CSE 4207 CT 4 Assignment
Roll No: 1903178

Assignment Problem: 7-bit ALU operation with NOT and Shift Right operations.
Category: C
Word Size = 7
ALU Operations = NOT and Shift Right

Solution:
Video:

Have you uploaded the video?	YES
Check List 1: Have you explained the design using testbenches to prove that your circuit is working correctly and giving correct results?	YES
Check List 2: Have you shown full synthesis results showing all the required info including RTL Synthesis, RTL Floorplan, RTL Power Analysis, GDS and Heatmap (for details, see assignment template doc)?	YES
NB: Failing to upload video will cause heavy point penalty (5-6 Marks)	
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

HDL Code:

Check List: Have you added all the modules written in verilog including ALU, ALU_OP1, ALU_OP2, CONTROLLER, TOP, TOP_TESTBENCH, ALU_TESTBENCH, CONTROLLER_TESTBENCH?	YES
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

ALU_7bit.v

```
module ALU_7bit (
    input wire [6:0] A, B,
    input wire OP,          // 0: NOT, 1: SHR
    output reg [6:0] result,
    output wire ZF          // Zero flag
);
    wire [6:0] R_NOT, R_SHR;

    // Instantiate modules
    ALU_NOT_7bit NOT1 (.A(A), .result(R_NOT));
    ALU_SHR_7bit SHR1 (.in(A), .shift(B[2:0]), .out(R_SHR));

    always @(*) begin
        case (OP)
            1'b0: result = R_NOT;  // NOT operation
            1'b1: result = R_SHR;  // SHR operation
            default: result = 7'b0000000;
        endcase
    end

    // Zero flag (1 when result is all zeros)
    assign ZF = (result == 7'b0000000);
endmodule
```

ALU_7bit_tb.v

```
`timescale 1ns/1ns
module ALU_7bit_tb;

    reg [6:0] A, B;
    reg OP;
    wire [6:0] result;
    wire ZF;
    ALU_7bit uut (
        .A(A),
        .B(B),
        .OP(OP),
        .result(result),
        .ZF(ZF)
    );
    initial begin
        $dumpfile("alu_7bit_test.vcd");
        $dumpvars(0, ALU_7bit_tb);

        // Test NOT operation
        A = 7'b1010101; B = 7'b0000000; OP = 1'b0;
        #10;

        // Test SHR operation with different shift amounts
        A = 7'b1100110; B = 7'b0000001; OP = 1'b1;  // Shift
by 1
        #10;
        A = 7'b1100110; B = 7'b0000011; OP = 1'b1;  // Shift
by 3
        #10;
        A = 7'b1100110; B = 7'b0000111; OP = 1'b1;  // Shift
by 7 (all bits out)
        #10;

        // Test zero flag
        A = 7'b0000000; B = 7'b0000000; OP = 1'b0;  // NOT of
0 should be all 1s
        #10;
        A = 7'b0000001; B = 7'b0000001; OP = 1'b1;  // Shift
1 right by 1 (should be 0)
        #10;

        $finish;
    end
    initial begin
```

```
        $monitor("Time=%3t A=%b B=%b OP=%b -> Result=%b
ZF=%b",
                 $time, A, B, OP, result, ZF);
    end
endmodule
```

ALU_NOT_7bit.v

```
module ALU_NOT_7bit (
    input wire [6:0] A,
    output wire [6:0] result
);
    assign result = ~A;
endmodule
```

ALU_SHR_7bit.v

```
                                    module ALU_SHR_7bit (
    input wire [6:0] in,
    input wire [2:0] shift,  // Shift amount (0-7)
    output reg [6:0] out
);
    always @(*) begin
        case(shift)
            3'b000: out = in;
            3'b001: out = {1'b0, in[6:1]};
            3'b010: out = {2'b00, in[6:2]};
            3'b011: out = {3'b000, in[6:3]};
            3'b100: out = {4'b0000, in[6:4]};
            3'b101: out = {5'b00000, in[6:5]};
            3'b110: out = {6'b000000, in[6]};
            3'b111: out = 7'b0000000;  // Shift all bits out
        endcase
    end
endmodule
```

top.v

```
module top (
    input wire clk, reset,
    output wire [6:0] result,
    output wire flag_gt_zero
);
    wire [6:0] A, B;
    wire OP;
    wire [6:0] R_result;
    wire R_ZF;

    controller controller_inst (
        .clk(clk),
        .reset(reset),
        .A(A),
        .B(B),
        .OP(OP)
    );

    ALU_7bit alu_inst (
        .A(A),
        .B(B),
        .OP(OP),
        .result(R_result),
        .ZF(R_ZF)
    );

    assign result = R_result;
    assign flag_gt_zero = ~R_ZF;  // Active high when result
is not zero
endmodule
```

