MARMARA UNIVERSITY – FACULTY OF ENGINEERING

LABORATORY ASSIGNMENT #2 REPORT

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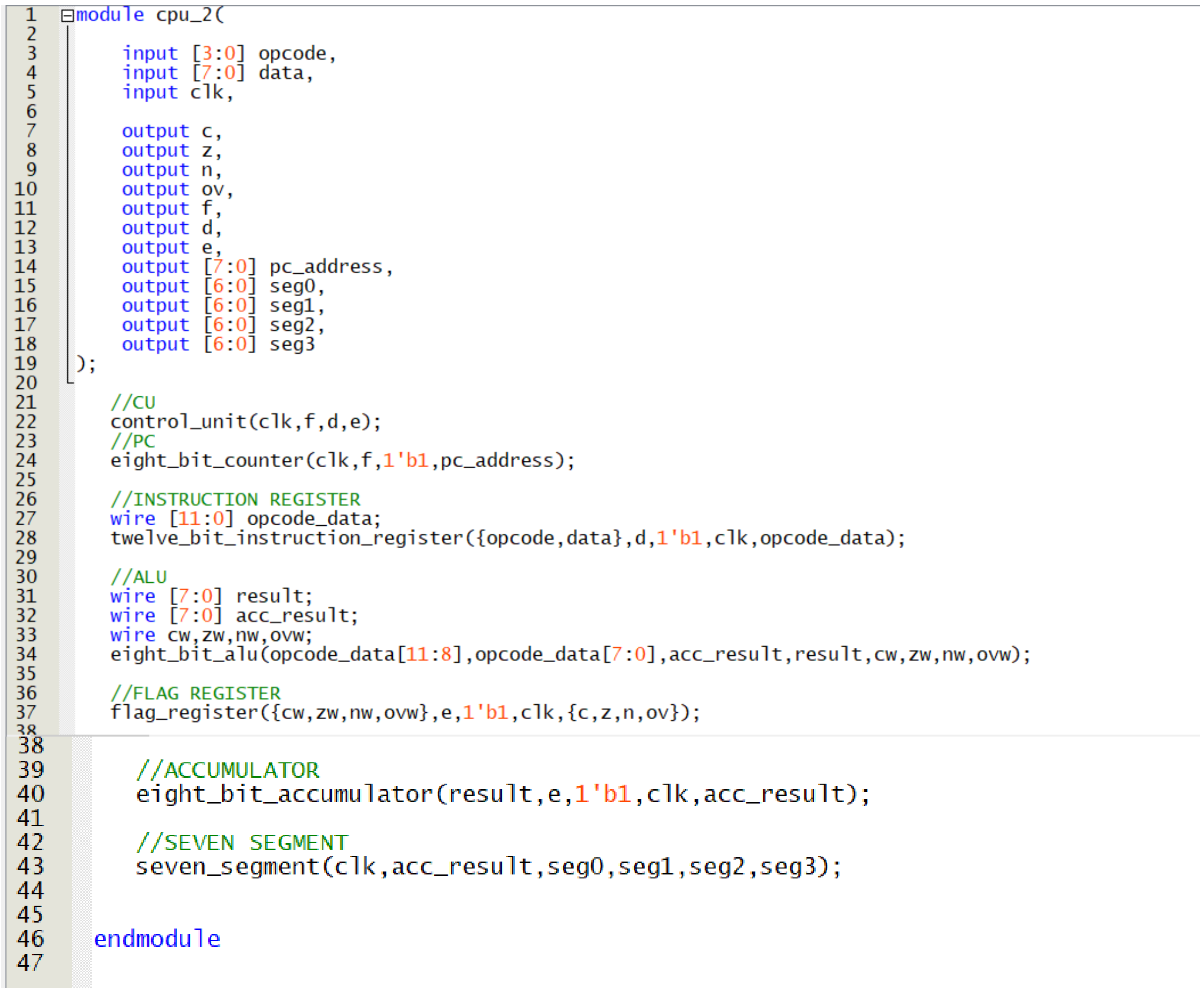
CPU DESIGN

We have designed 8-bit CPU with 4-bit opcode. It is designed for only L-type instructions. It has 7 components as shown below. This processor receives instruction from us as input. Gives us output in 4 ways. The first is with 7-segment driver. After each operation the value in accumulator is seen on this driver. In addition, Flag register values, PC value and current clock cycle are indicated by the LEDs on the FPGA on which we will install our processor. For this, we assign the appropriate output values to the correct LED pins.



```verilog
module cpu_2(

    input [3:0] opcode,
    input [7:0] data,
    input clk,

    output c,
    output z,
    output n,
    output ov,
    output f,
    output d,
    output e,
    output [7:0] pc_address,
    output [6:0] seg0,
    output [6:0] seg1,
    output [6:0] seg2,
    output [6:0] seg3
);

   //CU
   control_unit(clk,f,d,e);
   //PC
   eight_bit_counter(clk,f,1'b1,pc_address);

   //INSTRUCTION REGISTER
   wire [11:0] opcode_data;
   twelve_bit_instruction_register({opcode,data},d,1'b1,clk,opcode_data);

   //ALU
   wire [7:0] result;
   wire [7:0] acc_result;
   wire cw,zw,nw,ovw;
   eight_bit_alu(opcode_data[11:8],opcode_data[7:0],acc_result,result,cw,zw,nw,ovw);

   //FLAG REGISTER
   flag_register({cw,zw,nw,ovw},e,1'b1,clk,{c,z,n,ov});

   //ACCUMULATOR
   eight_bit_accumulator(result,e,1'b1,clk,acc_result);

   //SEVEN SEGMENT
   seven_segment(clk,acc_result,seg0,seg1,seg2,seg3);


endmodule
```

Figure-1: Verilog Code for the 8-bit CPU

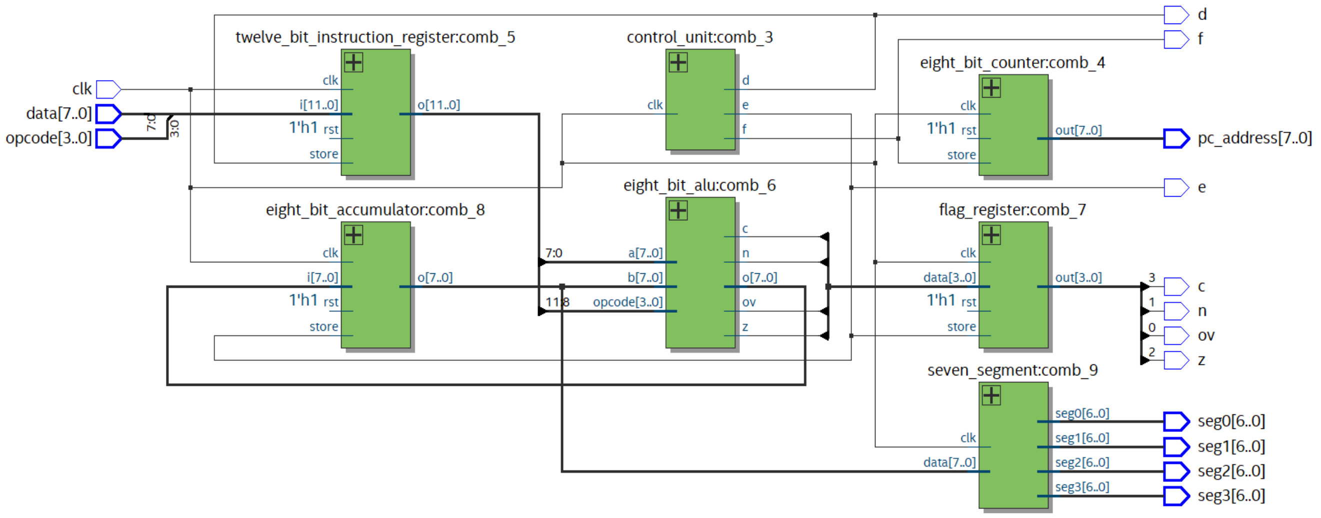


Figure-2: RTL View for the 8-bit CPU

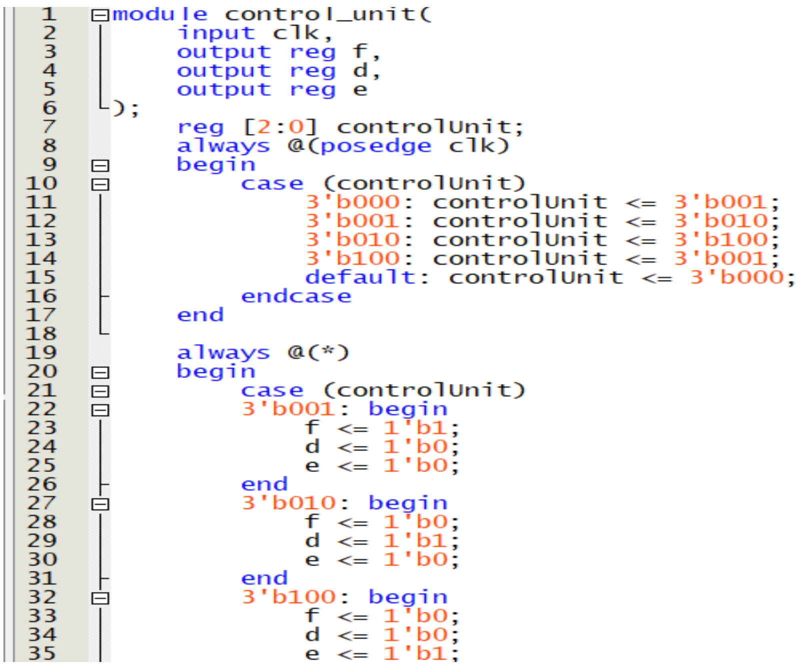
COMPONENTS FOR CPU

8-BIT ALU

We had designed the 8-bit ALU for the previous lab project so the details about the ALU available there.

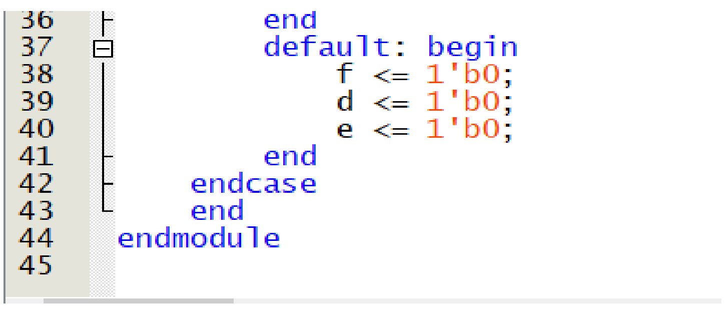
CONTROL UNIT

We control 3 clock cycles with the Control Unit. These three cycles are Fetch, Decode and Execute respectively. Each cycle signal is connected to an LED pin on the FPGA. The appropriate LED lights up according to which cycle is running. Control Unit is not in any clock cycle by default. It moves to the next cycle at every clock that comes to itself. In this way, it controls that the instruction is running correctly.



```
module control_unit(
        input clk,
        output reg f,
        output reg d,
        output reg e
);
        reg [2:0] controlUnit;
        always @(posedge clk)
        begin
            case (controlUnit)
                3'b000: controlUnit <= 3'b001;
                3'b001: controlUnit <= 3'b010;
                3'b010: controlUnit <= 3'b100;
                3'b100: controlUnit <= 3'b001;
                default: controlUnit <= 3'b000;
            endcase
        end

        always @(*)
        begin
            case (controlUnit)
            3'b001: begin
                f <= 1'b1;
                d <= 1'b0;
                e <= 1'b0;
            end
            3'b010: begin
                f <= 1'b0;
                d <= 1'b1;
                e <= 1'b0;
            end
            3'b100: begin
                f <= 1'b0;
                d <= 1'b0;
                e <= 1'b1;
```

Figure-1: Verilog Code for Control Unit (1)



```
            end
            default: begin
                f <= 1'b0;
                d <= 1'b0;
                e <= 1'b0;
            end
        endcase
        end
endmodule
```

Figure-2: Verilog Code for Control Unit (2)

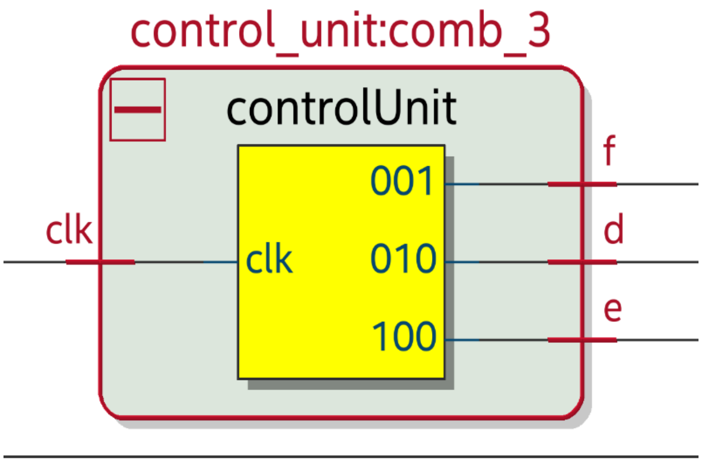
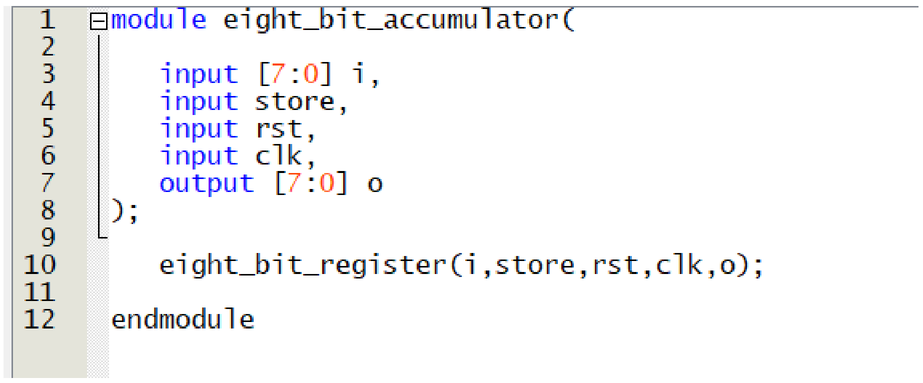


Figure-3: RTL View of Control Unit

8-BIT ACCUMULATOR

Accumulator is a register. We use an 8-bit accumulator for this processor. It consists of 8 1-bit registers. We keep the ALU results in this register. For the next operation, an input of the ALU comes from the accumulator.



```
module eight_bit_accumulator(

    input [7:0] i,
    input store,
    input rst,
    input clk,
    output [7:0] o
);

    eight_bit_register(i,store,rst,clk,o);

endmodule
```

