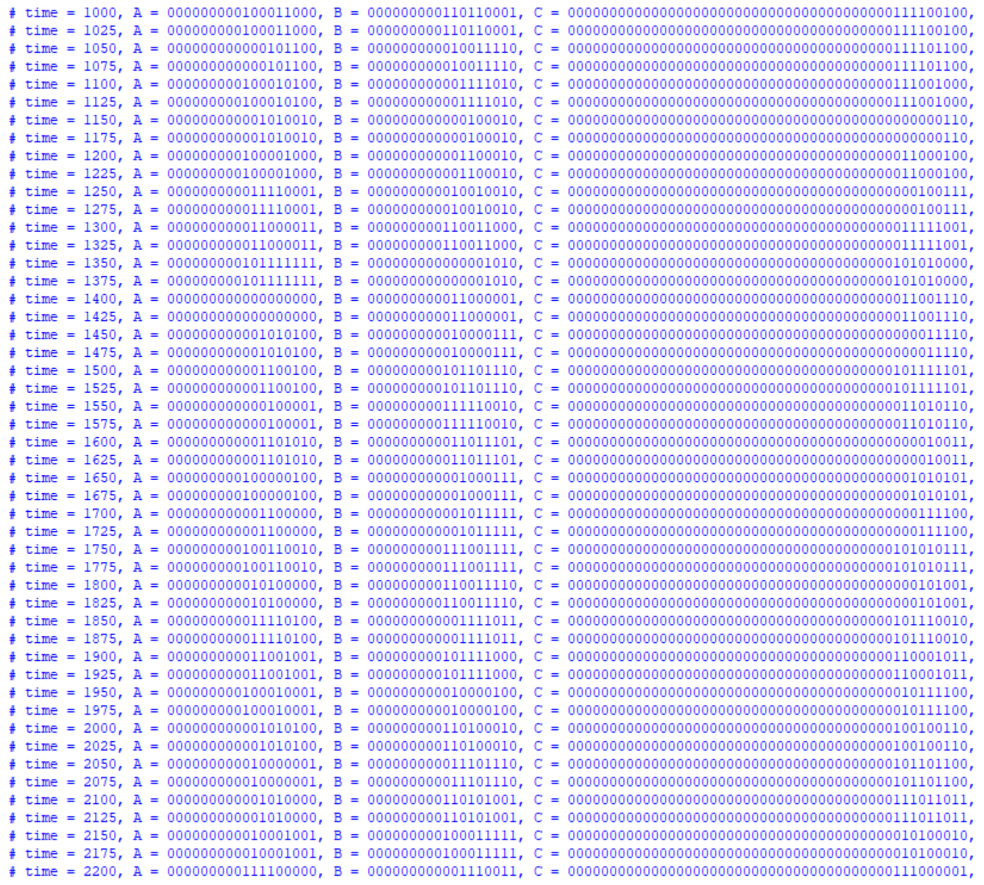
Waveform:



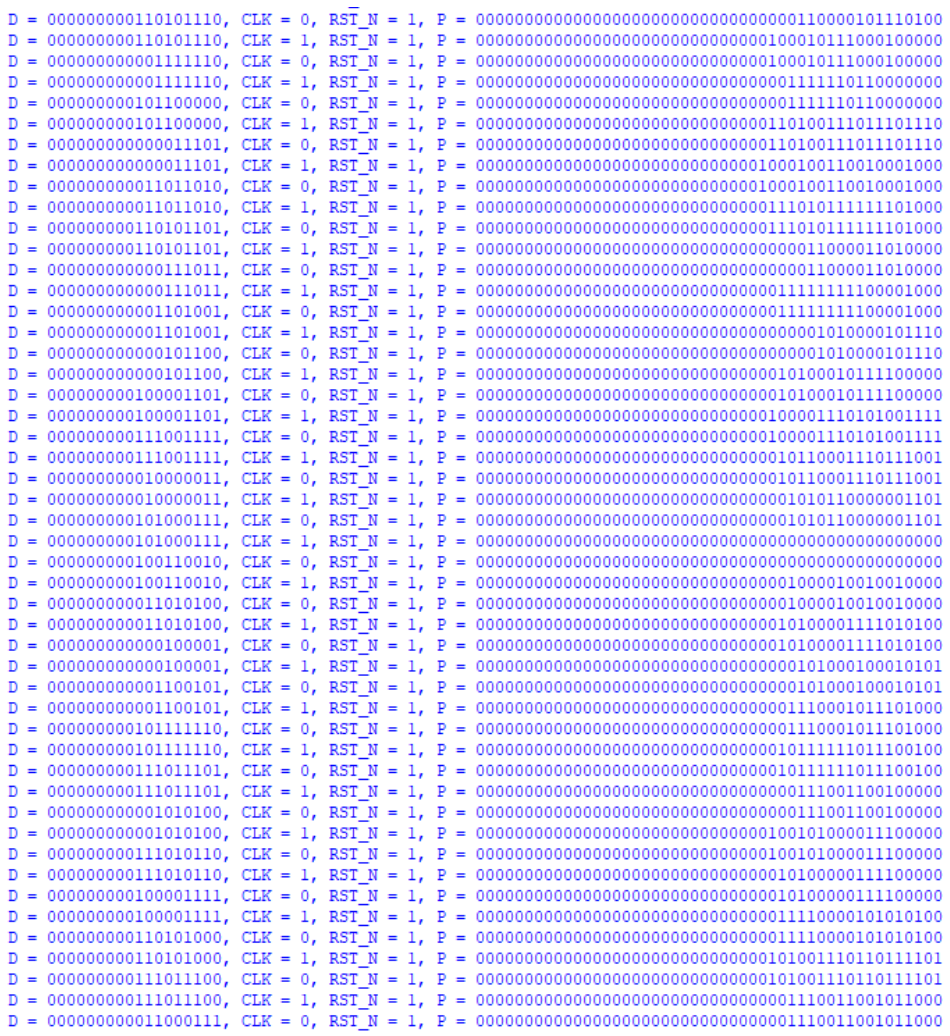
```
Wave - Default
                      Msgs
/DSP_tb/A             18'h00117
/DSP_tb/B             18'h00164
/DSP_tb/D             18'h001af
/DSP_tb/C             48'h0000000001a8
/DSP_tb/clk           1'h0
/DSP_tb/rst_n         1'h1
/DSP_tb/P             48'h000000016d58

A: 00135 000e2 00046 001a5 00061 000df 00029 00125 00167 001c4 0016c 001a5 00140 00086 000d8 0008e 000a8 00032 00117
B: 00088 00122 00081 00002 000bc 0018b 00158 000e8 001c9 001d1 0017b 00083 0006e 000ce 0013a 001b0 001da 0009c 00164
D: 001c7 0016f 000f0 001ce 000a1 001e2 00181 00146 00016 0015a 000db 001ed 00155 00042 00077 000e5 0007a 000ea 001af

[19]  1'h0
[18]  1'h0
[17]  1'h0
[16]  1'h1
[15]  1'h0
[14]  1'h1
[13]  1'h1
[12]  1'h0
[11]  1'h1
[10]  1'h1
[9]   1'h0
[8]   1'h1
[7]   1'h0
[6]   1'h1
[5]   1'h0
[4]   1'h1
[3]   1'h1
[2]   1'h0
[1]   1'h0
[0]   1'h0

Now       5500 ns
Cursor 1  0 ns
4600 ns  4700 ns  4800 ns  4900 ns  5000 ns  5100 ns  5200 ns  5300 ns  5400 ns  5500 ns
Wave   DSP_tb.v
```



```
Wave - Default
                      Msgs
/DSP_tb/A             18'h00117
/DSP_tb/B             18'h00164
/DSP_tb/D             18'h001af
/DSP_tb/C             48'h0000000001a8
/DSP_tb/clk           1'h1
/DSP_tb/rst_n         1'h1
/DSP_tb/P             48'h000000016d58

[19]  1'h0
[18]  1'h0
[17]  1'h0
[16]  1'h1
[15]  1'h0
[14]  1'h1
[13]  1'h1
[12]  1'h0
[11]  1'h1
[10]  1'h1
[9]   1'h0
[8]   1'h1
[7]   1'h0
[6]   1'h1
[5]   1'h0
[4]   1'h1
[3]   1'h1
[2]   1'h0
[1]   1'h0
[0]   1'h0

Now       5500 ns
Cursor 1  5478 ns
ns  500 ns  1000 ns  1500 ns  2000 ns  2500 ns  3000 ns  3500 ns  4000 ns  4500 ns  5000 ns  5500 ns
5478 ns
Wave   DSP_tb.v
```



```
# time = 1000, A = 000000000100011000, B = 000000000110110001, C = 000000000000000000000000000000000000000111100100,
# time = 1025, A = 000000000100011000, B = 000000000110110001, C = 000000000000000000000000000000000000000111100100,
# time = 1050, A = 000000000000101100, B = 000000000010011110, C = 000000000000000000000000000000000000000111101100,
# time = 1075, A = 000000000000101100, B = 000000000010011110, C = 000000000000000000000000000000000000000111101100,
# time = 1100, A = 000000000100010100, B = 000000000001111010, C = 000000000000000000000000000000000000000111001000,
# time = 1125, A = 000000000100010100, B = 000000000001111010, C = 000000000000000000000000000000000000000111001000,