top_tb.v

```
`timescale 1ns/1ns
module top_tb;

    reg clk, reset;
    wire [6:0] result;
    wire flag_gt_zero;

    top uut (
        .clk(clk),
        .reset(reset),
        .result(result),
        .flag_gt_zero(flag_gt_zero)
    );

    initial begin
        clk = 0;
        forever #5 clk = ~clk;
    end

    initial begin
        $dumpfile("top_test.vcd");
        $dumpvars(0, top_tb);

        reset = 1;
        #10;
        reset = 0;

        #100;
        $finish;
    end

    initial begin
        $monitor("Time=%3t Result=%b Flag=%b",
                 $time, result, flag_gt_zero);
    end
endmodule
```

controller.v

```
module controller (
    input wire clk, reset,
    output reg [6:0] A, B,
    output reg OP
);
    reg [2:0] pstate, nstate;

    parameter [2:0] START = 3'b000,
                    TEST_NOT = 3'b001,
                    TEST_SHR = 3'b010,
                    FINISH = 3'b011;

    // State register
    always @(posedge clk or posedge reset) begin
        if (reset)
            pstate <= START;
        else
            pstate <= nstate;
    end

    // Next state and output logic
    always @(*) begin
        // Default outputs
        A = 7'b0000000;
        B = 7'b0000000;
        OP = 1'b0;
        nstate = pstate;

        case (pstate)
            START: begin
                nstate = TEST_NOT;
            end

            TEST_NOT: begin
                A = 7'b1010101;  // Test pattern for NOT
                B = 7'b0000000;  // Not used for NOT
operation
                OP = 1'b0;       // NOT operation
                nstate = TEST_SHR;
            end
```

```
            TEST_SHR: begin
                A = 7'b1100110;  // Test pattern for SHR
                B = 7'b0000011;  // Shift by 3
                OP = 1'b1;       // SHR operation
                nstate = FINISH;
            end

            FINISH: begin
                nstate = START;
            end

            default: nstate = START;
        endcase
    end
endmodule
```

controller_tb.v

```
`timescale 1ns/1ns
module controller_tb;

    reg clk, reset;
    wire [6:0] A, B;
    wire OP;

    controller uut (
        .clk(clk),
        .reset(reset),
        .A(A),
        .B(B),
        .OP(OP)
    );

    initial begin
        clk = 0;
        forever #5 clk = ~clk;
    end

    initial begin
        $dumpfile("controller_test.vcd");
        $dumpvars(0, controller_tb);

        reset = 1;
        #10;
        reset = 0;

        #100;
```

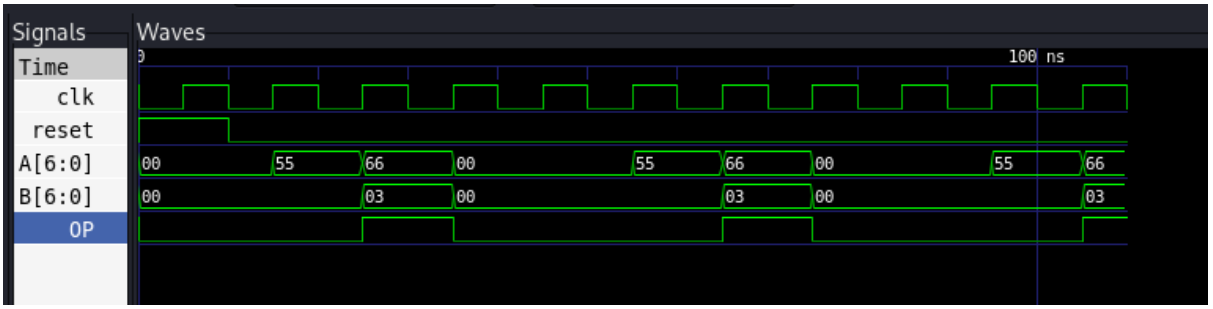
```
        $finish;
    end

    initial begin
        $monitor("Time=%3t State=%b A=%b B=%b OP=%b",
                 $time, uut.pstate, A, B, OP);
    end
endmodule
```

RTL Timing Diagram:

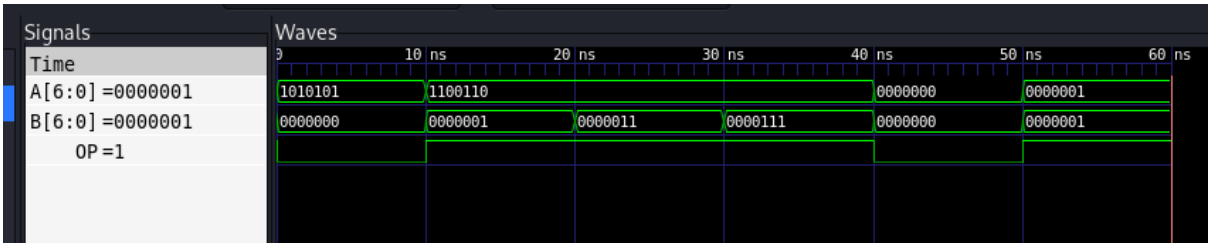
Check List: Have you added all the timing diagrams of ALU_TESTBENCH, CONTROLLER_TESTBENCH, TOP_TESTBENCH?	YES
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