Figure-1: Verilog Code of 8-bit accumulator

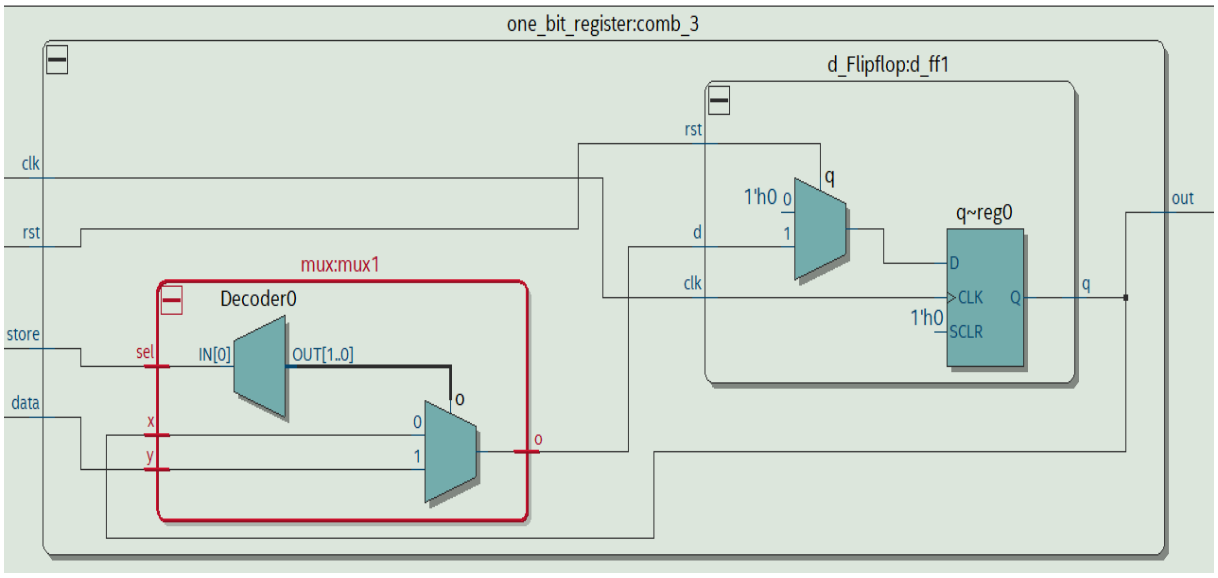


Figure-2: RTL View of 1-bit register

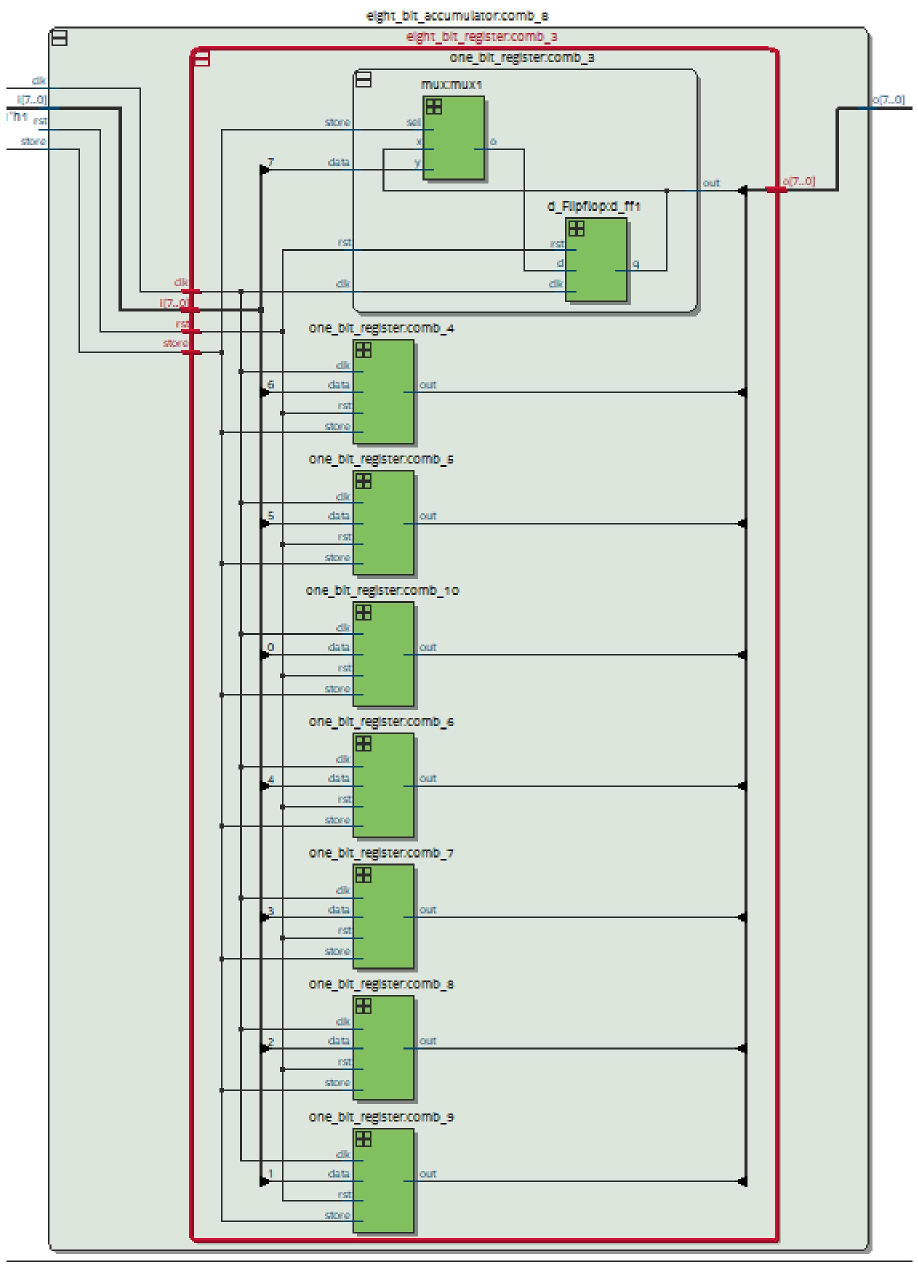
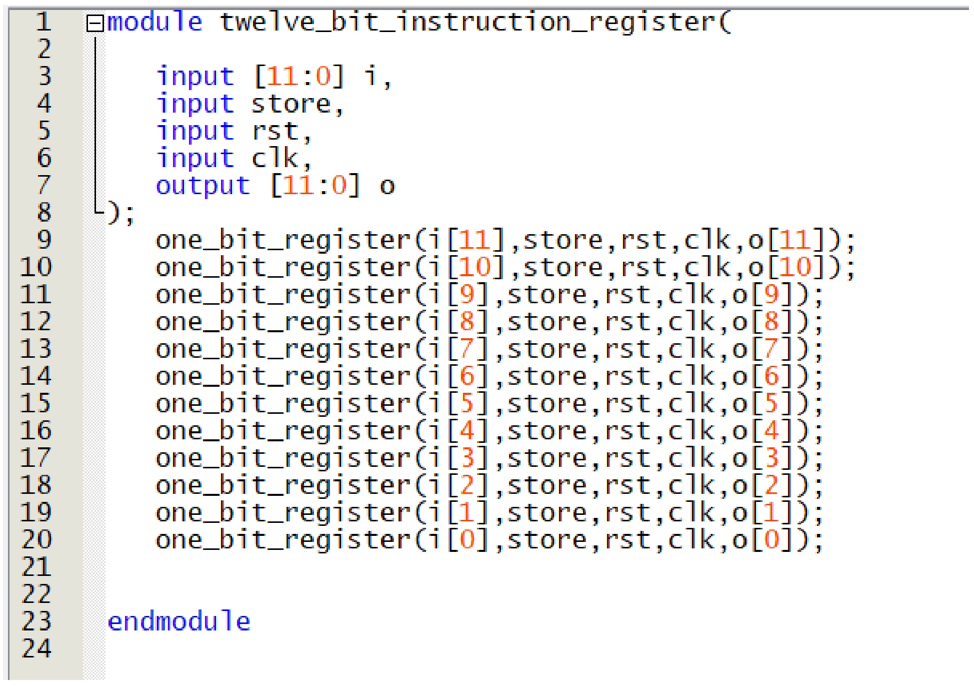


Figure-3: RTL View of 8-bit accumulator

12 BIT INSTRUCTION REGISTER

The 12-bit instruction register consists of 12 1-bit registers. The instruction to be executed on the CPU arrives in this register, where it is decoded and the appropriate code snippets are passed to other appropriate components in the processor.



```verilog
module twelve_bit_instruction_register(

    input [11:0] i,
    input store,
    input rst,
    input clk,
    output [11:0] o
);
    one_bit_register(i[11],store,rst,clk,o[11]);
    one_bit_register(i[10],store,rst,clk,o[10]);
    one_bit_register(i[9],store,rst,clk,o[9]);
    one_bit_register(i[8],store,rst,clk,o[8]);
    one_bit_register(i[7],store,rst,clk,o[7]);
    one_bit_register(i[6],store,rst,clk,o[6]);
    one_bit_register(i[5],store,rst,clk,o[5]);
    one_bit_register(i[4],store,rst,clk,o[4]);
    one_bit_register(i[3],store,rst,clk,o[3]);
    one_bit_register(i[2],store,rst,clk,o[2]);
    one_bit_register(i[1],store,rst,clk,o[1]);
    one_bit_register(i[0],store,rst,clk,o[0]);


endmodule

```

Figure-1: Verilog Code of 12-bit Instruction Register

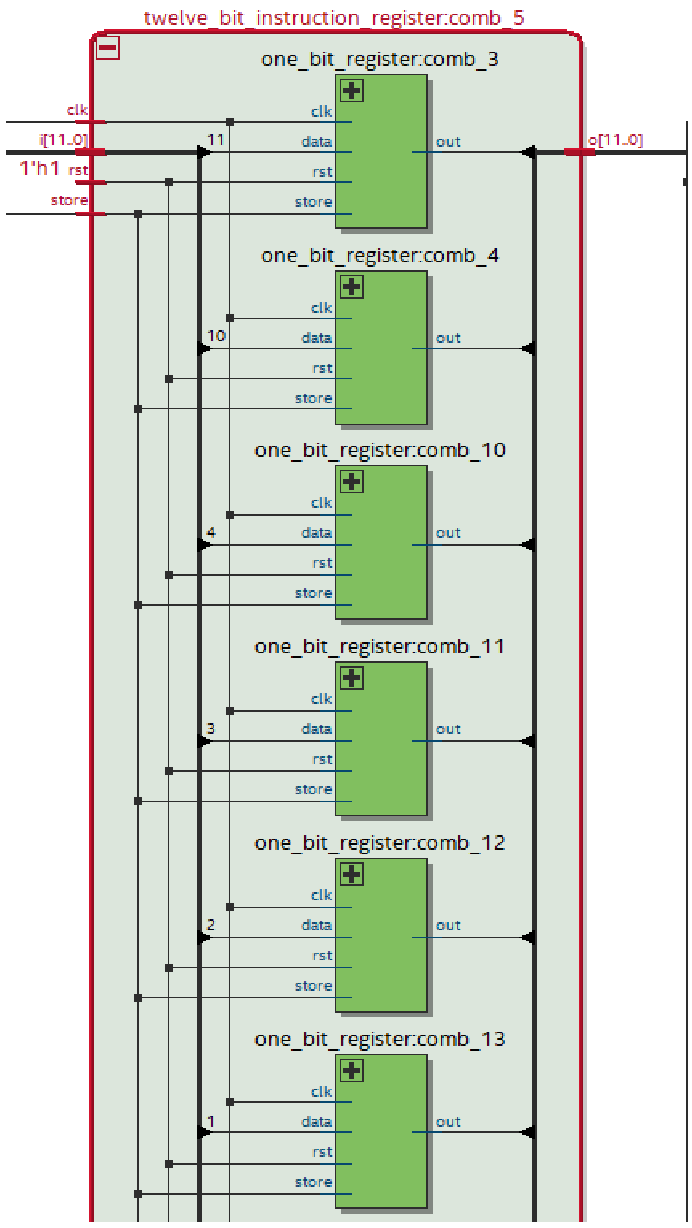


Figure-2: RTL View of 12-bit Instruction Register (1)

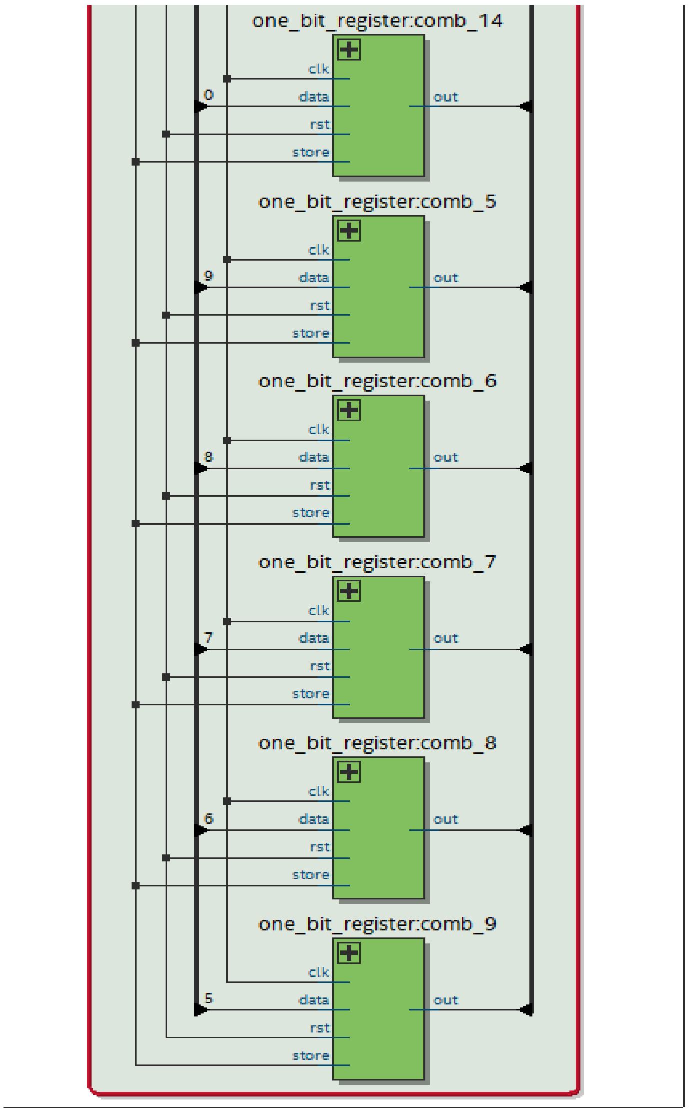
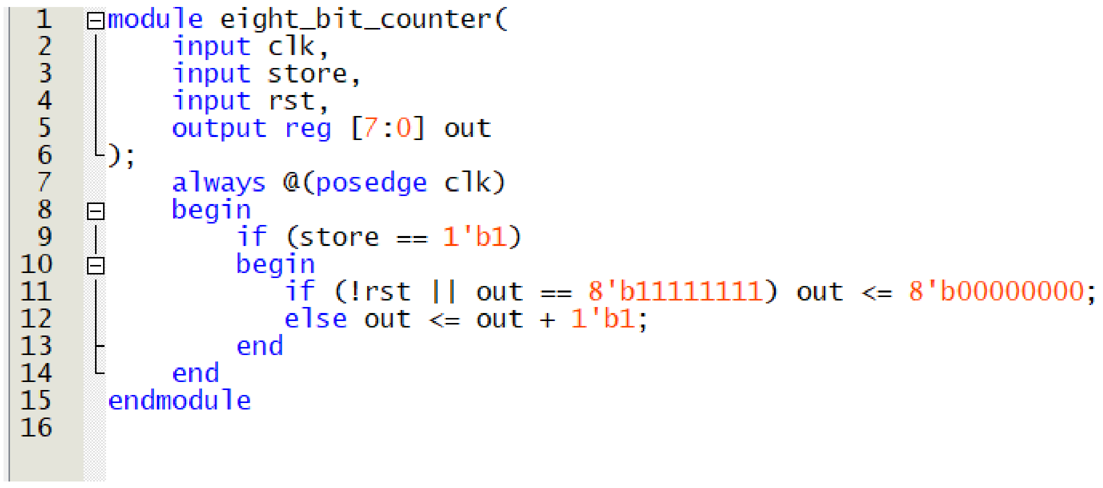


Figure-3: RTL View of 12-bit Instruction Register (2)

8-BIT PROGRAM COUNTER

A PC is a component that normally gives an instruction address. However, we do not use ROM in this processor, and the output from the PC is connected to the LED pins. It has an incrementer and its value increases by one after each fetch signal from the control unit.



```
module eight_bit_counter(
    input clk,
    input store,
    input rst,
    output reg [7:0] out
);
    always @(posedge clk)
    begin
        if (store == 1'b1)
        begin
            if (!rst || out == 8'b11111111) out <= 8'b00000000;
            else out <= out + 1'b1;
        end
    end
endmodule
```

Figure-1: Verilog Code of 8-bit Program Counter

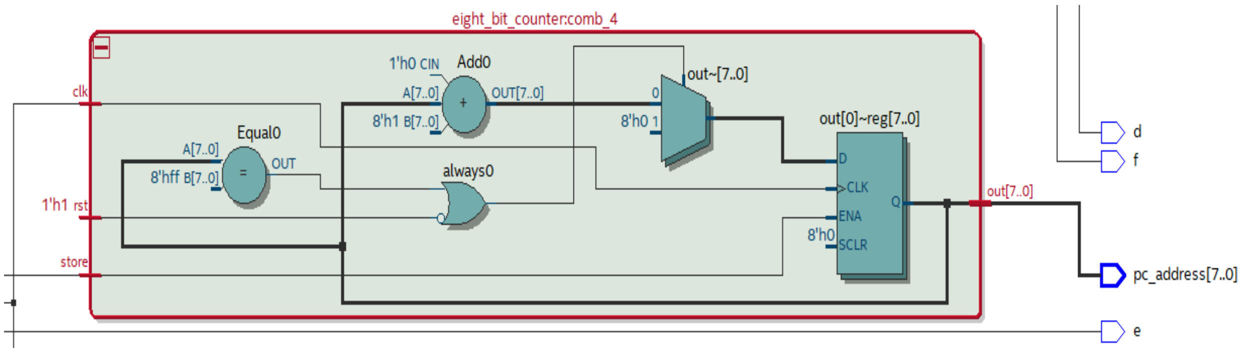
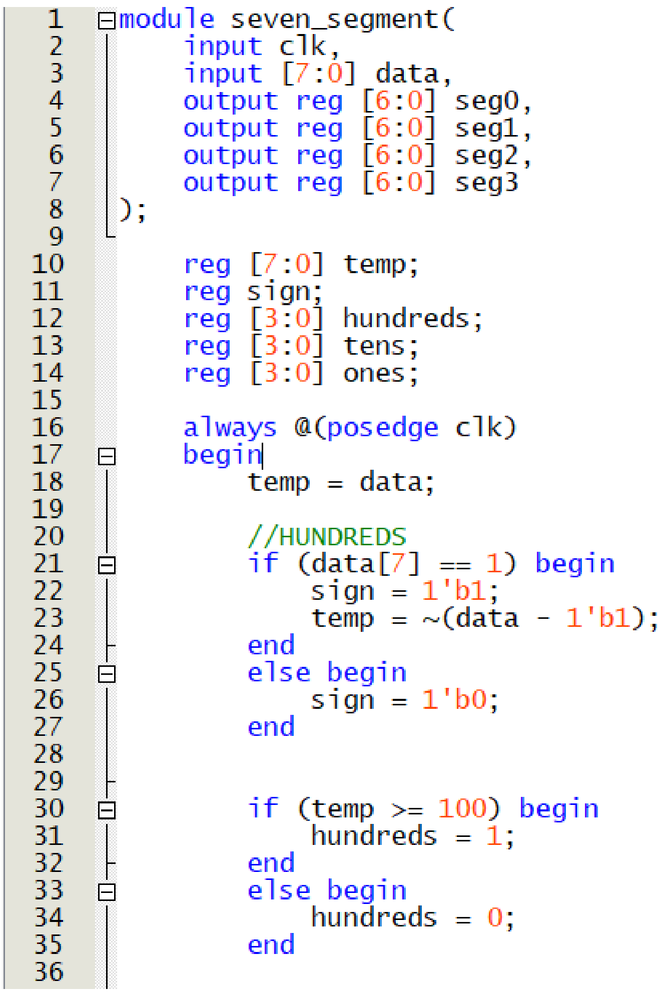


Figure-2: RTL View of 8-bit Program Counter

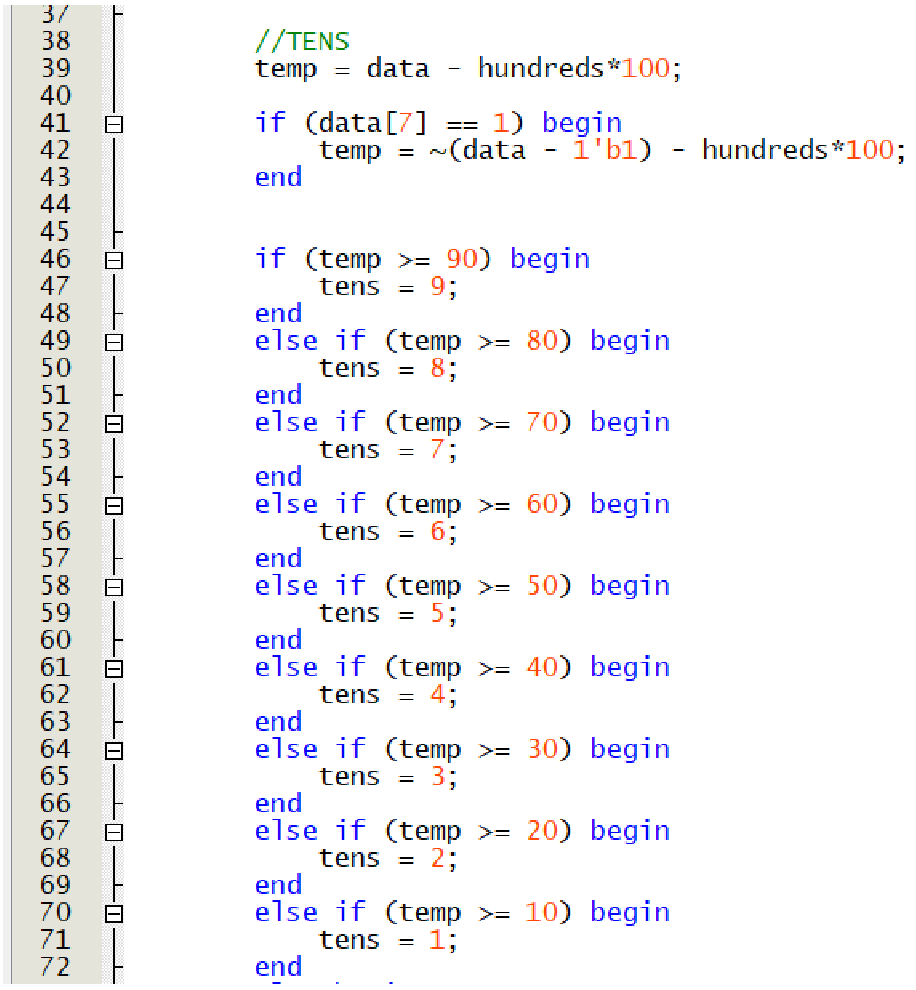
7-SEGMENT DRIVER

7-Segment Driver is connecting to the accumulator. In our processor, it is responsible for displaying the data in the accumulator. It analyzes the binary data it coming from acc, converts it to decimal and displays that decimal value.