# time = 1150, A = 000000000001010010, B = 000000000000100010, C = 000000000000000000000000000000000000000000000110,
# time = 1175, A = 000000000001010010, B = 000000000000100010, C = 000000000000000000000000000000000000000000000110,
# time = 1200, A = 000000000100001000, B = 000000000001100010, C = 000000000000000000000000000000000000000011000100,
# time = 1225, A = 000000000100001000, B = 000000000001100010, C = 000000000000000000000000000000000000000011000100,
# time = 1250, A = 000000000011110001, B = 000000000010010010, C = 000000000000000000000000000000000000000000100111,
# time = 1275, A = 000000000011110001, B = 000000000010010010, C = 000000000000000000000000000000000000000000100111,
# time = 1300, A = 000000000011000011, B = 000000000110011000, C = 000000000000000000000000000000000000000011111001,
# time = 1325, A = 000000000011000011, B = 000000000110011000, C = 000000000000000000000000000000000000000011111001,
# time = 1350, A = 000000000101111111, B = 000000000000001010, C = 000000000000000000000000000000000000000101010000,
# time = 1375, A = 000000000101111111, B = 000000000000001010, C = 000000000000000000000000000000000000000101010000,
# time = 1400, A = 000000000000000000, B = 000000000011000001, C = 000000000000000000000000000000000000000011001110,
# time = 1425, A = 000000000000000000, B = 000000000011000001, C = 000000000000000000000000000000000000000011001110,
# time = 1450, A = 000000000001010100, B = 000000000010000111, C = 000000000000000000000000000000000000000000011110,
# time = 1475, A = 000000000001010100, B = 000000000010000111, C = 000000000000000000000000000000000000000000011110,
# time = 1500, A = 000000000001100100, B = 000000000101101110, C = 000000000000000000000000000000000000000101111101,
# time = 1525, A = 000000000001100100, B = 000000000101101110, C = 000000000000000000000000000000000000000101111101,
# time = 1550, A = 000000000000100001, B = 000000000111110010, C = 000000000000000000000000000000000000000011010110,
# time = 1575, A = 000000000000100001, B = 000000000111110010, C = 000000000000000000000000000000000000000011010110,
# time = 1600, A = 000000000001101010, B = 000000000011011101, C = 000000000000000000000000000000000000000000010011,
# time = 1625, A = 000000000001101010, B = 000000000011011101, C = 000000000000000000000000000000000000000000010011,
# time = 1650, A = 000000000100000100, B = 000000000001000111, C = 000000000000000000000000000000000000000001010101,