`top_tb.v`

`controller_tb.v`



`ALU_7bit_tb.v`



RTL Synthesis (130nm Skywater PDK with OpenLane toolchain):

Check List: Have you added *RTL synthesis summary*, *RTL synthesized design figure* and *Standard cell usage in synthesized design*?	YES
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

RTL synthesis summary

RTL synthesis summary (TOP)

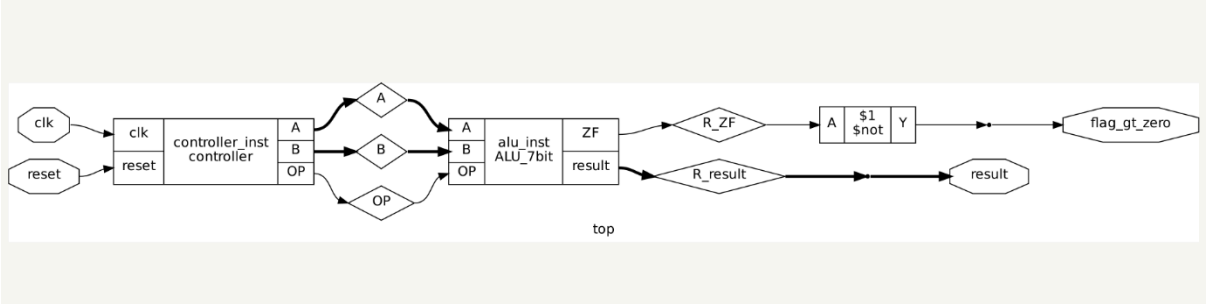
```
=== top ===

   Number of wires:                 12
   Number of wire bits:             18
   Number of public wires:           8
   Number of public wire bits:      14
   Number of ports:                  4
   Number of port bits:             10
   Number of memories:               0
   Number of memory bits:            0
   Number of processes:              0
   Number of cells:                 16
```

RTL synthesis summary (ALU)

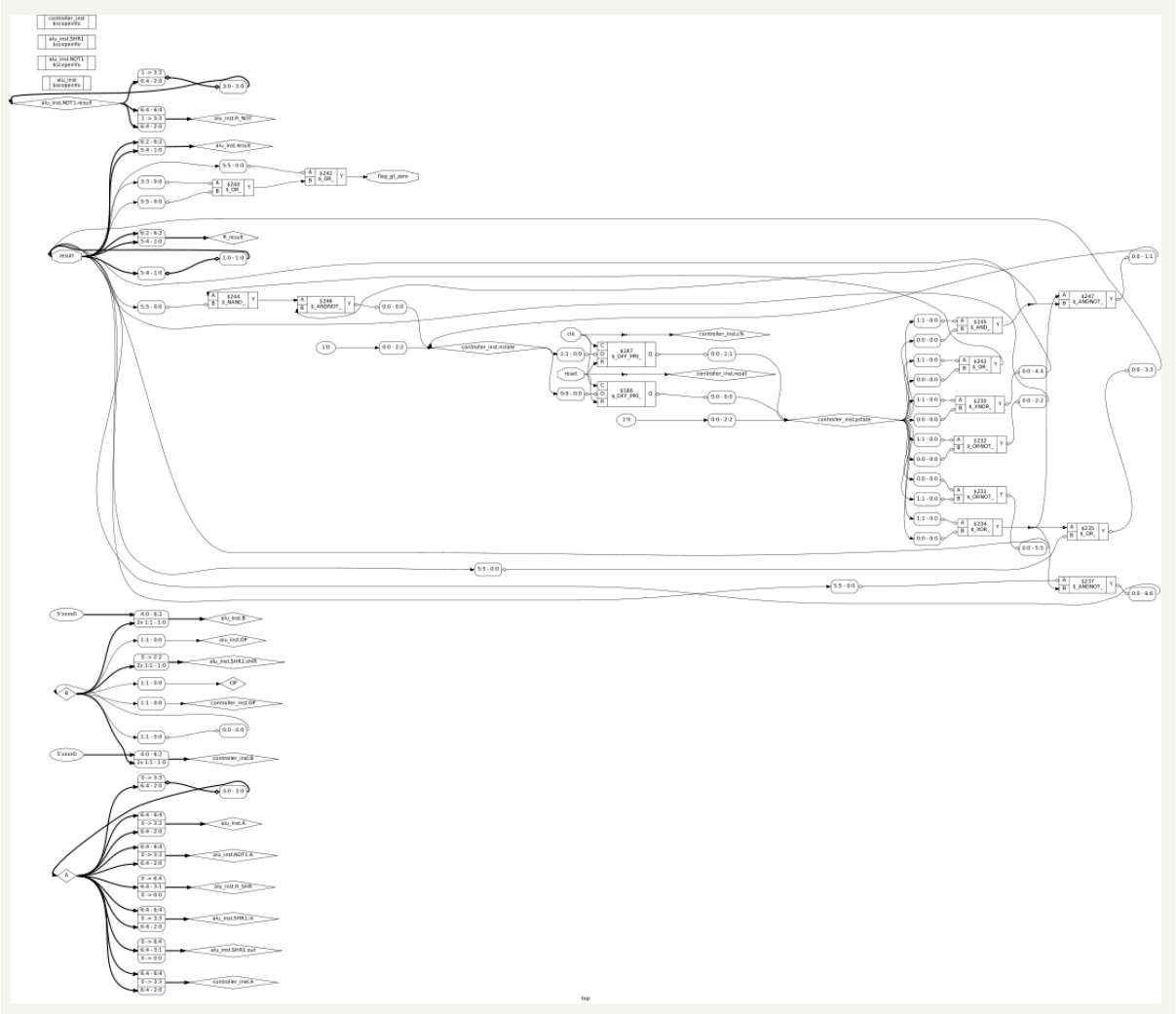
```
=== ALU_7bit ===

   Number of wires:                 43
   Number of wire bits:             61
   Number of public wires:           5
   Number of public wire bits:      23
   Number of ports:                  5
   Number of port bits:             23
   Number of memories:               0
   Number of memory bits:            0
   Number of processes:              0
   Number of cells:                 46
```