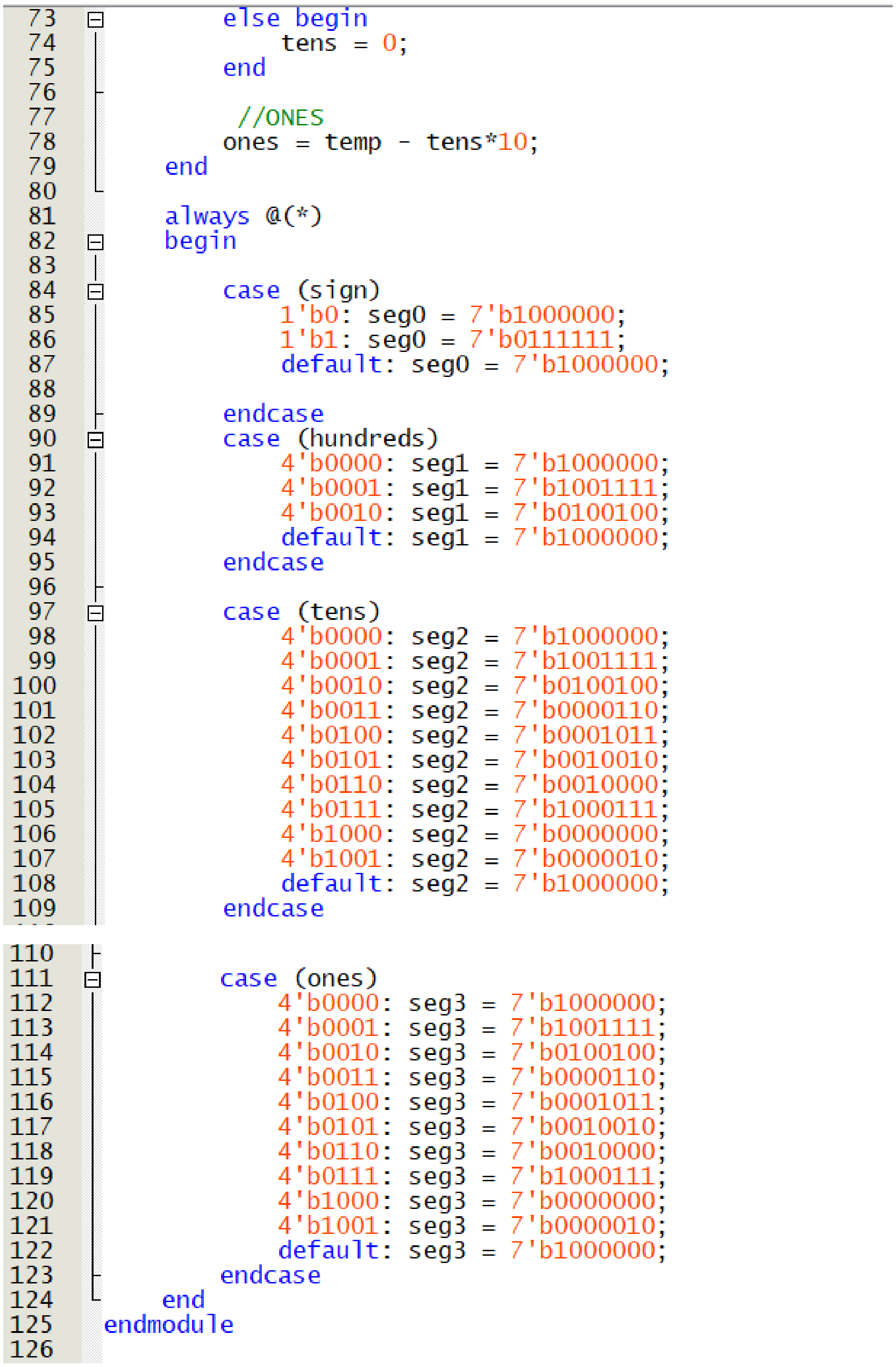
```verilog
module seven_segment(
    input clk,
    input [7:0] data,
    output reg [6:0] seg0,
    output reg [6:0] seg1,
    output reg [6:0] seg2,
    output reg [6:0] seg3
);

    reg [7:0] temp;
    reg sign;
    reg [3:0] hundreds;
    reg [3:0] tens;
    reg [3:0] ones;

    always @(posedge clk)
    begin
        temp = data;

        //HUNDREDS
        if (data[7] == 1) begin
            sign = 1'b1;
            temp = ~(data - 1'b1);
        end
        else begin
            sign = 1'b0;
        end


        if (temp >= 100) begin
            hundreds = 1;
        end
        else begin
            hundreds = 0;
        end

```

Figure-1: Verilog Code of 7-bit Segment Driver (1)



```
        //TENS
        temp = data - hundreds*100;

        if (data[7] == 1) begin
            temp = ~(data - 1'b1) - hundreds*100;
        end


        if (temp >= 90) begin
            tens = 9;
        end
        else if (temp >= 80) begin
            tens = 8;
        end
        else if (temp >= 70) begin
            tens = 7;
        end
        else if (temp >= 60) begin
            tens = 6;
        end
        else if (temp >= 50) begin
            tens = 5;
        end
        else if (temp >= 40) begin
            tens = 4;
        end
        else if (temp >= 30) begin
            tens = 3;
        end
        else if (temp >= 20) begin
            tens = 2;
        end
        else if (temp >= 10) begin
            tens = 1;
        end
```

Figure-2: Verilog Code of 7-bit Segment Driver (2)



```verilog
        else begin
            tens = 0;
        end

         //ONES
        ones = temp - tens*10;
    end

    always @(*)
    begin

        case (sign)
            1'b0: seg0 = 7'b1000000;
            1'b1: seg0 = 7'b0111111;
            default: seg0 = 7'b1000000;

        endcase
        case (hundreds)
            4'b0000: seg1 = 7'b1000000;
            4'b0001: seg1 = 7'b1001111;
            4'b0010: seg1 = 7'b0100100;
            default: seg1 = 7'b1000000;
        endcase

        case (tens)
            4'b0000: seg2 = 7'b1000000;
            4'b0001: seg2 = 7'b1001111;
            4'b0010: seg2 = 7'b0100100;
            4'b0011: seg2 = 7'b0000110;
            4'b0100: seg2 = 7'b0001011;
            4'b0101: seg2 = 7'b0010010;
            4'b0110: seg2 = 7'b0010000;
            4'b0111: seg2 = 7'b1000111;
            4'b1000: seg2 = 7'b0000000;
            4'b1001: seg2 = 7'b0000010;
            default: seg2 = 7'b1000000;
        endcase


        case (ones)
            4'b0000: seg3 = 7'b1000000;
            4'b0001: seg3 = 7'b1001111;
            4'b0010: seg3 = 7'b0100100;
            4'b0011: seg3 = 7'b0000110;
            4'b0100: seg3 = 7'b0001011;
            4'b0101: seg3 = 7'b0010010;
            4'b0110: seg3 = 7'b0010000;
            4'b0111: seg3 = 7'b1000111;
            4'b1000: seg3 = 7'b0000000;
            4'b1001: seg3 = 7'b0000010;
            default: seg3 = 7'b1000000;
        endcase
    end
endmodule
```

Figure-3: Verilog Code of 7-bit Segment Driver (3)

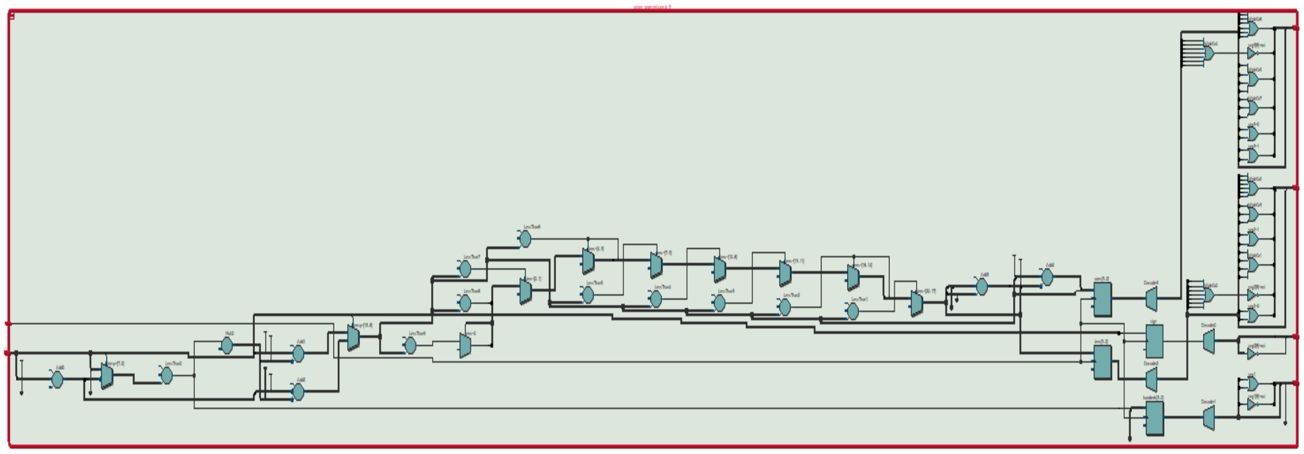
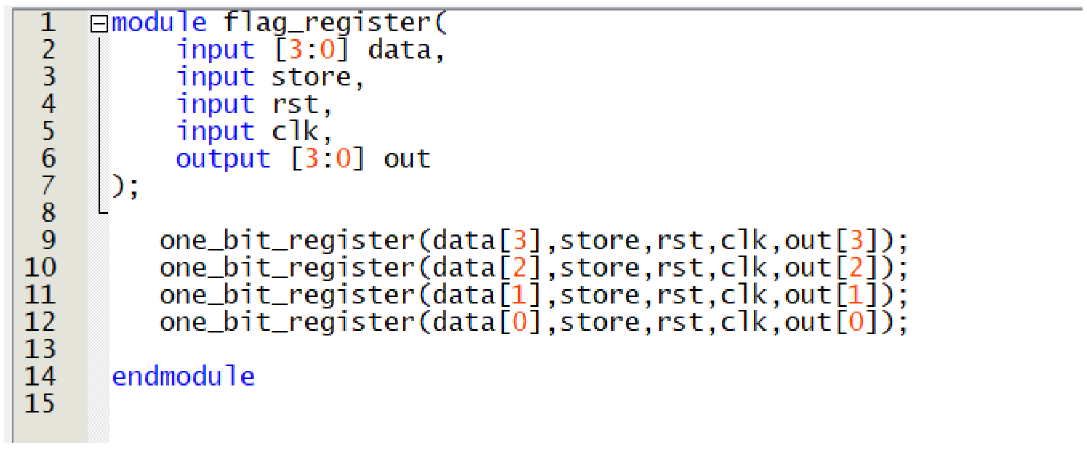


Figure-4: RTL View of 7-bit Segment Driver

FLAG REGISTER

The Flag Register consists of 4 1-bit registers. Each holds the value of a flag. Flag values come from the ALU. Each register is also connected to some LEDs on the FPGA and when their value is 1, the LED they are connected to lights up.



```
module flag_register(
      input [3:0] data,
      input store,
      input rst,
      input clk,
      output [3:0] out
);

    one_bit_register(data[3],store,rst,clk,out[3]);
    one_bit_register(data[2],store,rst,clk,out[2]);
    one_bit_register(data[1],store,rst,clk,out[1]);
    one_bit_register(data[0],store,rst,clk,out[0]);

endmodule
```

Figure-1: Verilog Code of Flag Register

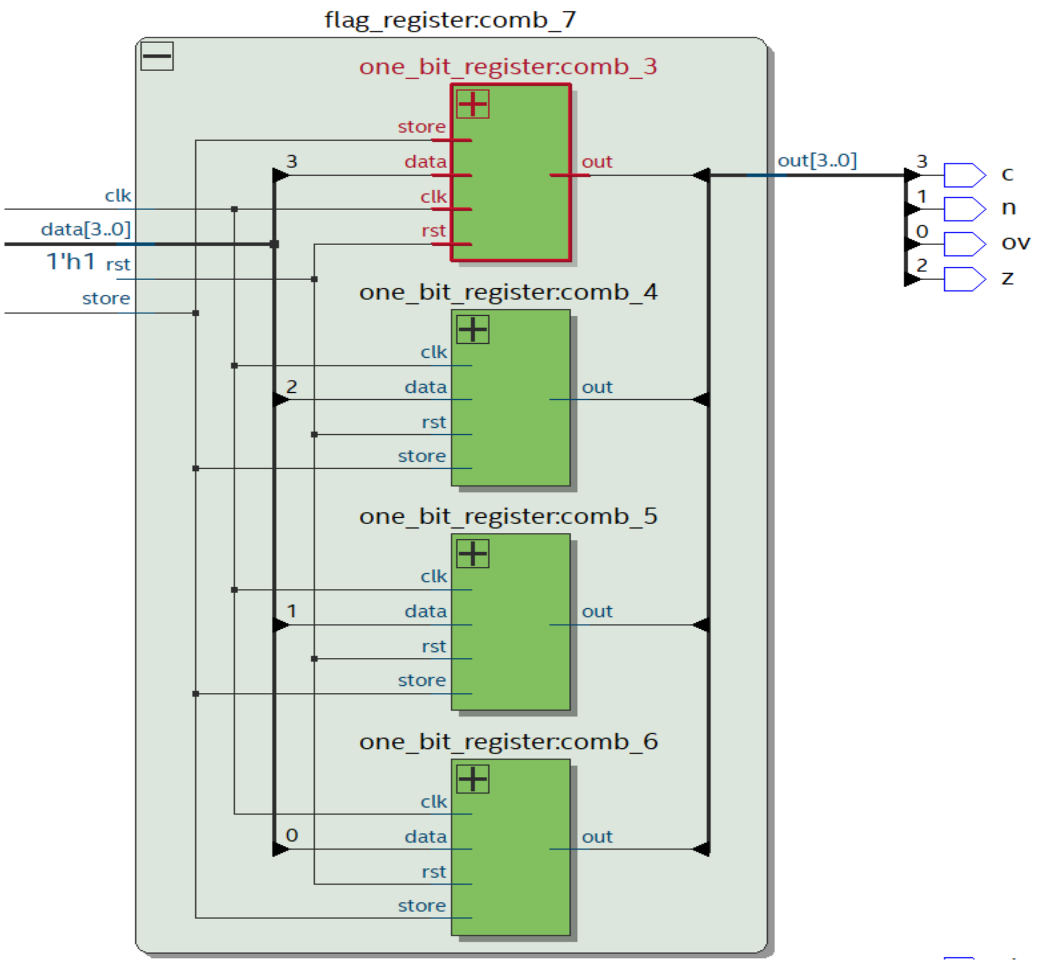
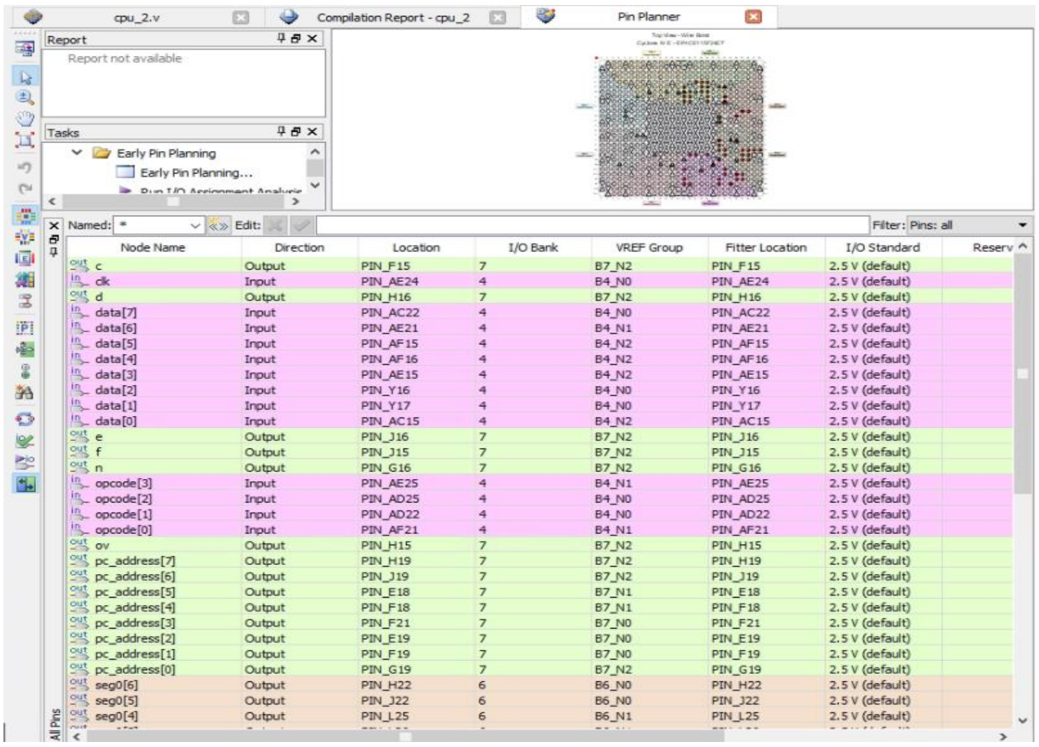


Figure-2: RTL View of Flag Register

8 SAMPLE OPERATION EXECUTING ON THE FPGA

First of all, we have compiled our CPU code by connecting to the lab computer. We made the necessary pin assignments. We have connected the right inputs to the appropriate switch pins for the instructions to be given as input and the suitable outputs to the correct LED pins. Then we uploaded our code to FPGA with programmer. Below, there are 8 operations and its details executed in the FPGA with our CPU.