# time = 1675, A = 000000000100000100, B = 000000000001000111, C = 000000000000000000000000000000000000000001010101,
# time = 1700, A = 000000000001100000, B = 000000000001011111, C = 000000000000000000000000000000000000000000111100,
# time = 1725, A = 000000000001100000, B = 000000000001011111, C = 000000000000000000000000000000000000000000111100,
# time = 1750, A = 000000000100110010, B = 000000000111001111, C = 000000000000000000000000000000000000000101010111,
# time = 1775, A = 000000000100110010, B = 000000000111001111, C = 000000000000000000000000000000000000000101010111,
# time = 1800, A = 000000000010100000, B = 000000000110011110, C = 000000000000000000000000000000000000000000101001,
# time = 1825, A = 000000000010100000, B = 000000000110011110, C = 000000000000000000000000000000000000000000101001,
# time = 1850, A = 000000000011110100, B = 000000000001111011, C = 000000000000000000000000000000000000000101110010,
# time = 1875, A = 000000000011110100, B = 000000000001111011, C = 000000000000000000000000000000000000000101110010,
# time = 1900, A = 000000000011001001, B = 000000000101111000, C = 000000000000000000000000000000000000000110001011,
# time = 1925, A = 000000000011001001, B = 000000000101111000, C = 000000000000000000000000000000000000000110001011,
# time = 1950, A = 000000000100010001, B = 000000000010000100, C = 000000000000000000000000000000000000000010111100,
# time = 1975, A = 000000000100010001, B = 000000000010000100, C = 000000000000000000000000000000000000000010111100,
# time = 2000, A = 000000000001010100, B = 000000000110100010, C = 000000000000000000000000000000000000000100100110,
# time = 2025, A = 000000000001010100, B = 000000000110100010, C = 000000000000000000000000000000000000000100100110,
# time = 2050, A = 000000000010000001, B = 000000000011101110, C = 000000000000000000000000000000000000000101101100,
# time = 2075, A = 000000000010000001, B = 000000000011101110, C = 000000000000000000000000000000000000000101101100,
# time = 2100, A = 000000000001010000, B = 000000000110101001, C = 000000000000000000000000000000000000000111011011,
# time = 2125, A = 000000000001010000, B = 000000000110101001, C = 000000000000000000000000000000000000000111011011,
# time = 2150, A = 000000000010001001, B = 000000000100011111, C = 000000000000000000000000000000000000000010100010,
# time = 2175, A = 000000000010001001, B = 000000000100011111, C = 000000000000000000000000000000000000000010100010,
# time = 2200, A = 000000000111100000, B = 000000000001110011, C = 000000000000000000000000000000000000000111000001,
```