RTL synthesized design figure:

Hierarchy (top)

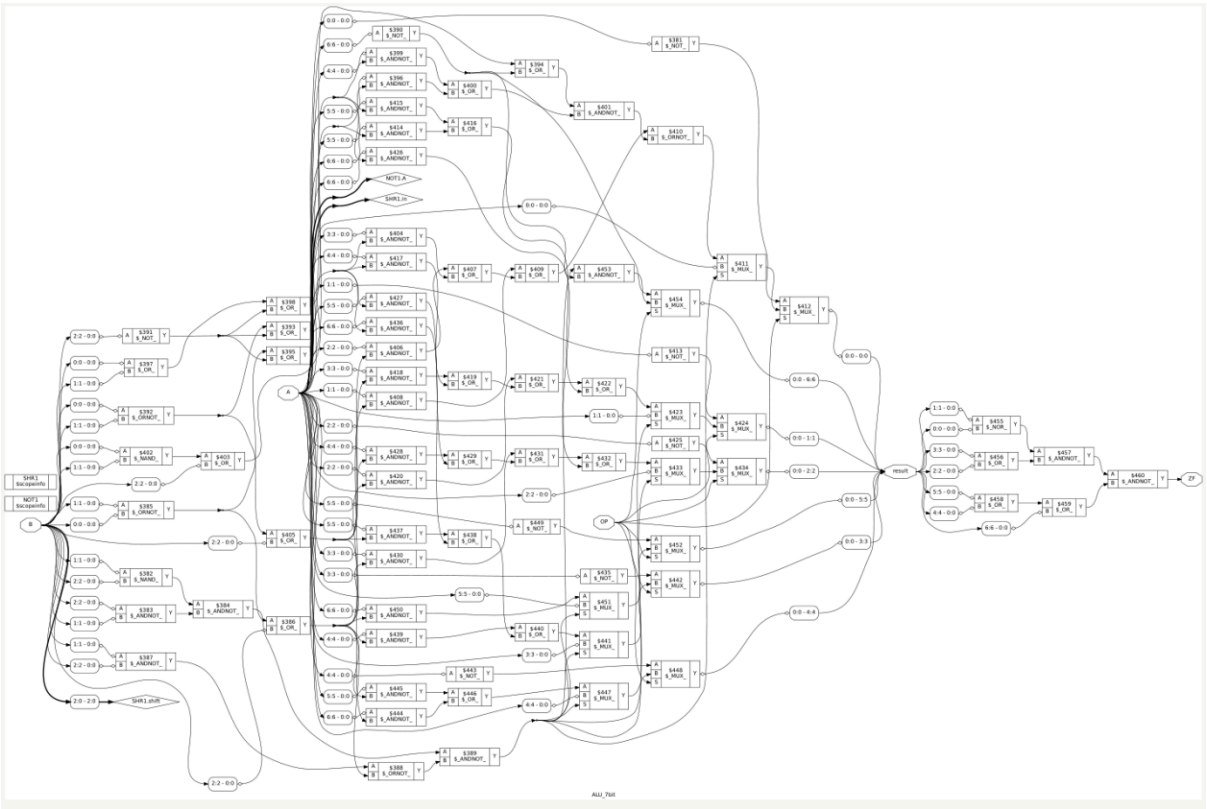


Primitive techmap (top)