Node Name	Direction	Location	I/O Bank	VREF Group	Fitter Location	I/O Standard	Reserv
c	Output	PIN_F15	7	B7_N2	PIN_F15	2.5 V (default)	
clk	Input	PIN_AE24	4	B4_N0	PIN_AE24	2.5 V (default)	
d	Output	PIN_H16	7	B7_N2	PIN_H16	2.5 V (default)	
data[7]	Input	PIN_AC22	4	B4_N0	PIN_AC22	2.5 V (default)	
data[6]	Input	PIN_AE21	4	B4_N1	PIN_AE21	2.5 V (default)	
data[5]	Input	PIN_AF15	4	B4_N2	PIN_AF15	2.5 V (default)	
data[4]	Input	PIN_AF16	4	B4_N2	PIN_AF16	2.5 V (default)	
data[3]	Input	PIN_AE15	4	B4_N2	PIN_AE15	2.5 V (default)	
data[2]	Input	PIN_Y16	4	B4_N0	PIN_Y16	2.5 V (default)	
data[1]	Input	PIN_Y17	4	B4_N0	PIN_Y17	2.5 V (default)	
data[0]	Input	PIN_AC15	4	B4_N2	PIN_AC15	2.5 V (default)	
e	Output	PIN_J16	7	B7_N2	PIN_J16	2.5 V (default)	
f	Output	PIN_J15	7	B7_N2	PIN_J15	2.5 V (default)	
n	Output	PIN_G16	7	B7_N2	PIN_G16	2.5 V (default)	
opcode[3]	Input	PIN_AE25	4	B4_N1	PIN_AE25	2.5 V (default)	
opcode[2]	Input	PIN_AD25	4	B4_N0	PIN_AD25	2.5 V (default)	
opcode[1]	Input	PIN_AD22	4	B4_N0	PIN_AD22	2.5 V (default)	
opcode[0]	Input	PIN_AF21	4	B4_N1	PIN_AF21	2.5 V (default)	
ov	Output	PIN_H15	7	B7_N2	PIN_H15	2.5 V (default)	
pc_address[7]	Output	PIN_H19	7	B7_N2	PIN_H19	2.5 V (default)	
pc_address[6]	Output	PIN_J19	7	B7_N2	PIN_J19	2.5 V (default)	
pc_address[5]	Output	PIN_E18	7	B7_N1	PIN_E18	2.5 V (default)	
pc_address[4]	Output	PIN_F18	7	B7_N1	PIN_F18	2.5 V (default)	
pc_address[3]	Output	PIN_F21	7	B7_N0	PIN_F21	2.5 V (default)	
pc_address[2]	Output	PIN_E19	7	B7_N0	PIN_E19	2.5 V (default)	
pc_address[1]	Output	PIN_F19	7	B7_N0	PIN_F19	2.5 V (default)	
pc_address[0]	Output	PIN_G19	7	B7_N2	PIN_G19	2.5 V (default)	
seg0[6]	Output	PIN_H22	6	B6_N0	PIN_H22	2.5 V (default)	
seg0[5]	Output	PIN_J22	6	B6_N0	PIN_J22	2.5 V (default)	
seg0[4]	Output	PIN_L25	6	B6_N1	PIN_L25	2.5 V (default)	

Figure-1: Some pin assignments on the FPGA

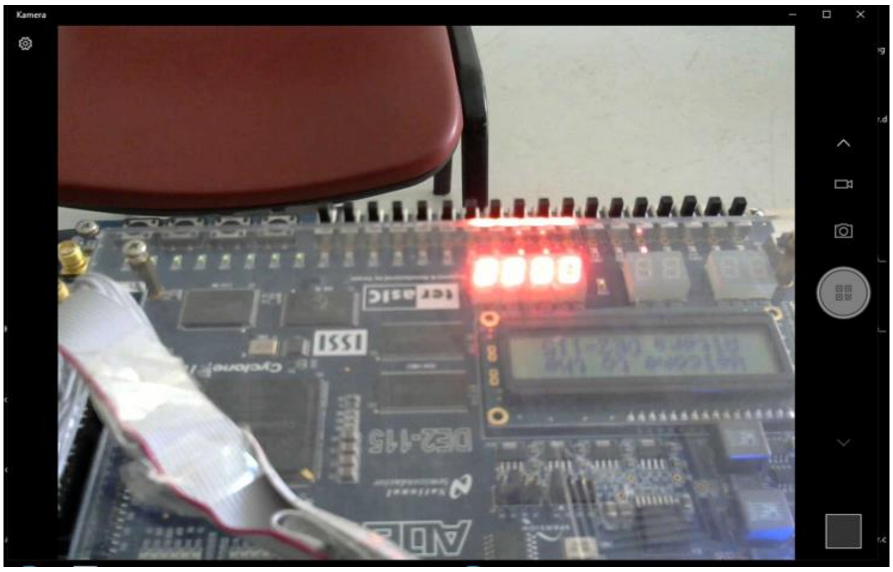


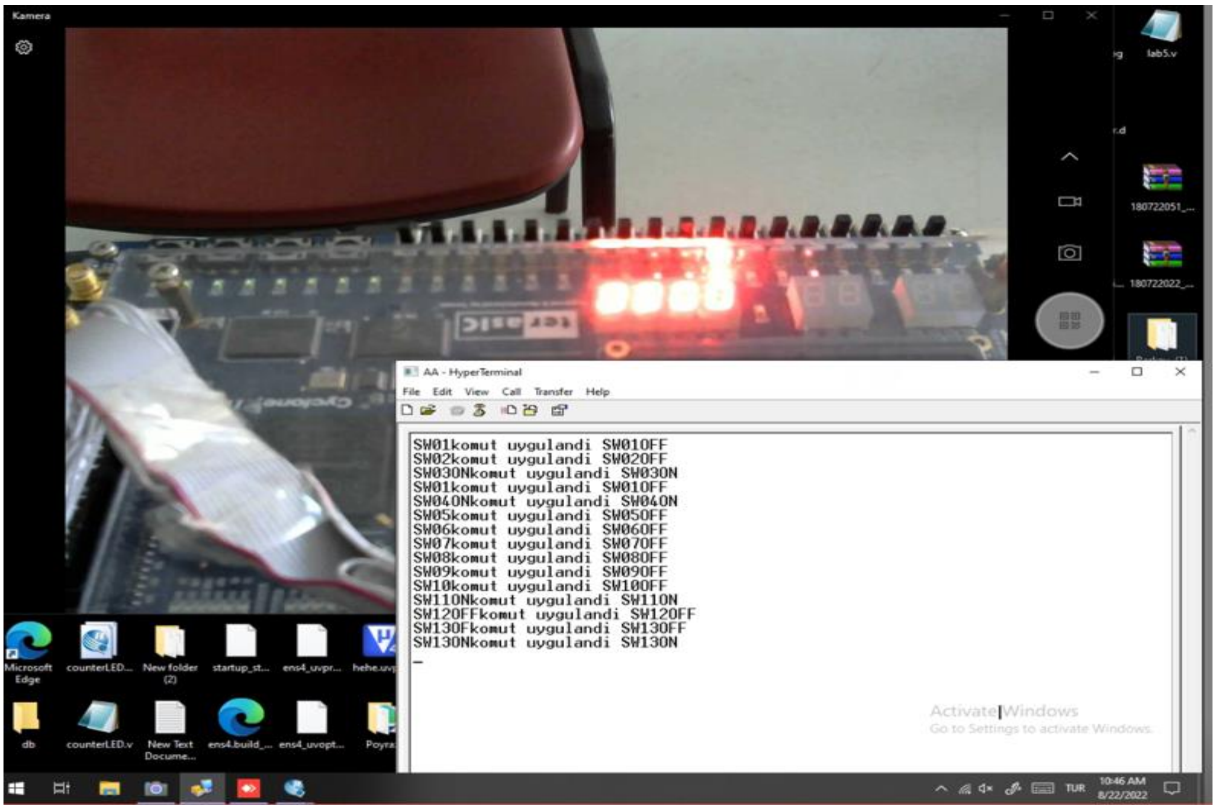
Figure-2: First condition of the FPGA

In the first condition of the FPGA, all LEDs are off and 7-segment is set to 0000. There are totally 18 LEDs in our FPGA. The first 8 left LEDs [0,7] are for the PC. [10, 12] LEDs are for the states; fetch, decode and execute respectively. [14,17] are for the flags; carry, zero, negative and overflow respectively. LED’s 8, 9 and 13 are not used for our project.

After each clock signal to be given to the control unit, the next state will be active. PC increments by one after each fetch state is completed. After each execute state is completed the flags are set and the accumulator keeps the ALU result. In order to write this result to 7-segment, one more state is needed. When the fetch state of the instruction is complete, the accumulator value from the previous instruction is written to the 7-segment.

OPERATION 1:

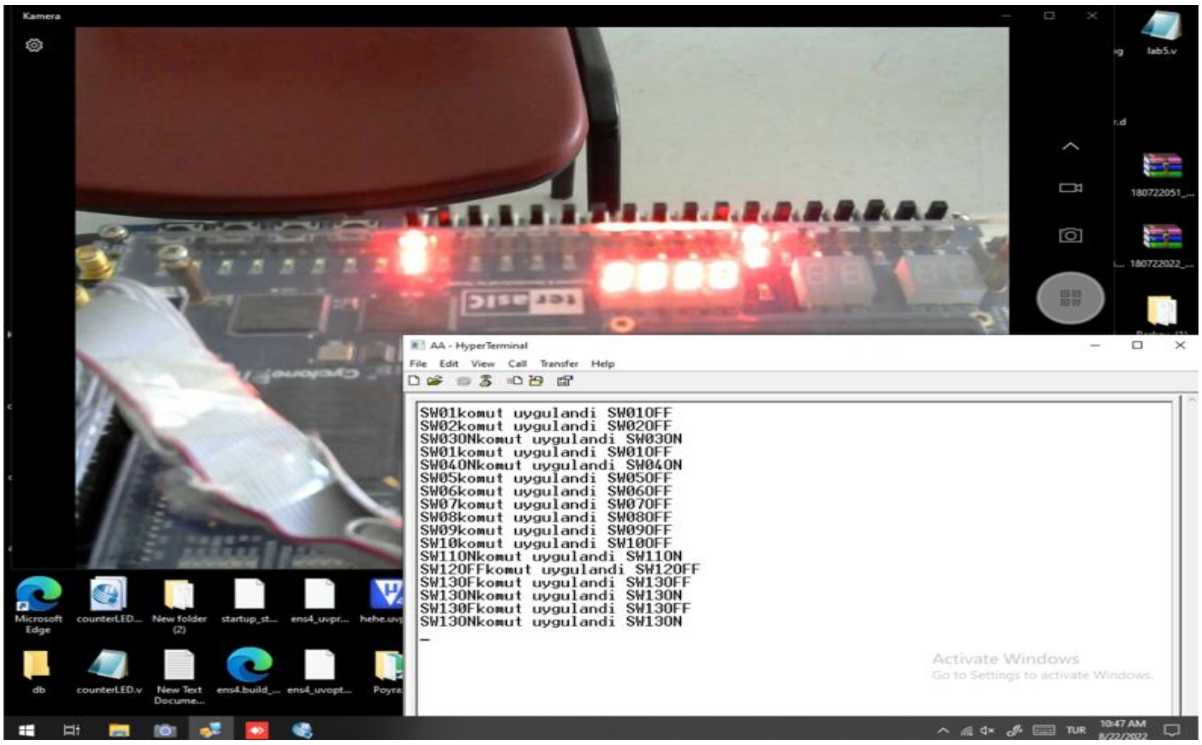
MOVE 12 010000001100(Opcode + value 12) After the operation ACC should be: 12


Kamera
AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.
10:46 AM
8/22/2022

```
SW01komut uygulandi SW01OFF
SW02komut uygulandi SW02OFF
SW03ONkomut uygulandi SW03ON
SW01komut uygulandi SW01OFF
SW04ONkomut uygulandi SW04ON
SW05komut uygulandi SW05OFF
SW06komut uygulandi SW06OFF
SW07komut uygulandi SW07OFF
SW08komut uygulandi SW08OFF
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW12OFFkomut uygulandi SW12OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-3: First Clock of the Operation 1

Current State: Fetch - PC:0 - Flags: 0000 - ACC:0 - 7-Segment: 0

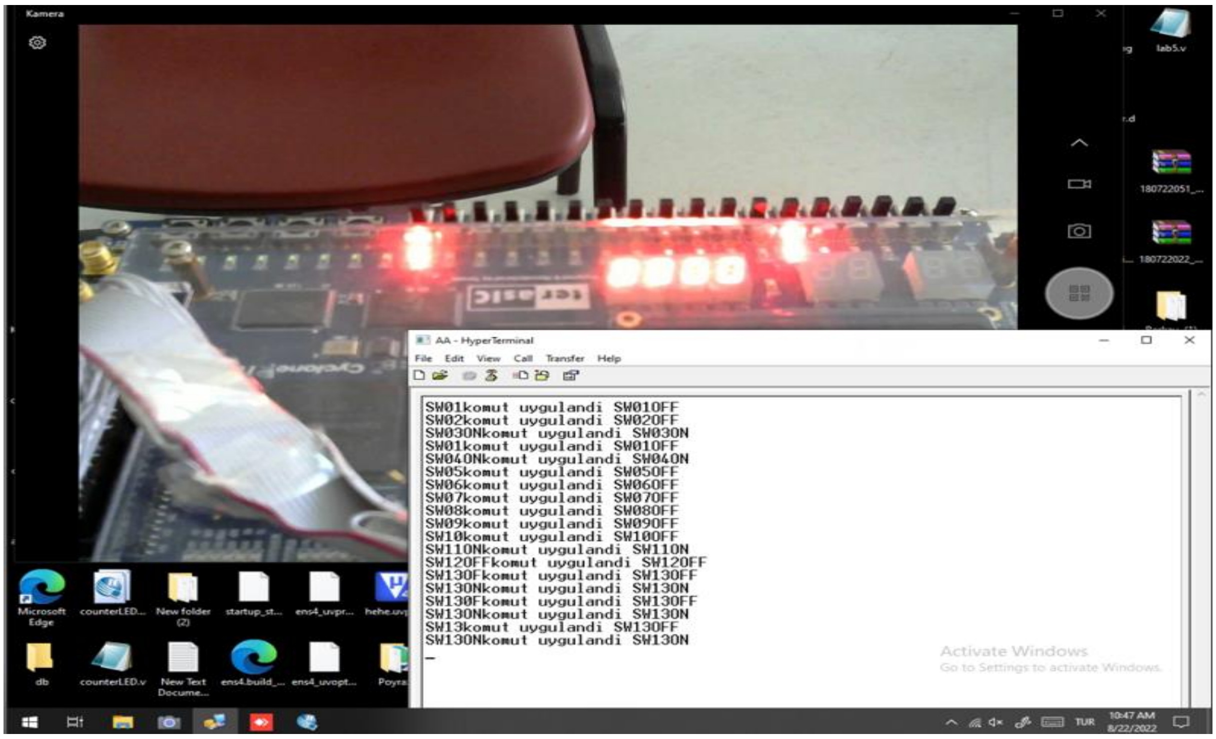


```
SW01komut uygulandi SW01OFF
SW02komut uygulandi SW02OFF
SW03ONkomut uygulandi SW03ON
SW01komut uygulandi SW01OFF
SW04ONkomut uygulandi SW04ON
SW05komut uygulandi SW05OFF
SW06komut uygulandi SW06OFF
SW07komut uygulandi SW07OFF
SW08komut uygulandi SW08OFF
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW12OFFkomut uygulandi SW12OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-4: Second Clock of the Operation 1