```
D = 000000000110101110, CLK = 0, RST_N = 1, P = 000000000000000000000000000000001100001011110100
D = 000000000110101110, CLK = 1, RST_N = 1, P = 000000000000000000000000000000010001011100100000
D = 000000000001111110, CLK = 0, RST_N = 1, P = 000000000000000000000000000000010001011100100000
D = 000000000001111110, CLK = 1, RST_N = 1, P = 000000000000000000000000000000001111110110000000
D = 000000000101100000, CLK = 0, RST_N = 1, P = 000000000000000000000000000000001111110110000000
D = 000000000101100000, CLK = 1, RST_N = 1, P = 000000000000000000000000000000110100111011101110
D = 000000000000011101, CLK = 0, RST_N = 1, P = 000000000000000000000000000000110100111011101110
D = 000000000000011101, CLK = 1, RST_N = 1, P = 000000000000000000000000000001000100110010001000
D = 000000000011011010, CLK = 0, RST_N = 1, P = 000000000000000000000000000001000100110010001000
D = 000000000011011010, CLK = 1, RST_N = 1, P = 000000000000000000000000000001110101111111101000
D = 000000000110101101, CLK = 0, RST_N = 1, P = 000000000000000000000000000001110101111111101000
D = 000000000110101101, CLK = 1, RST_N = 1, P = 000000000000000000000000000000000011000011010000
D = 000000000000111011, CLK = 0, RST_N = 1, P = 000000000000000000000000000000000011000011010000
D = 000000000000111011, CLK = 1, RST_N = 1, P = 000000000000000000000000000000001111111100001000
D = 000000000001101001, CLK = 0, RST_N = 1, P = 000000000000000000000000000000001111111100001000
D = 000000000001101001, CLK = 1, RST_N = 1, P = 000000000000000000000000000000000001010000101110
D = 000000000000101100, CLK = 0, RST_N = 1, P = 000000000000000000000000000000000001010000101110
D = 000000000000101100, CLK = 1, RST_N = 1, P = 000000000000000000000000000000010100010111100000
D = 000000000100001101, CLK = 0, RST_N = 1, P = 000000000000000000000000000000010100010111100000
D = 000000000100001101, CLK = 1, RST_N = 1, P = 000000000000000000000000000000100001110101001111
D = 000000000111001111, CLK = 0, RST_N = 1, P = 000000000000000000000000000000100001110101001111
D = 000000000111001111, CLK = 1, RST_N = 1, P = 000000000000000000000000000000010110001110111001
D = 000000000010000011, CLK = 0, RST_N = 1, P = 000000000000000000000000000000010110001110111001
D = 000000000010000011, CLK = 1, RST_N = 1, P = 000000000000000000000000000000000101011000001101