Hierarchy (ALU)

Primitive techmap (ALU)



Standard cell usage in synthesized design

Standard Cells(Top)

```
    sky130_fd_sc_hd__buf_2          2
    sky130_fd_sc_hd__buf_6          2
    sky130_fd_sc_hd__conb_1         2
    sky130_fd_sc_hd__dfrtp_2        2
    sky130_fd_sc_hd__inv_2          3
    sky130_fd_sc_hd__nand2b_4       2
    sky130_fd_sc_hd__xnor2_4        2
    sky130_fd_sc_hd__xor2_4         1

Chip area for module '\top': 213.955200
  of which used for sequential elements: 52.550400 (24.56%)
```

Standard Cells(ALU)

```
    sky130_fd_sc_hd__a211o_2        3
    sky130_fd_sc_hd__a21o_2         1
    sky130_fd_sc_hd__a21oi_2        1
    sky130_fd_sc_hd__a2bb2o_4       2
    sky130_fd_sc_hd__a311o_2        1
    sky130_fd_sc_hd__a31o_2         2
    sky130_fd_sc_hd__and2_2         2
    sky130_fd_sc_hd__and2b_2        4
    sky130_fd_sc_hd__and4b_2        1
    sky130_fd_sc_hd__inv_2          6
    sky130_fd_sc_hd__mux2_2         5
    sky130_fd_sc_hd__mux4_2         1
    sky130_fd_sc_hd__nor2_2         2
    sky130_fd_sc_hd__nor4_4         1
    sky130_fd_sc_hd__o2111a_2       1
    sky130_fd_sc_hd__o211a_2        3
    sky130_fd_sc_hd__o211a_4        1
    sky130_fd_sc_hd__o21a_2         2
    sky130_fd_sc_hd__o21a_4         1
    sky130_fd_sc_hd__o22a_2         1
    sky130_fd_sc_hd__or3_2          1
    sky130_fd_sc_hd__or3_4          1
    sky130_fd_sc_hd__or3b_2         2
    sky130_fd_sc_hd__or4_4          1

Chip area for module '\ALU_7bit': 462.944000
  of which used for sequential elements: 0.000000 (0.00%)
```

RTL Floorplan (130nm Skywater PDK with OpenLane toolchain)

Check List: Have you added RTL Floorplan info?	YES
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

RTL Floorplan (ALU): or_metrics_out.json file info is given here

or_metrics_out.json

reports > alu > or_metrics_out.json > ...


```
{
    "design__die__bbox": "0.0 0.0 50.0 50.0",
    "design__core__bbox": "5.52 10.88 44.16 38.08",
    "design__io": 23,
    "design__die__area": 2500,
    "design__core__area": 1051.01,
    "design__instance__count": 46,
    "design__instance__area": 462.944,
    "design__instance__count__stdcell": 46,
    "design__instance__area__stdcell": 462.944,
    "design__instance__count__macros": 0,
    "design__instance__area__macros": 0,
    "design__instance__utilization": 0.440476,
    "design__instance__utilization__stdcell": 0.440476,
    "design__instance__count__class:inverter": 6,
    "design__instance__count__class:multi_input_combinational_cell": 40,
    "flow__warnings__count": 6,
    "flow__errors__count": 0
}
```


RTL Floorplan (top): or_metrics_out.json file info is given here

or_metrics_out.json

reports > top > or_metrics_out.json > ...


```
{
    "design__die__bbox": "0.0 0.0 50.0 50.0",
    "design__core__bbox": "5.52 10.88 44.16 38.08",
    "design__io": 10,
    "design__die__area": 2500,
    "design__core__area": 1051.01,
    "design__instance__count": 16,
    "design__instance__area": 213.955,
    "design__instance__count__stdcell": 16,
    "design__instance__area__stdcell": 213.955,
    "design__instance__count__macros": 0,
    "design__instance__area__macros": 0,
    "design__instance__utilization": 0.203571,
    "design__instance__utilization__stdcell": 0.203571,
    "design__instance__count__class:buffer": 4,
    "design__instance__count__class:inverter": 3,
    "design__instance__count__class:sequential_cell": 2,
    "design__instance__count__class:multi_input_combinational_cell": 7,
    "flow__warnings__count": 2,
    "flow__errors__count": 0
}
```

RTL Power Analysis (130nm Skywater PDK with OpenLane toolchain)

Check List: Have you added RTL Power Analysis info?	YES
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