Current State: Decode - Completed State: Fetch - PC:1 - Flags: 0000 - ACC: 0

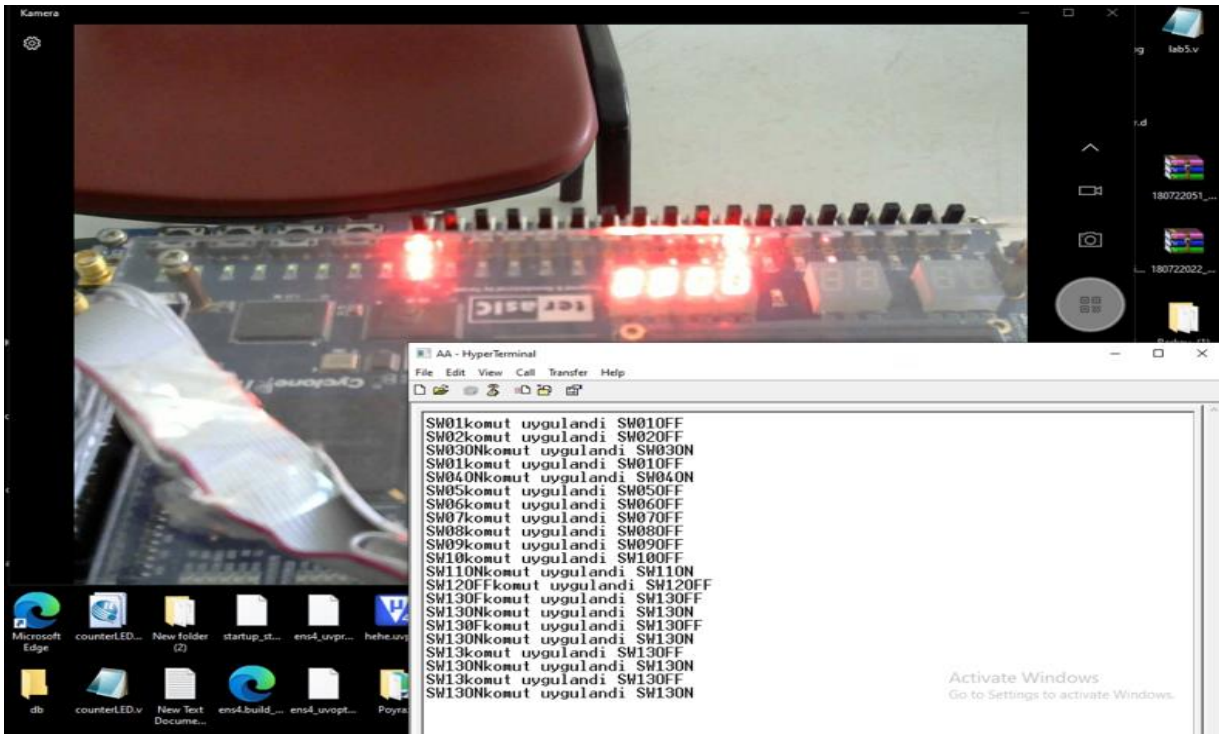
7-Segment: 0



```
SW01komut uygulandi SW01OFF
SW02komut uygulandi SW02OFF
SW03ONkomut uygulandi SW03ON
SW01komut uygulandi SW01OFF
SW04ONkomut uygulandi SW04ON
SW05komut uygulandi SW05OFF
SW06komut uygulandi SW06OFF
SW07komut uygulandi SW07OFF
SW08komut uygulandi SW08OFF
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW12OFFkomut uygulandi SW12OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-5:

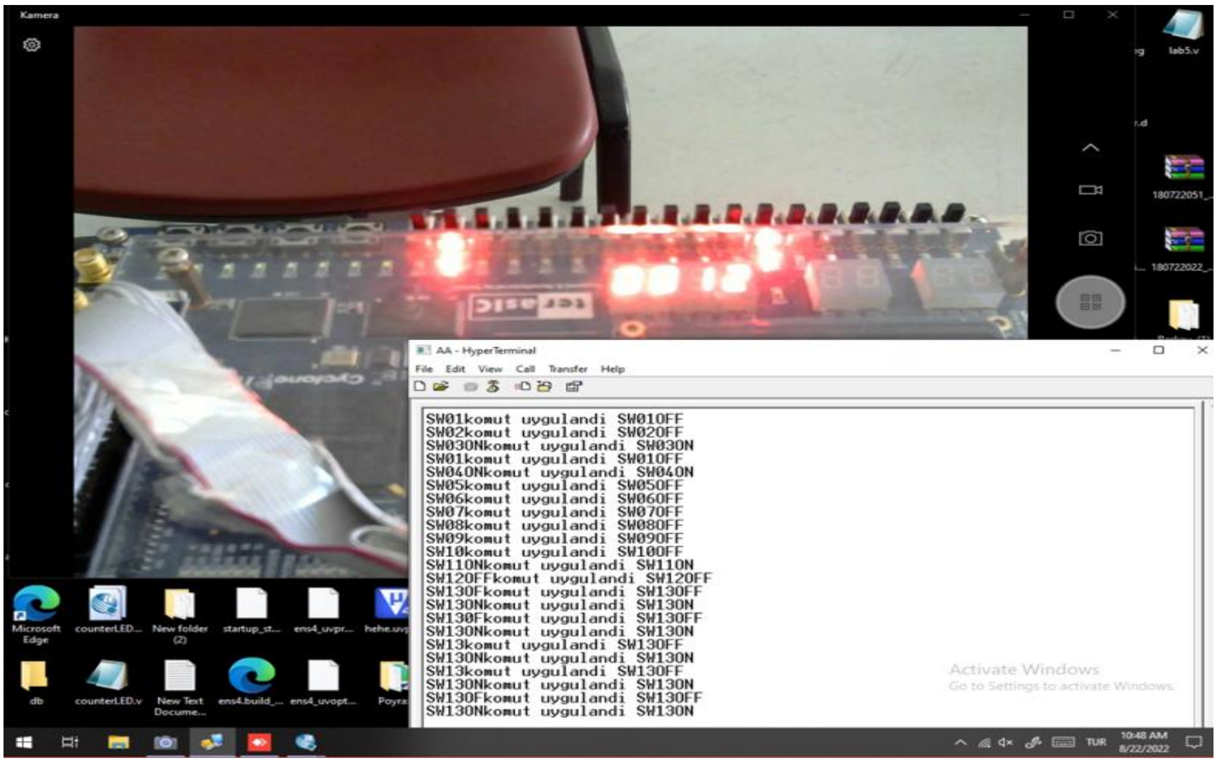
Current State: Execute - Completed State: Decode - PC:1 - Flags: 0000 - ACC: 0
7-Segment: 0


AA - HyperTerminal
File Edit View Call Transfer Help
Kamera
Activate Windows
Go to Settings to activate Windows.

```
SW01komut uygulandi SW010FF
SW02komut uygulandi SW020FF
SW030Nkomut uygulandi SW030N
SW01komut uygulandi SW010FF
SW040Nkomut uygulandi SW040N
SW05komut uygulandi SW050FF
SW06komut uygulandi SW060FF
SW07komut uygulandi SW070FF
SW08komut uygulandi SW080FF
SW09komut uygulandi SW090FF
SW10komut uygulandi SW100FF
SW110Nkomut uygulandi SW110N
SW120FFkomut uygulandi SW120FF
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
```

Figure-6:

Current State: Fetch - Completed State: Execute - PC:1 - Flags: 0000 (Flags are set in this state but all are still zero) - ACC: 12 - 7-Segment: 0



```
SW01komut uygulandi SW01OFF
SW02komut uygulandi SW02OFF
SW03ONkomut uygulandi SW03ON
SW01komut uygulandi SW01OFF
SW04ONkomut uygulandi SW04ON
SW05komut uygulandi SW05OFF
SW06komut uygulandi SW06OFF
SW07komut uygulandi SW07OFF
SW08komut uygulandi SW08OFF
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW12OFFkomut uygulandi SW12OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
```

Figure-7:

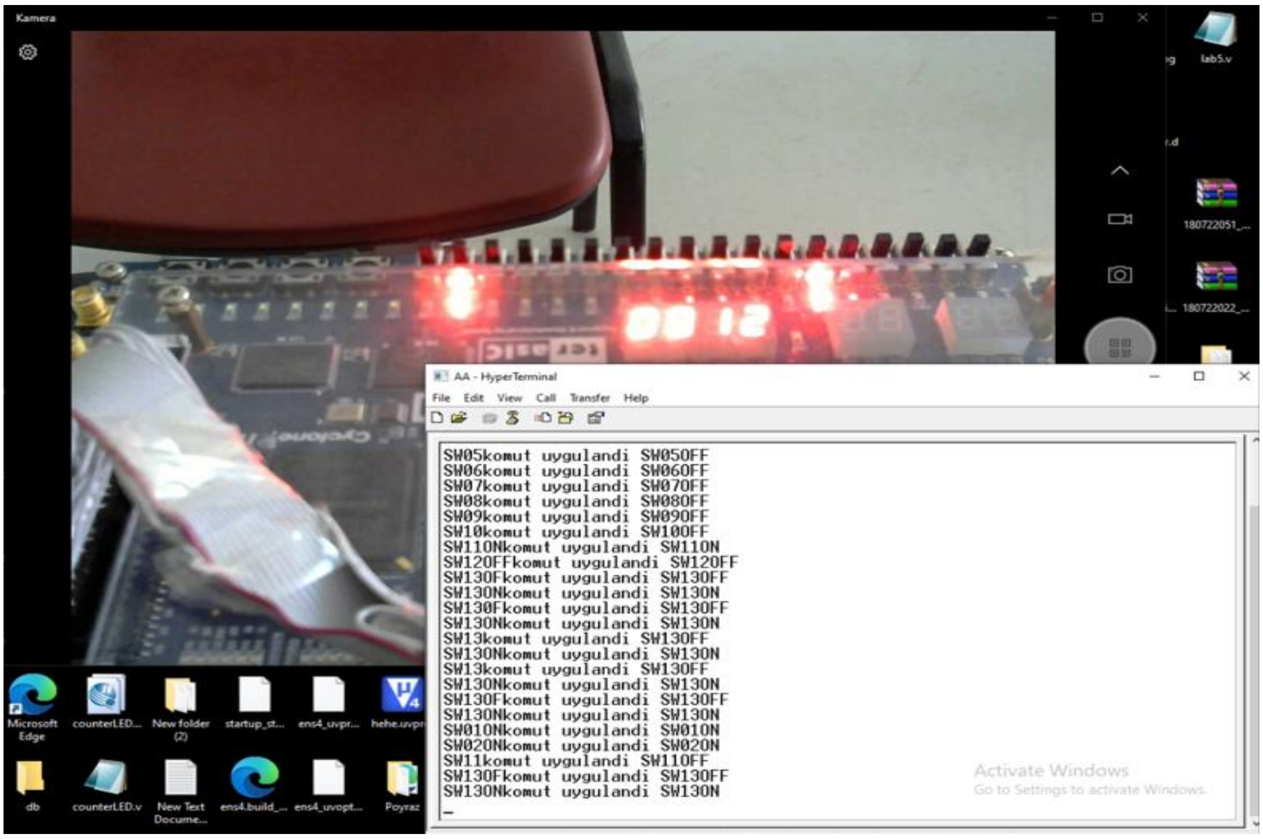
Current State: Decode - Completed State: Fetch - PC:2 - Flags: 0000 - ACC: 12

7-Segment: 12

OPERATION 2:

ADD 15 000000001111(Opcode + value 15) After the operation ACC should be: 27

For this operation, it is enough to open the 1st and 2nd switches and close the 11th switch. Then, we give the Control Unit a new clock, so that the decode state is completed and thus the new input is taken to IR.

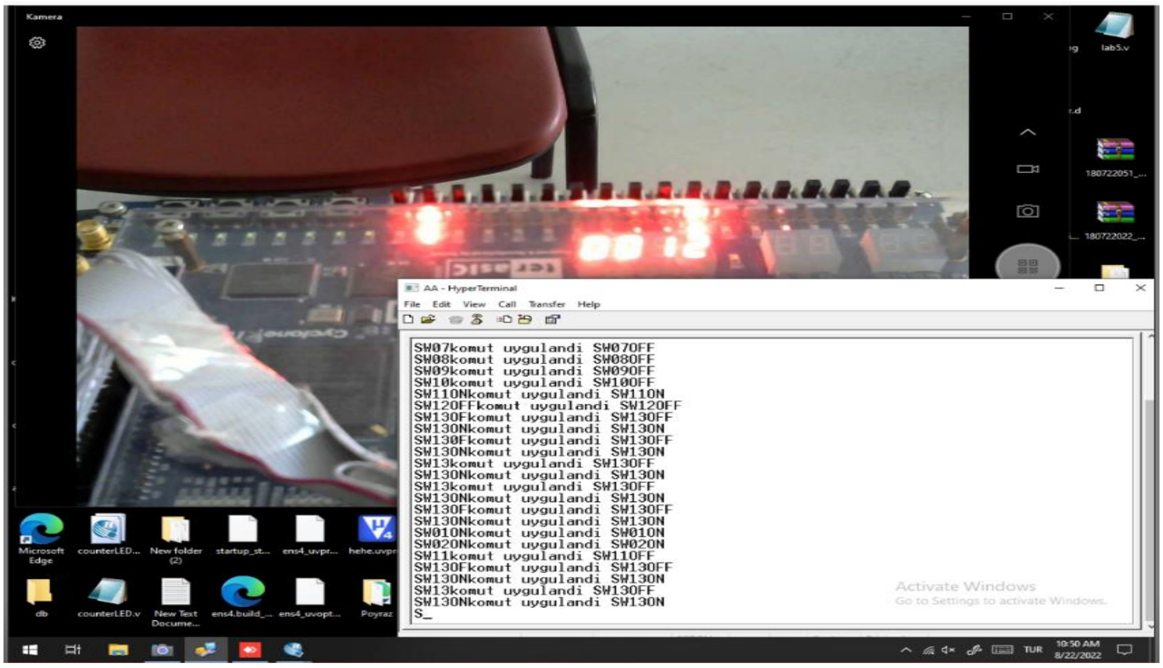


```
SW05komut uygulandi SW05OFF
SW06komut uygulandi SW06OFF
SW07komut uygulandi SW07OFF
SW08komut uygulandi SW08OFF
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW12OFFkomut uygulandi SW12OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW01ONkomut uygulandi SW01ON
SW02ONkomut uygulandi SW02ON
SW11komut uygulandi SW11OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-8:

Current State: Execute - Completed State: Decode - PC:2 - Flags: 0000 - ACC: 12

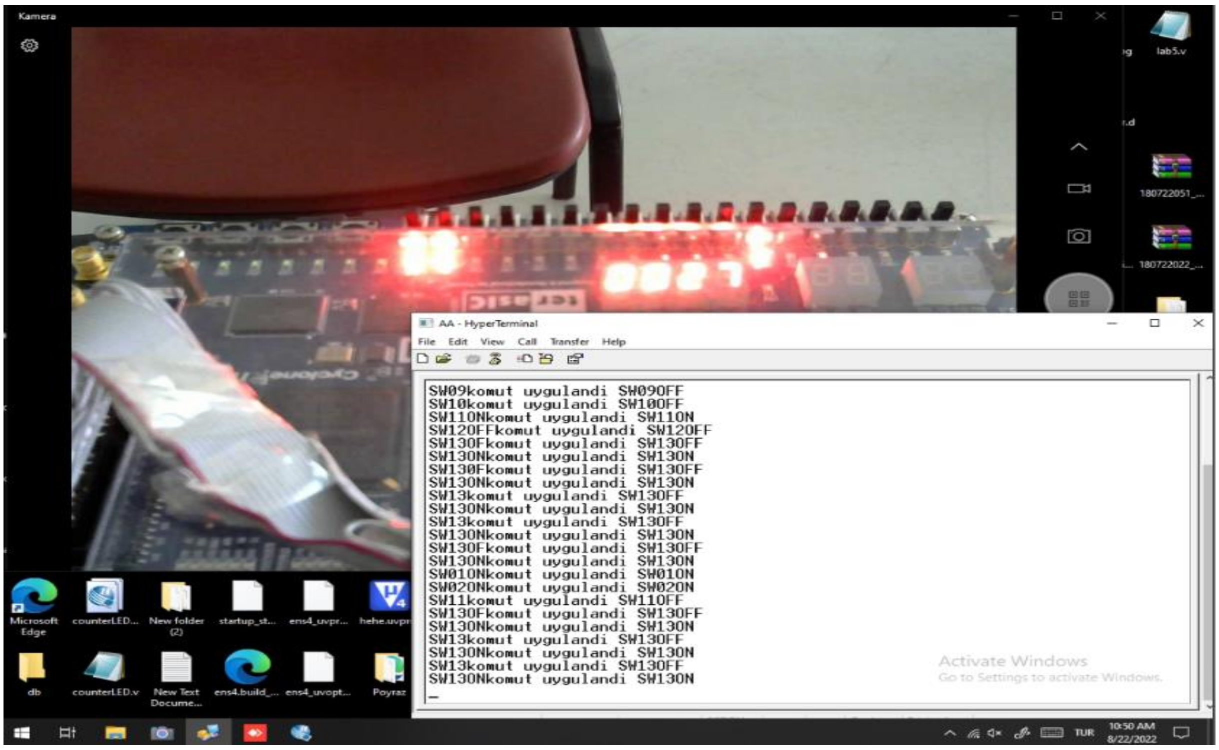
7-Segment: 12



```
SW07komut uygulandi SW07OFF
SW08komut uygulandi SW08OFF
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW12OFFkomut uygulandi SW12OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW01ONkomut uygulandi SW01ON
SW02ONkomut uygulandi SW02ON
SW11komut uygulandi SW11OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
S_
```

Figure-9:

Current State: Fetch - Completed State: Execute - PC:2 - Flags: 0000(Still all zero) ACC: 27 - 7-Segment: 12