D = 000000000101000111, CLK = 0, RST_N = 1, P = 000000000000000000000000000000000101011000001101
D = 000000000101000111, CLK = 1, RST_N = 1, P = 000000000000000000000000000000000000000000000000
D = 000000000100110010, CLK = 0, RST_N = 1, P = 000000000000000000000000000000000000000000000000
D = 000000000100110010, CLK = 1, RST_N = 1, P = 000000000000000000000000000000001000010010010000
D = 000000000011010100, CLK = 0, RST_N = 1, P = 000000000000000000000000000000001000010010010000
D = 000000000011010100, CLK = 1, RST_N = 1, P = 000000000000000000000000000000010100001111010100
D = 000000000000100001, CLK = 0, RST_N = 1, P = 000000000000000000000000000000010100001111010100
D = 000000000000100001, CLK = 1, RST_N = 1, P = 000000000000000000000000000000000101000100010101
D = 000000000001100101, CLK = 0, RST_N = 1, P = 000000000000000000000000000000000101000100010101
D = 000000000001100101, CLK = 1, RST_N = 1, P = 000000000000000000000000000000001110001011101000
D = 000000000101111110, CLK = 0, RST_N = 1, P = 000000000000000000000000000000001110001011101000
D = 000000000101111110, CLK = 1, RST_N = 1, P = 000000000000000000000000000000010111111011100100
D = 000000000111011101, CLK = 0, RST_N = 1, P = 000000000000000000000000000000010111111011100100
D = 000000000111011101, CLK = 1, RST_N = 1, P = 000000000000000000000000000000000111001100100000
D = 000000000001010100, CLK = 0, RST_N = 1, P = 000000000000000000000000000000000111001100100000
D = 000000000001010100, CLK = 1, RST_N = 1, P = 000000000000000000000000000000100101000011100000
D = 000000000111010110, CLK = 0, RST_N = 1, P = 000000000000000000000000000000100101000011100000
D = 000000000111010110, CLK = 1, RST_N = 1, P = 000000000000000000000000000000010100000111100000
D = 000000000100001111, CLK = 0, RST_N = 1, P = 000000000000000000000000000000010100000111100000
D = 000000000100001111, CLK = 1, RST_N = 1, P = 000000000000000000000000000000011110000101010100
D = 000000000110101000, CLK = 0, RST_N = 1, P = 000000000000000000000000000000011110000101010100
D = 000000000110101000, CLK = 1, RST_N = 1, P = 000000000000000000000000000000010100111011011101
D = 000000000111011100, CLK = 0, RST_N = 1, P = 000000000000000000000000000000010100111011011101
D = 000000000111011100, CLK = 1, RST_N = 1, P = 000000000000000000000000000000001110011001011000
D = 000000000011000111, CLK = 0, RST_N = 1, P = 000000000000000000000000000000001110011001011000
```