RTL Power Analysis (ALU)

```
============================================================================
 report_power
============================================================================
======================= nom_tt_025C_1v80 Corner ===================================

Group                    Internal    Switching      Leakage        Total
                            Power        Power        Power        Power (Watts)
----------------------------------------------------------------------------
Sequential           0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00   0.0%
Combinational        4.102680e-06 6.307530e-06 2.711749e-10 1.041048e-05 100.0%
Clock                0.000000e+00 0.000000e+00 1.328418e-10 1.328418e-10   0.0%
Macro                0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00   0.0%
Pad                  0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00   0.0%
----------------------------------------------------------------------------
Total                4.102680e-06 6.307530e-06 4.040168e-10 1.041061e-05 100.0%
                            39.4%        60.6%         0.0%
|
```

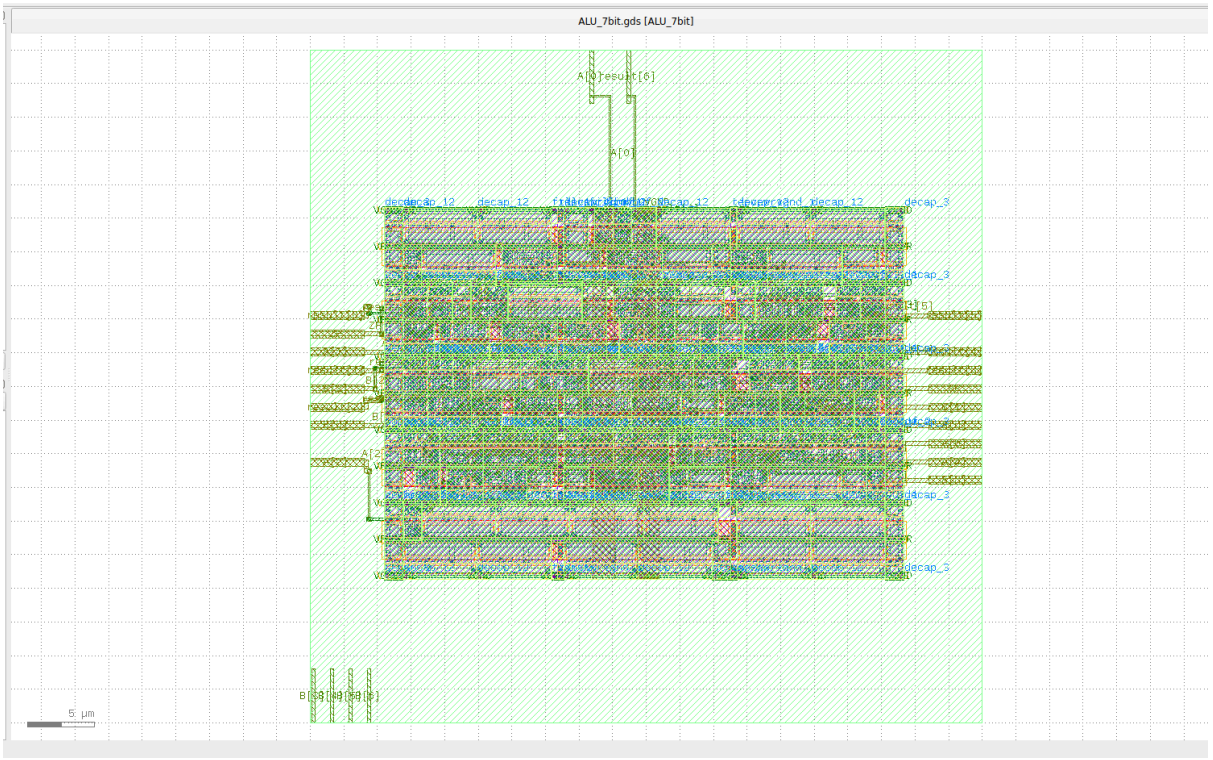
RTL Power Analysis (top)

```
============================================================================
 report_power
============================================================================
======================= nom_tt_025C_1v80 Corner ===================================

Group                    Internal    Switching      Leakage        Total
                            Power        Power        Power        Power (Watts)
----------------------------------------------------------------------------
Sequential           3.264559e-06 0.000000e+00 2.103740e-11 3.264580e-06  12.2%
Combinational        6.408108e-08 1.307327e-07 7.336588e-11 1.948871e-07   0.7%
Clock                2.021802e-05 3.054574e-06 1.471308e-10 2.327274e-05  87.1%
Macro                0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00   0.0%
Pad                  0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00   0.0%
----------------------------------------------------------------------------
Total                2.354666e-05 3.185306e-06 2.415341e-10 2.673221e-05 100.0%
                            88.1%        11.9%         0.0%
'
```