Kamera
AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.

```
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW12OFFkomut uygulandi SW12OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW01ONkomut uygulandi SW01ON
SW02ONkomut uygulandi SW02ON
SW11komut uygulandi SW11OFF
SW13OFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

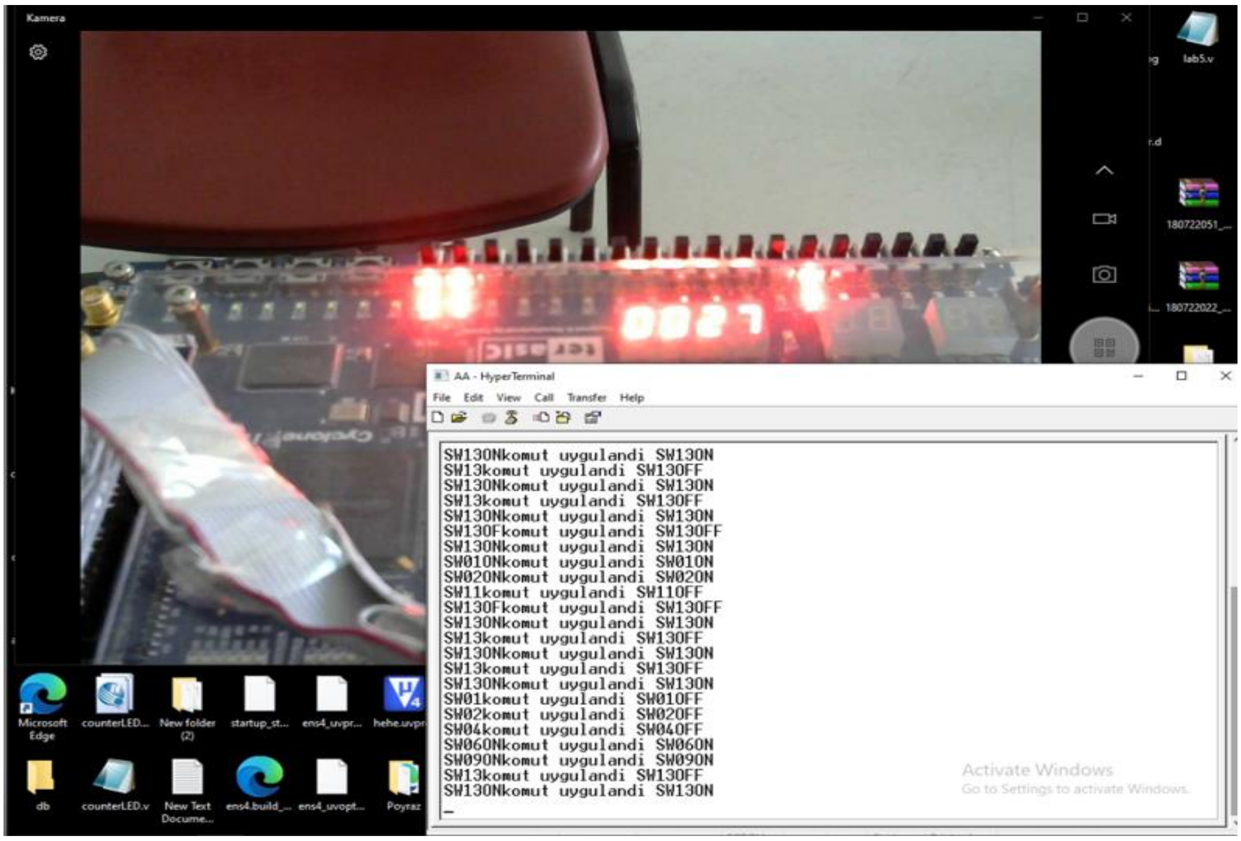
Figure-10:

Current State: Decode - Completed State: Fetch - PC:3 - Flags: 0000 - ACC: 27 7-Segment: 27

OPERATION 3:

SUB 36 000100100100(Opcode + value 36) After the operation ACC should be: 9

For this operation, we opened the 6th and 9th switches and closed the 1st, 2nd and 4th switches. Then, we give the Control Unit a new clock, so that the decode state is completed and thus the new input is taken to IR.

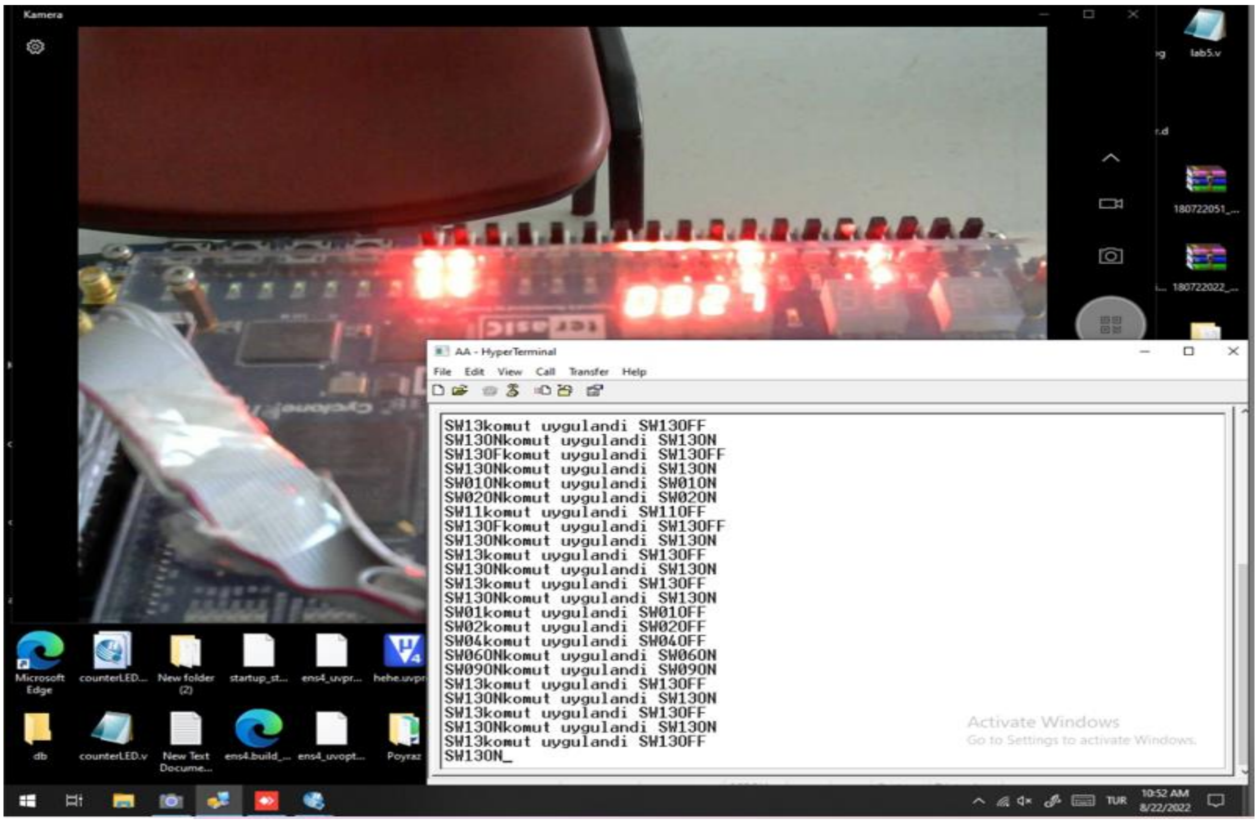


```
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW010Nkomut uygulandi SW010N
SW020Nkomut uygulandi SW020N
SW11komut uygulandi SW110FF
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW01komut uygulandi SW010FF
SW02komut uygulandi SW020FF
SW04komut uygulandi SW040FF
SW060Nkomut uygulandi SW060N
SW090Nkomut uygulandi SW090N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
_
```

Figure-11:

Current State: Execute - Completed State: Decode - PC:3 - Flags: 0000 - ACC: 27

7-Segment: 27

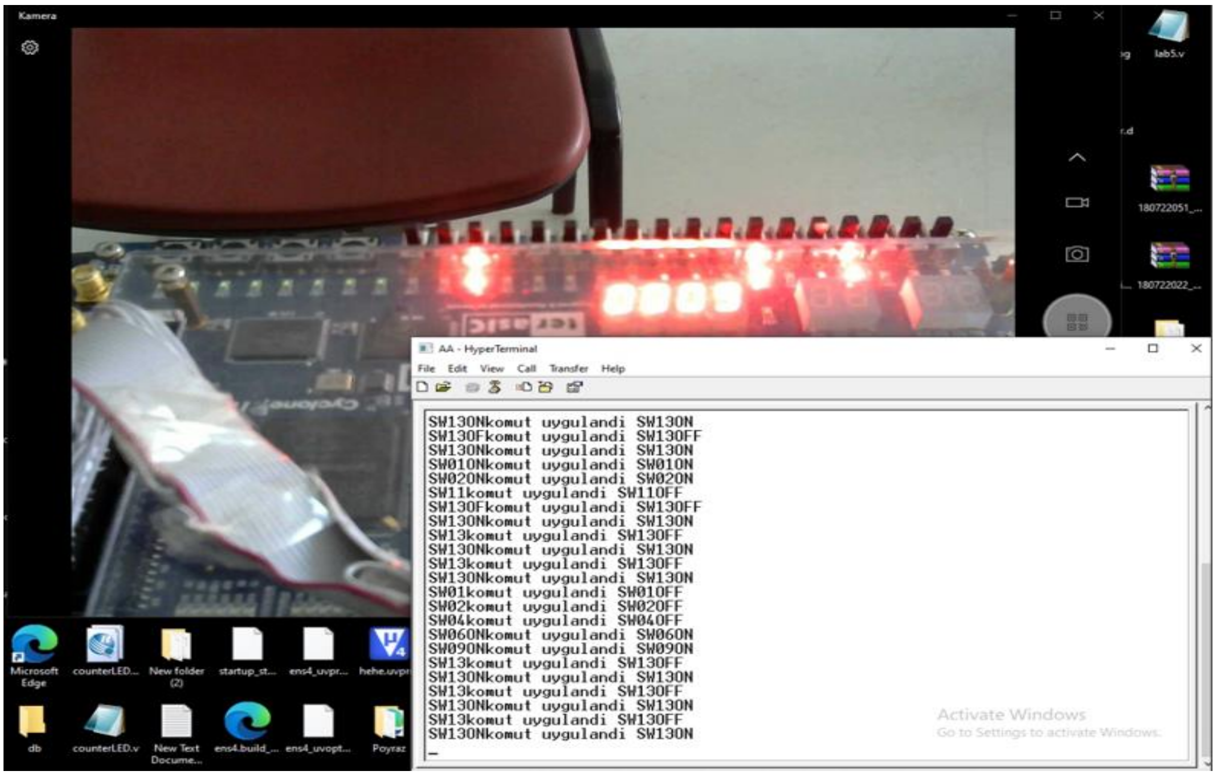

AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.

```
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW010Nkomut uygulandi SW010N
SW020Nkomut uygulandi SW020N
SW11komut uygulandi SW110FF
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW01komut uygulandi SW010FF
SW02komut uygulandi SW020FF
SW04komut uygulandi SW040FF
SW060Nkomut uygulandi SW060N
SW090Nkomut uygulandi SW090N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130N_
```

Figure-12:

Current State: Fetch - Completed State: Execute - PC:3 - Flags: 1000 - ACC: 9

7-Segment: 27


AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.

```
SW130Nkomut uygulandi SW130N
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW010Nkomut uygulandi SW010N
SW020Nkomut uygulandi SW020N
SW11komut uygulandi SW110FF
SW130Fkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW01komut uygulandi SW010FF
SW02komut uygulandi SW020FF
SW04komut uygulandi SW040FF
SW060Nkomut uygulandi SW060N
SW090Nkomut uygulandi SW090N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
_
```

Figure-13:

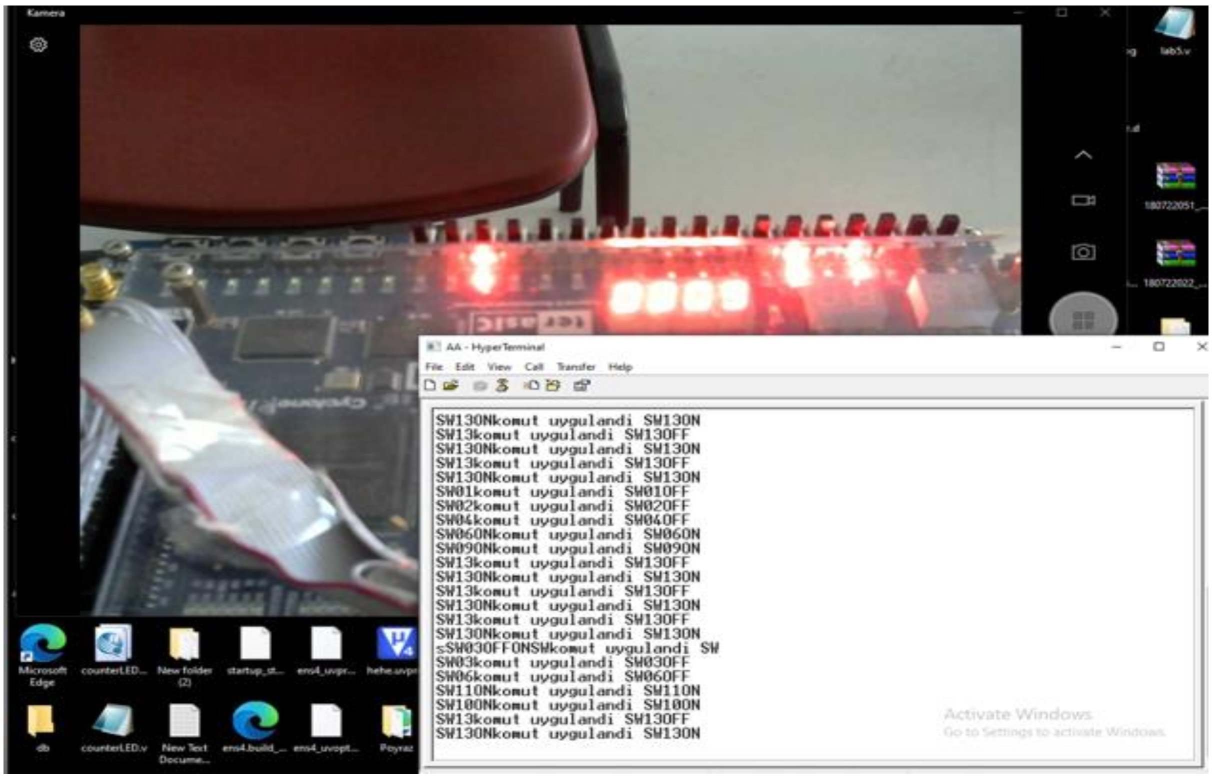
Current State: Decode - Completed State: Fetch - PC:4 - Flags: 1000 - ACC:9

7-Segment: 9

OPERATION 4:

INC 0 011100000000(Opcode + value 0) After the operation ACC should be: 10

For this operation, we opened the 10th and 11th switches and closed the 3rd and 6th switches. Then, we give the Control Unit a new clock, so that the decode state is completed and thus the new input is taken to IR.

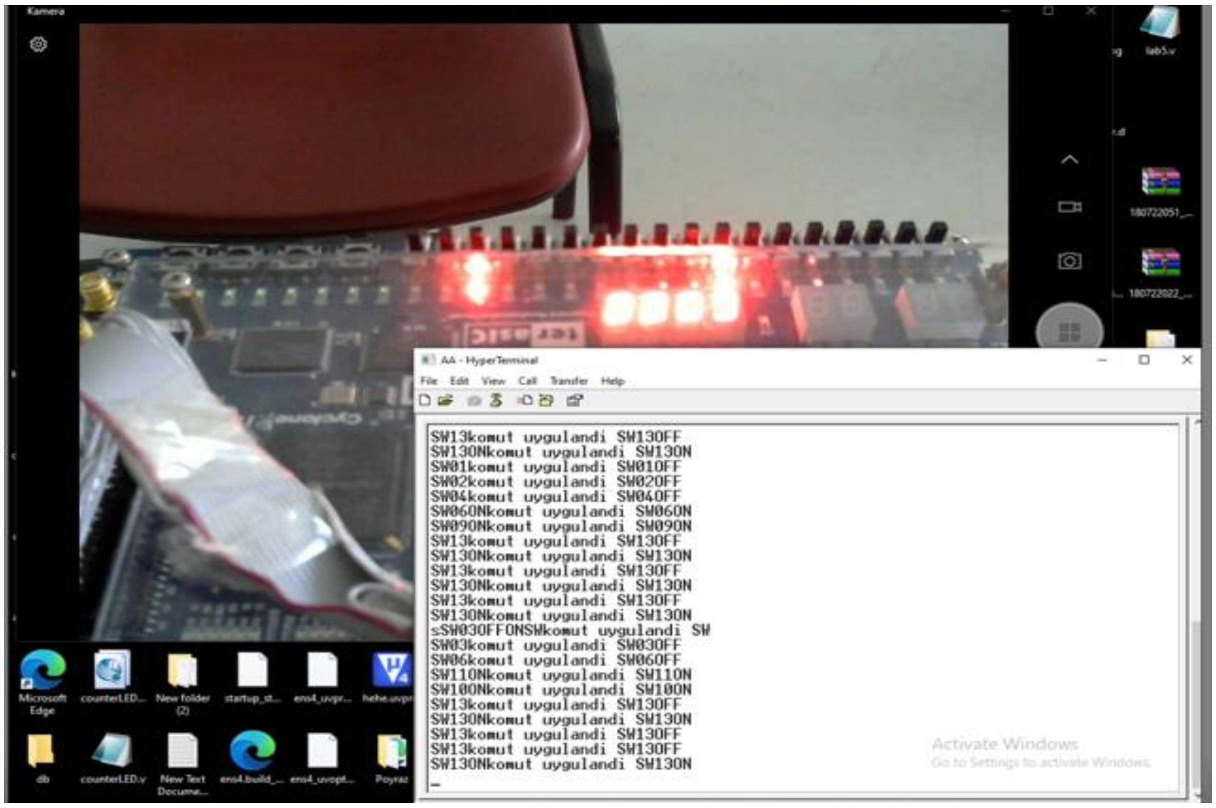

Kamera
AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.