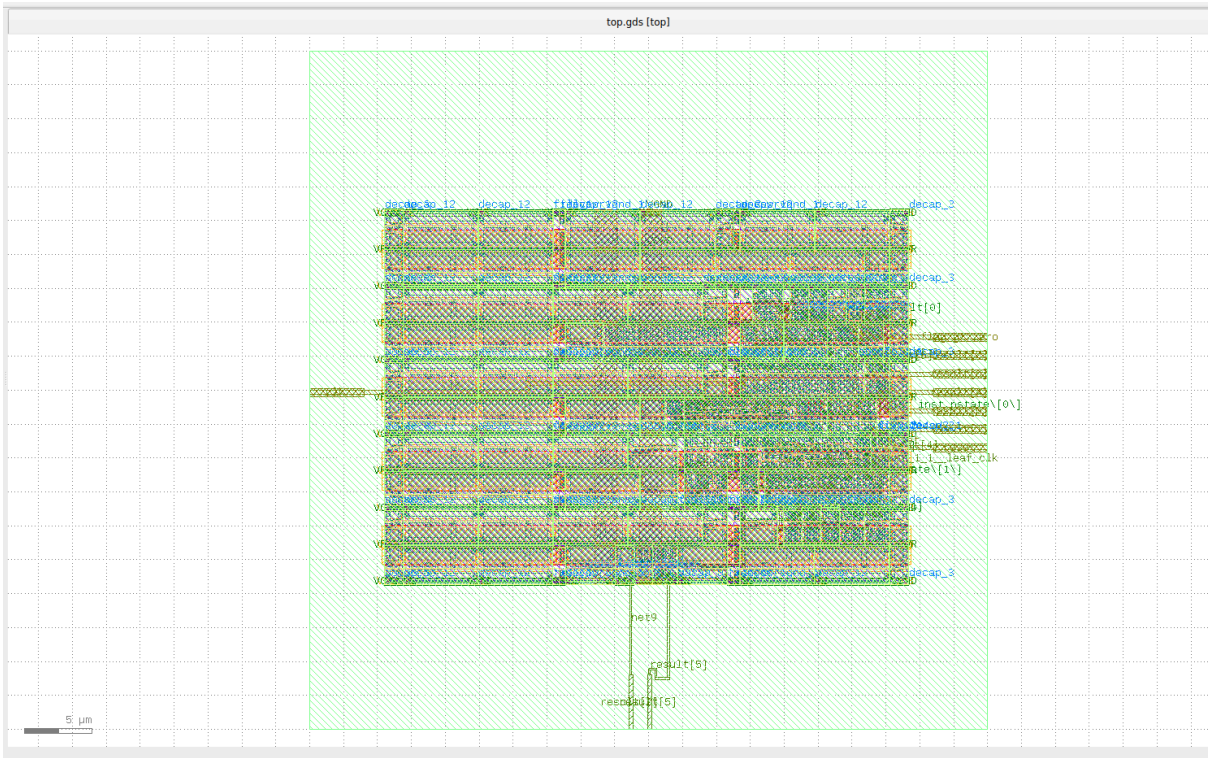
GDS Layout (130nm Skywater PDK with OpenLane toolchain)

Check List: Have you added the GDS Layout figure?	YES
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

GDS Layout (ALU)



GDS Layout (top)