```
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW01komut uygulandi SW010FF
SW02komut uygulandi SW020FF
SW04komut uygulandi SW040FF
SW060Nkomut uygulandi SW060N
SW090Nkomut uygulandi SW090N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
sSW030FFONSWkomut uygulandi SW
SW03komut uygulandi SW030FF
SW06komut uygulandi SW060FF
SW110Nkomut uygulandi SW110N
SW100Nkomut uygulandi SW100N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
```

Figure-14:

Current State: Execute - Completed State: Decode - PC:4 - Flags: 1000 - ACC:9

7-Segment: 9

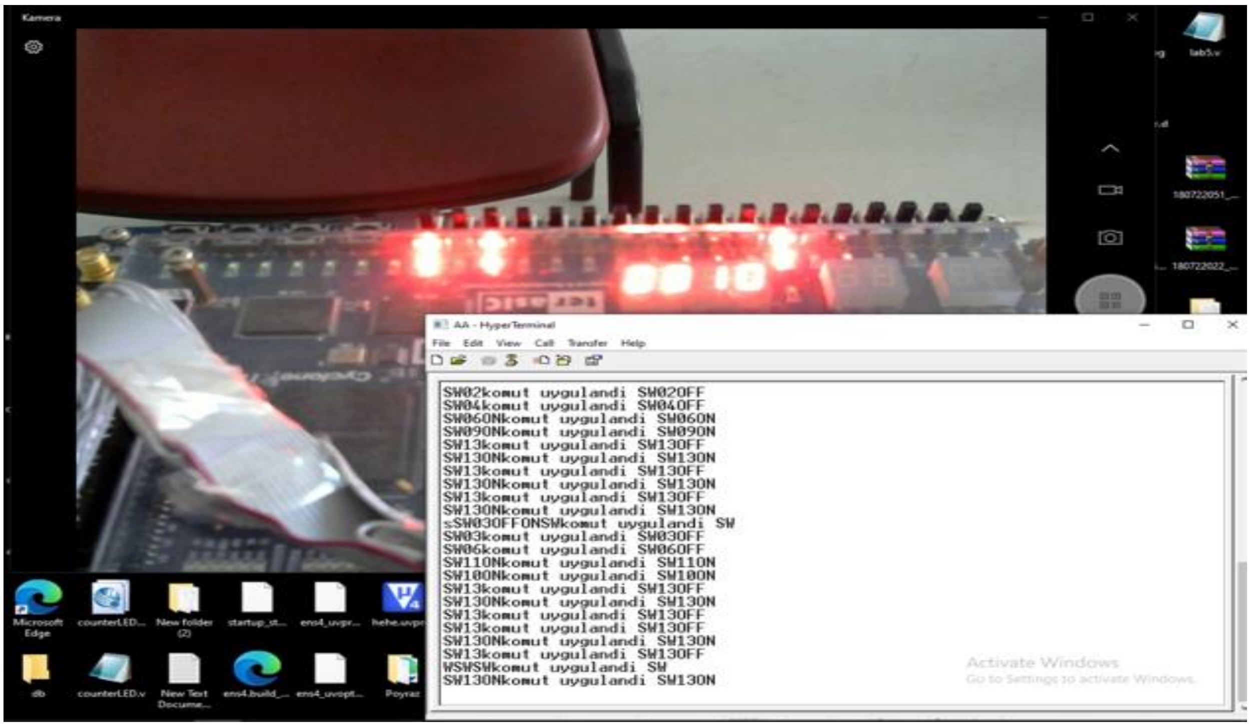


```
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW01komut uygulandi SW01OFF
SW02komut uygulandi SW02OFF
SW04komut uygulandi SW04OFF
SW06ONkomut uygulandi SW06ON
SW09ONkomut uygulandi SW09ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
sSW03OFFONSWkomut uygulandi SW
SW03komut uygulandi SW03OFF
SW06komut uygulandi SW06OFF
SW11ONkomut uygulandi SW11ON
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-15:

Current State: Fetch - Completed State: Execute - PC:4 - Flags: 0000 - ACC:10

7-Segment: 9



```
SW02komut uygulandi SW02OFF
SW04komut uygulandi SW04OFF
SW06ONkomut uygulandi SW06ON
SW09ONkomut uygulandi SW09ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
sSW03OFFONSWkomut uygulandi SW
SW03komut uygulandi SW03OFF
SW06komut uygulandi SW06OFF
SW11ONkomut uygulandi SW11ON
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
WSWSWkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
```

Figure-16:

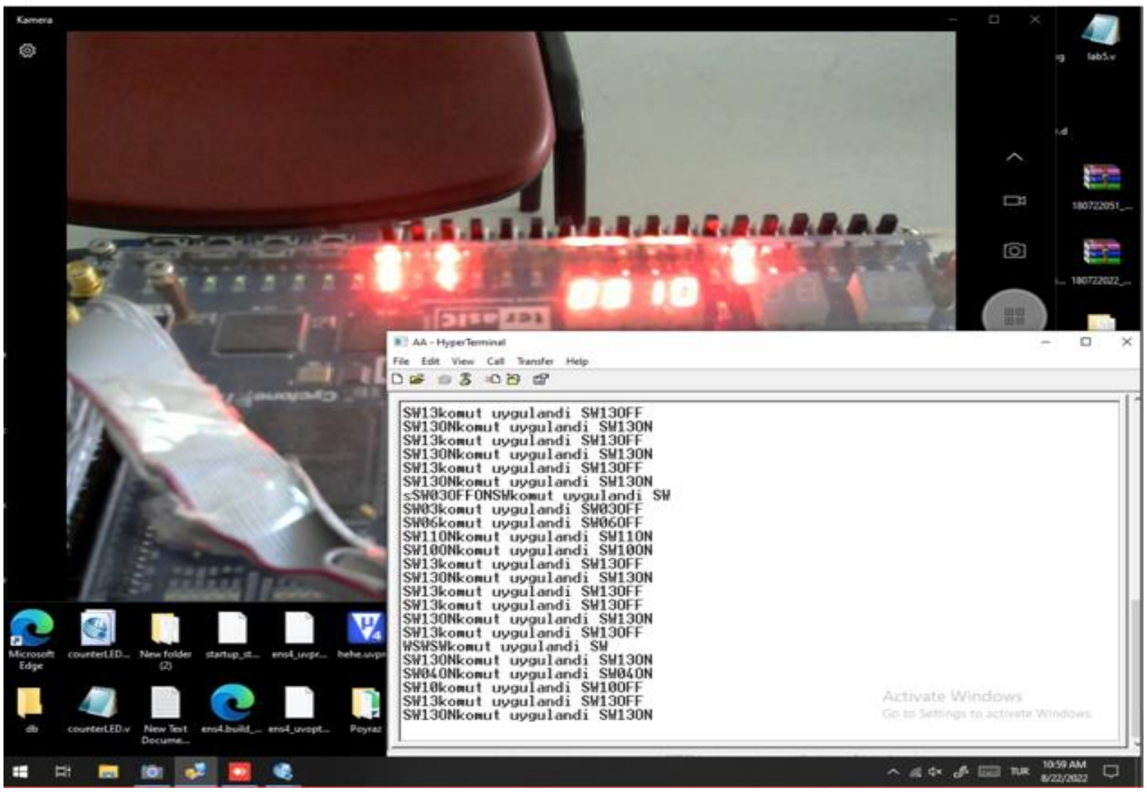
Current State: Decode - Completed State: Fetch - PC:5 - Flags: 0000 - ACC:10

7-Segment: 10

OPERATION 5:

SHFL 8 010100001000 (Opcode + value 8) After the operation ACC should be: 16

For this operation, we opened the 4th switch and closed the 10th switch. Then, we give the Control Unit a new clock, so that the decode state is completed and thus the new input is taken to IR.



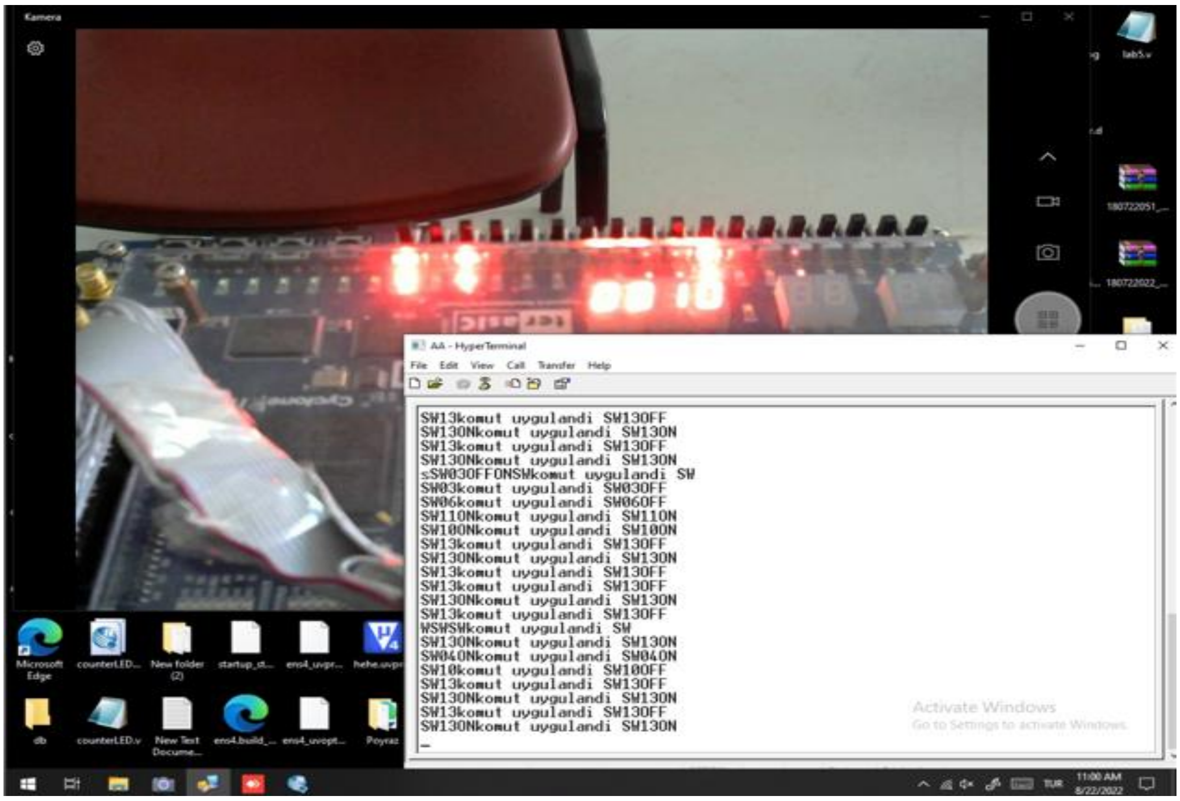
Kamera
AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.
10:59 AM
8/22/2022

```
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
sSW03OFFONSWkomut uygulandi SW
SW03komut uygulandi SW03OFF
SW06komut uygulandi SW06OFF
SW11ONkomut uygulandi SW11ON
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
WSWSWkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW04ONkomut uygulandi SW04ON
SW10komut uygulandi SW10OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
```

Figure-17:

Current State: Execute - Completed State: Decode - PC:5 - Flags: 0000 - ACC:10

7-Segment: 10

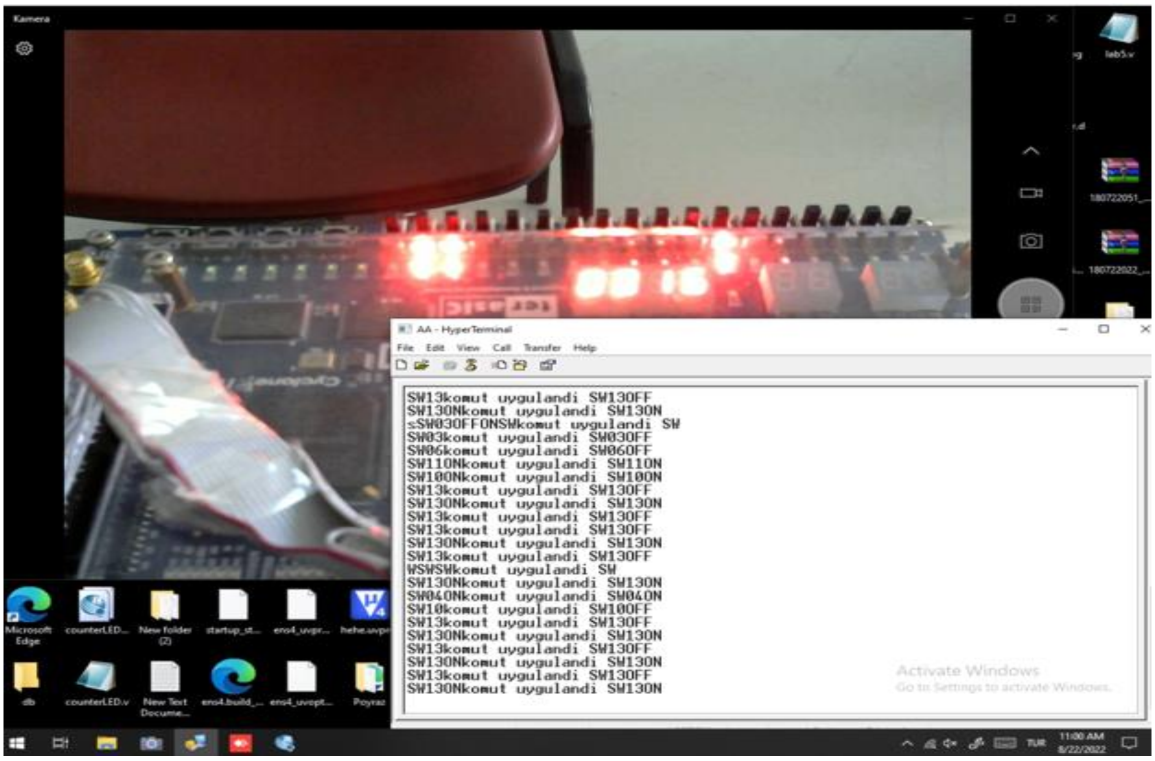


```
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
≤SW03OFFONSWkomut uygulandi SW
SW03komut uygulandi SW03OFF
SW06komut uygulandi SW06OFF
SW11ONkomut uygulandi SW11ON
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
WSWSWkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW04ONkomut uygulandi SW04ON
SW10komut uygulandi SW10OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-18:

Current State: Fetch - Completed State: Execute - PC:5 - Flags: 0000 - ACC:16

7-Segment: 10



```
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
≤SW03OFFONSWkomut uygulandi SW
SW03komut uygulandi SW03OFF
SW06komut uygulandi SW06OFF
SW11ONkomut uygulandi SW11ON
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
WSWSWkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW04ONkomut uygulandi SW04ON
SW10komut uygulandi SW10OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
```

Figure-19:

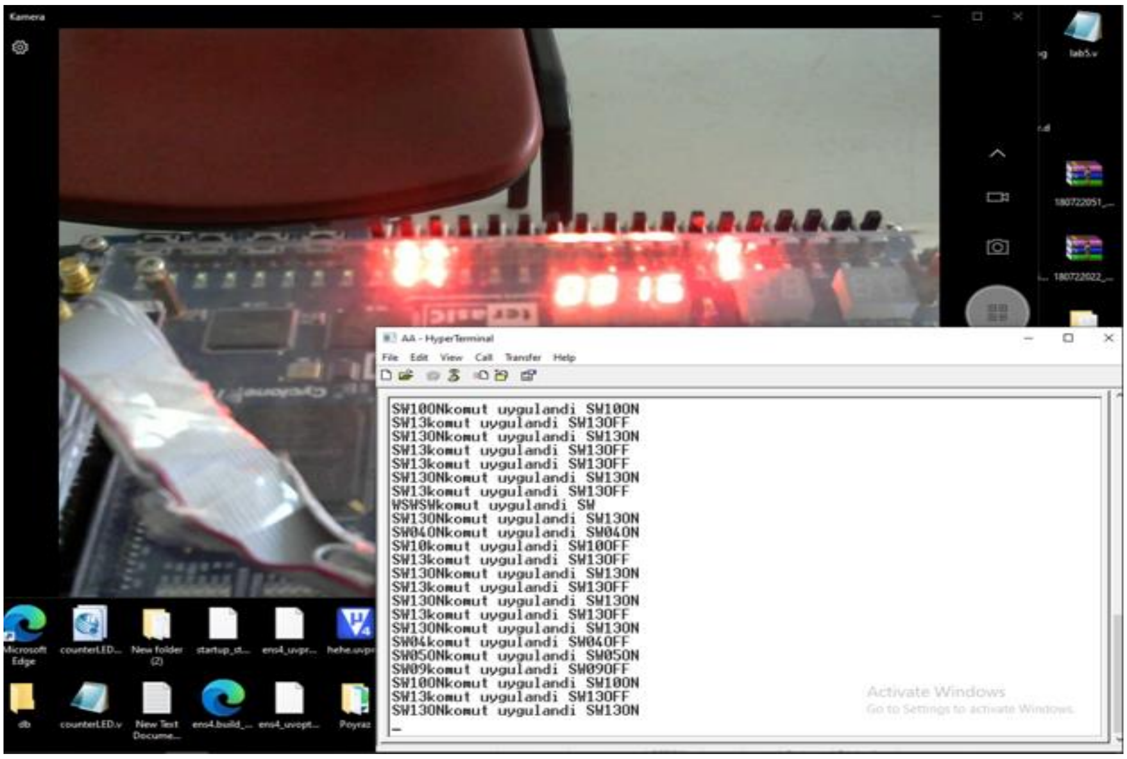
Current State: Decode - Completed State: Fetch - PC:6 - Flags: 0000 - ACC:16

7-Segment: 16

OPERATION 6:

SHFR 16 011000010000 (Opcode + value 16) After the operation ACC should be: 8

For this operation, we opened the 5th and 10th switches and closed the 4th and 9th switches. Then, we give the Control Unit a new clock, so that the decode state is completed and thus the new input is taken to IR.

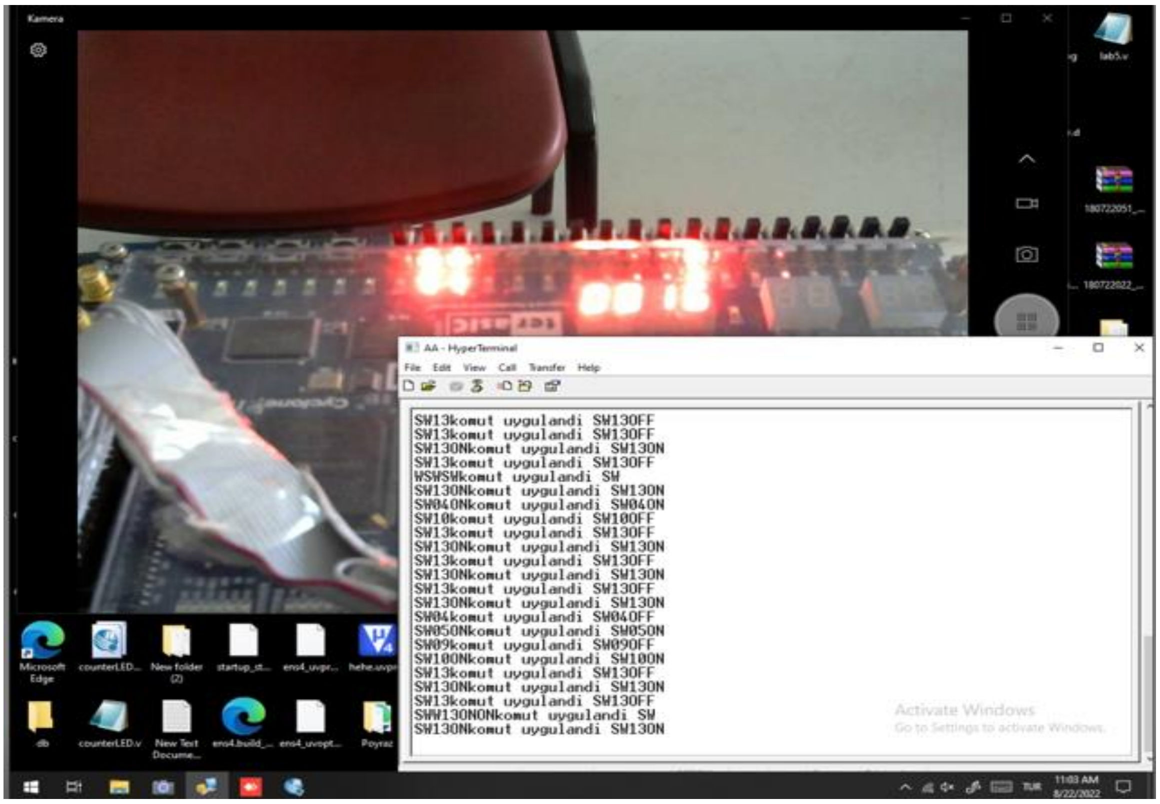