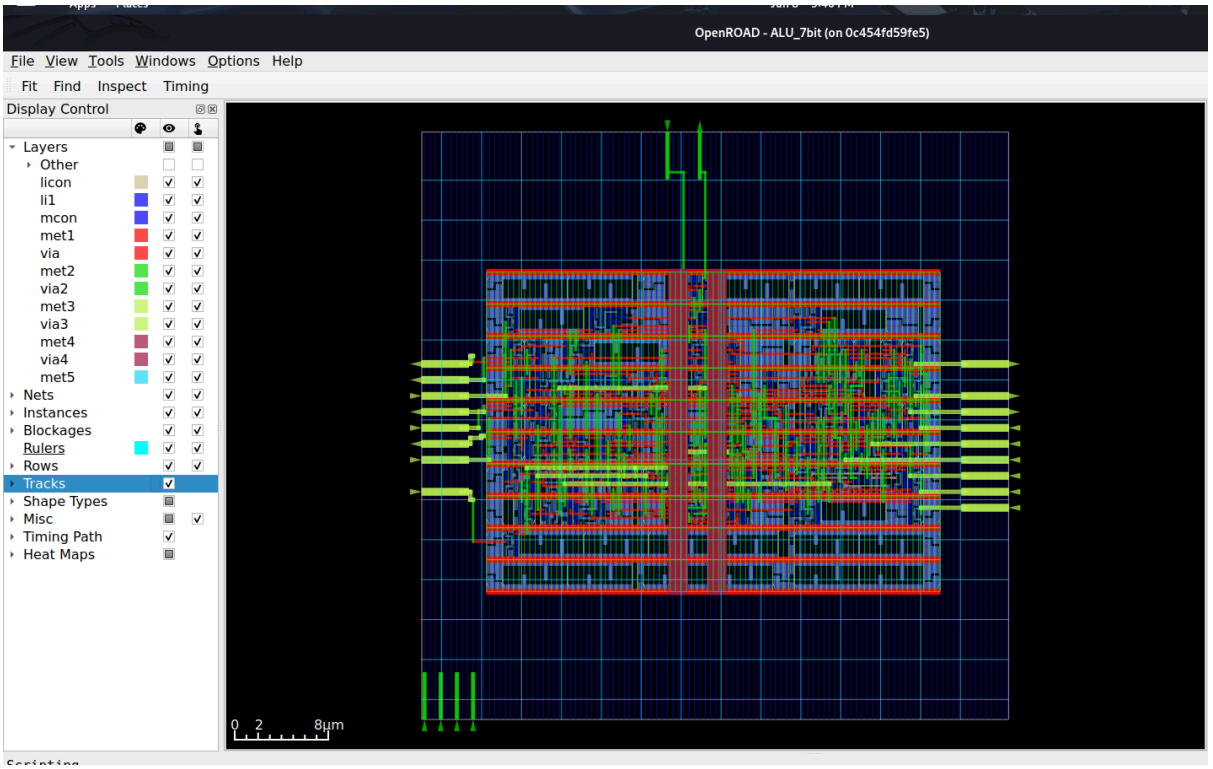


Heatmap (130nm Skywater PDK with OpenLane toolchain)

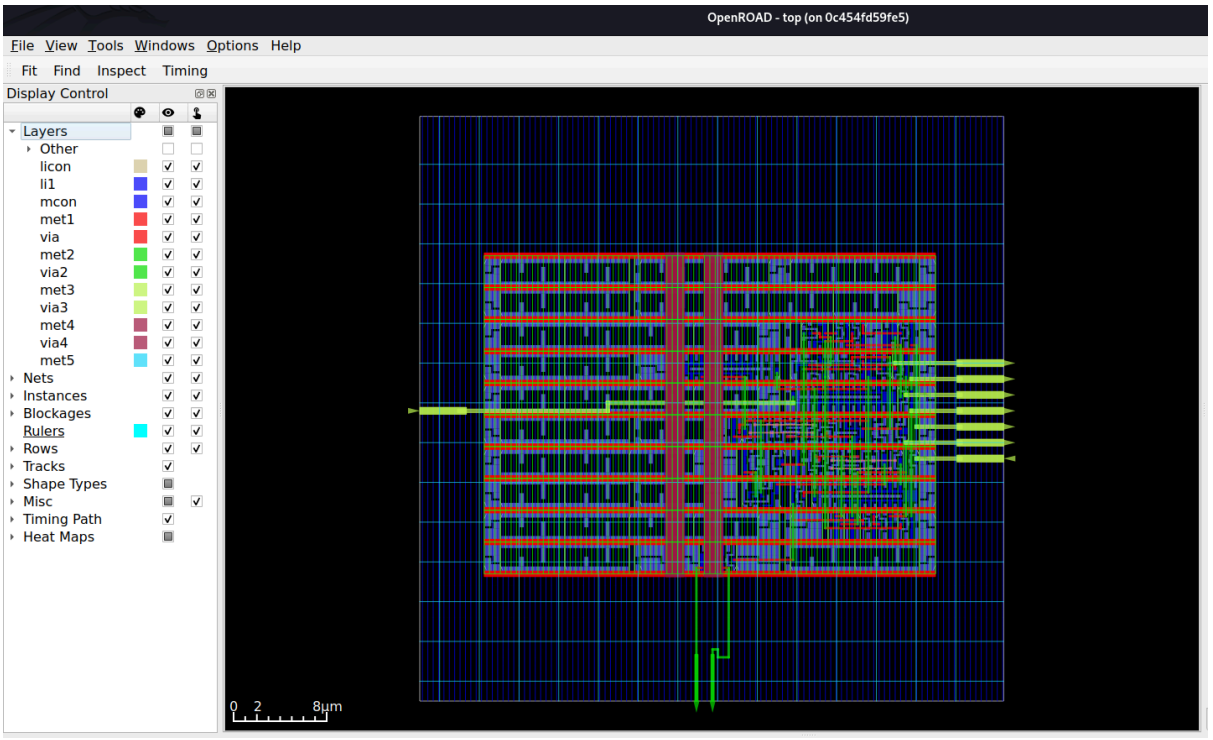
Check List: Have you added the heatmap?	YES/NO
NB: Failing to add any required info will cause point penalty (1-2 Marks)	

(Following figure is showing what info need to be shown /Just copy paste these figures)

Heatmap (ALU)



Heatmap (top)


OpenROAD - top (on 0c454fd59fe5)
File View Tools Windows Options Help
Fit Find Inspect Timing
Display Control
Layers
Other
licon
li1
mcon
met1
via
met2
via2
met3
via3
met4
via4
met5
Nets
Instances
Blockages
Rulers
Rows
Tracks
Shape Types
Misc
Timing Path
Heat Maps
0 2 8μm