```
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
WSWSWkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW04ONkomut uygulandi SW04ON
SW10komut uygulandi SW10OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW04komut uygulandi SW04OFF
SW05ONkomut uygulandi SW05ON
SW09komut uygulandi SW09OFF
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-20:

Current State: Execute - Completed State: Decode - PC:6 - Flags: 0000 - ACC:16

7-Segment: 16

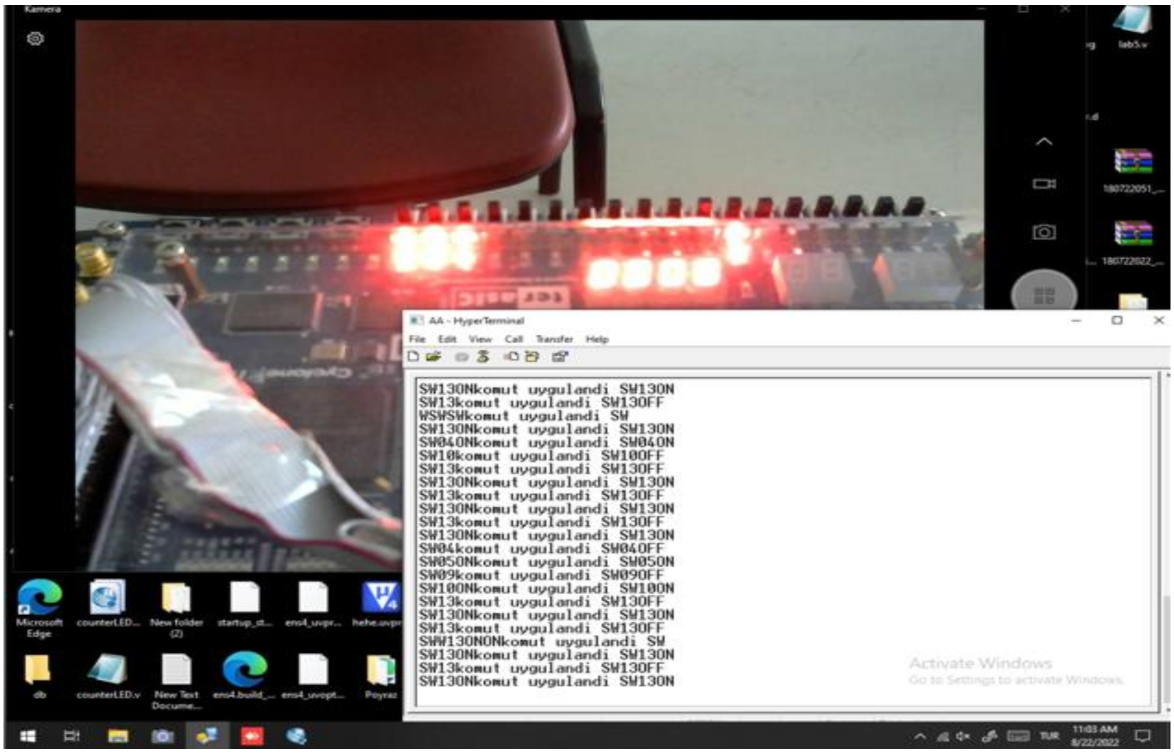


```
SW13komut uygulandi SW13OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
WSWSWkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW04ONkomut uygulandi SW04ON
SW10komut uygulandi SW10OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW04komut uygulandi SW04OFF
SW05ONkomut uygulandi SW05ON
SW09komut uygulandi SW09OFF
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SWW13ONONkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
```

Figure-21:

Current State: Fetch - Completed State: Execute - PC:6 - Flags: 0000 (not changed)

ACC: 8 - 7-Segment: 16



```
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
WSWSWkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW04ONkomut uygulandi SW04ON
SW10komut uygulandi SW10OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW04komut uygulandi SW04OFF
SW05ONkomut uygulandi SW05ON
SW09komut uygulandi SW09OFF
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SWW13ONONkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
```

Figure-22:

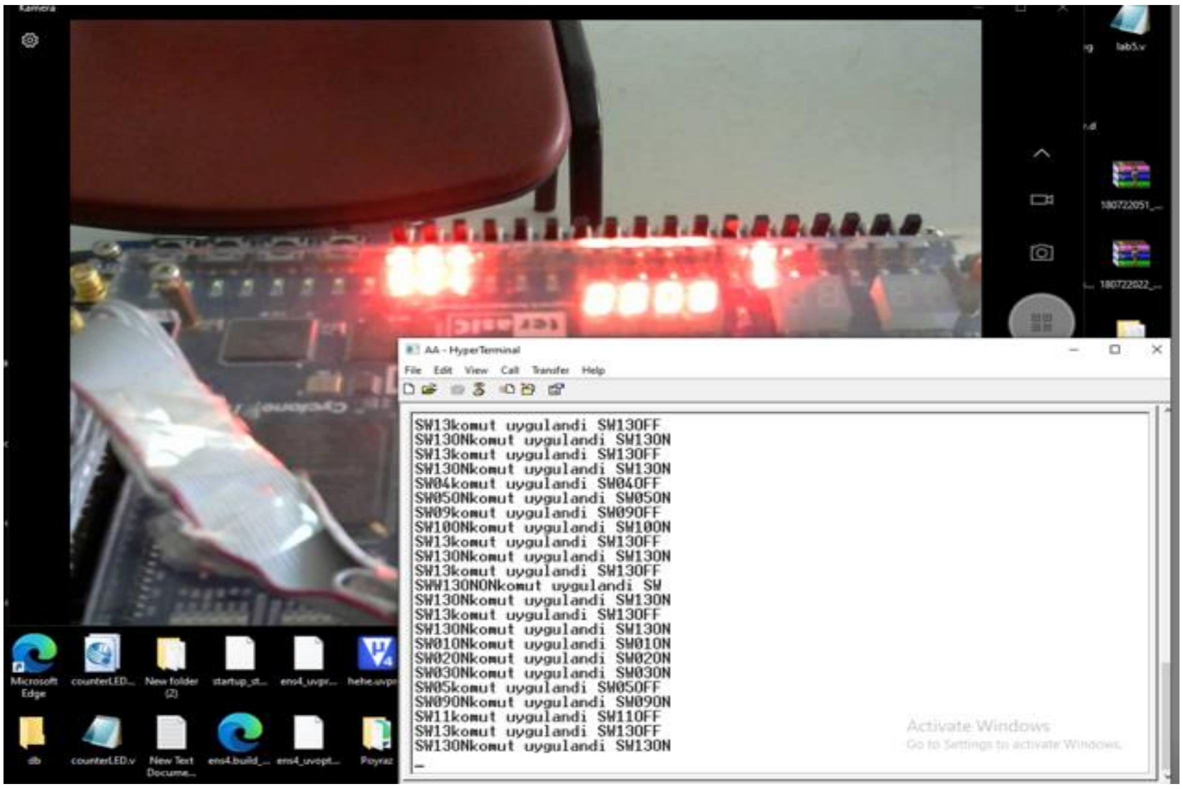
Current State: Decode - Completed State: Fetch - PC:7 - Flags: 0000 ACC: 8

7-Segment: 8

OPERATION 7:

OR 7 001100000111 (Opcode + value 7) After the operation ACC should be: 15

For this operation, we opened the 1st, 2nd, 3rd and 9th switches and closed the 5th and 11th switches. Then, we give the Control Unit a new clock, so that the decode state is completed and thus the new input is taken to IR.

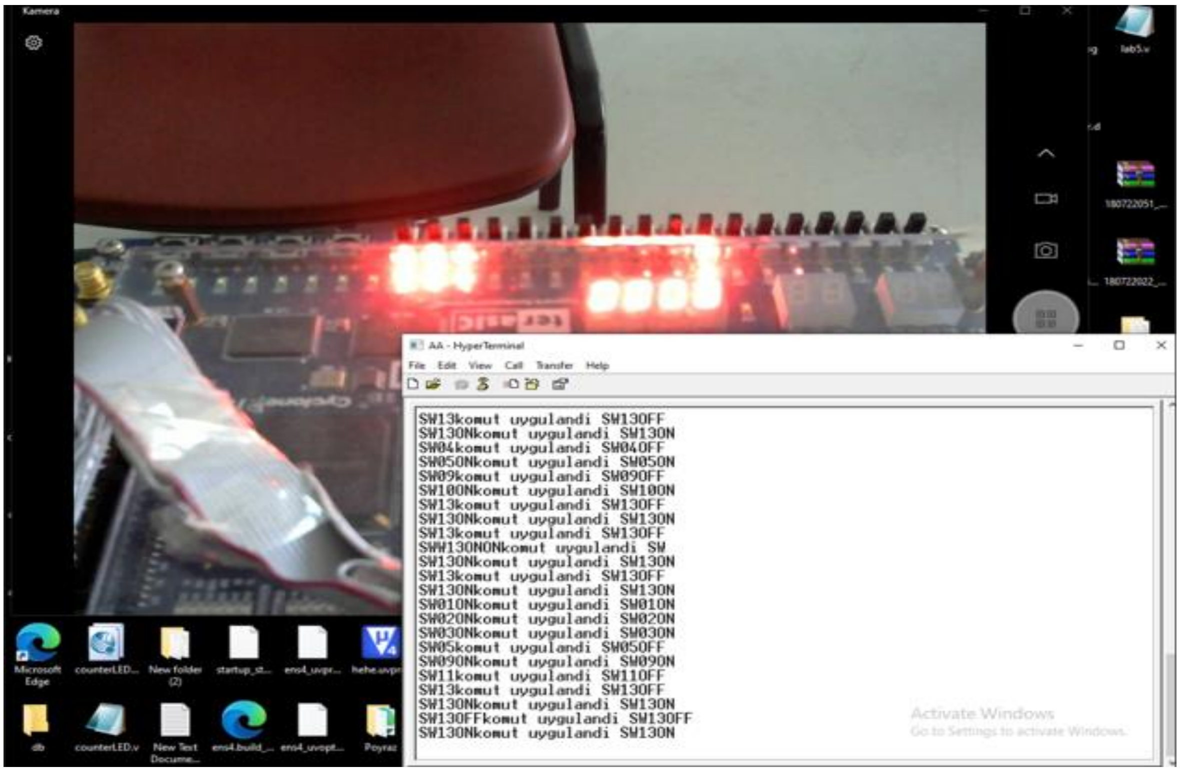

AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.

```
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW04komut uygulandi SW04OFF
SW05ONkomut uygulandi SW05ON
SW09komut uygulandi SW09OFF
SW10ONkomut uygulandi SW10ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SWW13ONONkomut uygulandi SW
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW01ONkomut uygulandi SW01ON
SW02ONkomut uygulandi SW02ON
SW03ONkomut uygulandi SW03ON
SW05komut uygulandi SW05OFF
SW09ONkomut uygulandi SW09ON
SW11komut uygulandi SW11OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-23:

Current State: Execute - Completed State: Decode - PC:7 - Flags: 0000 ACC:8

7-Segment: 8

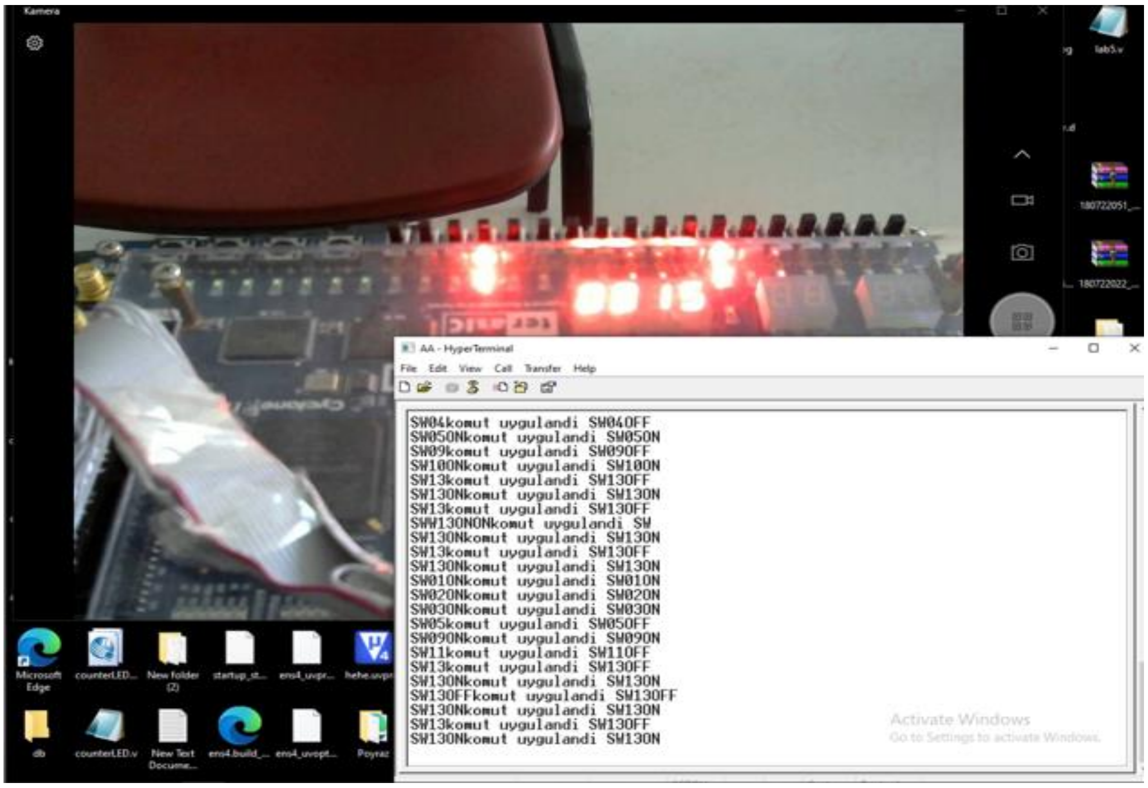


```
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW04komut uygulandi SW040FF
SW050Nkomut uygulandi SW050N
SW09komut uygulandi SW090FF
SW100Nkomut uygulandi SW100N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SWW130NONkomut uygulandi SW
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW010Nkomut uygulandi SW010N
SW020Nkomut uygulandi SW020N
SW030Nkomut uygulandi SW030N
SW05komut uygulandi SW050FF
SW090Nkomut uygulandi SW090N
SW11komut uygulandi SW110FF
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW130FFkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
```

Figure-24:

Current State: Fetch - Completed State: Execute - PC:7 - Flags: 0000(not changed)

ACC: 15 7-Segment: 8



```
SW04komut uygulandi SW040FF
SW050Nkomut uygulandi SW050N
SW09komut uygulandi SW090FF
SW100Nkomut uygulandi SW100N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SWW130NONkomut uygulandi SW
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW010Nkomut uygulandi SW010N
SW020Nkomut uygulandi SW020N
SW030Nkomut uygulandi SW030N
SW05komut uygulandi SW050FF
SW090Nkomut uygulandi SW090N
SW11komut uygulandi SW110FF
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW130FFkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
```

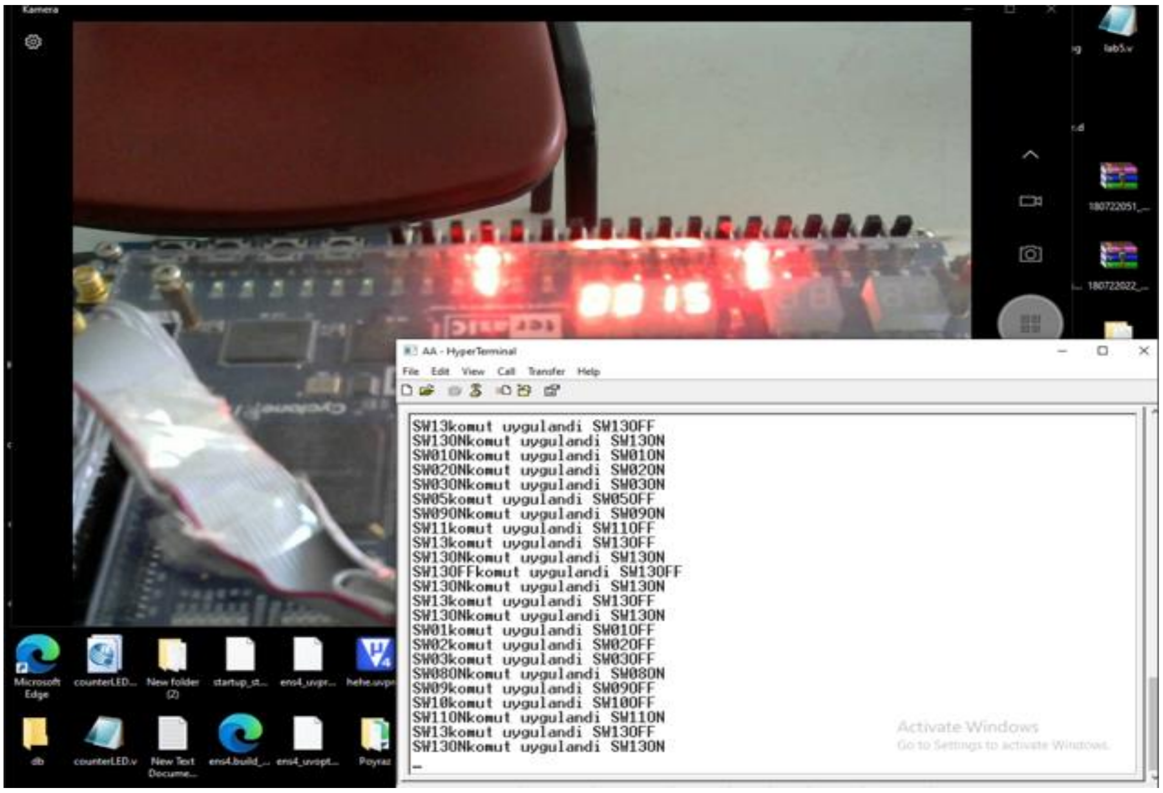
Figure-25:

Current State: Decode - Completed State: Fetch - PC:8 - Flags: 0000 - ACC: 15
7-Segment: 15

OPERATION 8:

MOVE -128 010010000000 (Opcode + value -128) After the operation ACC should be: -128

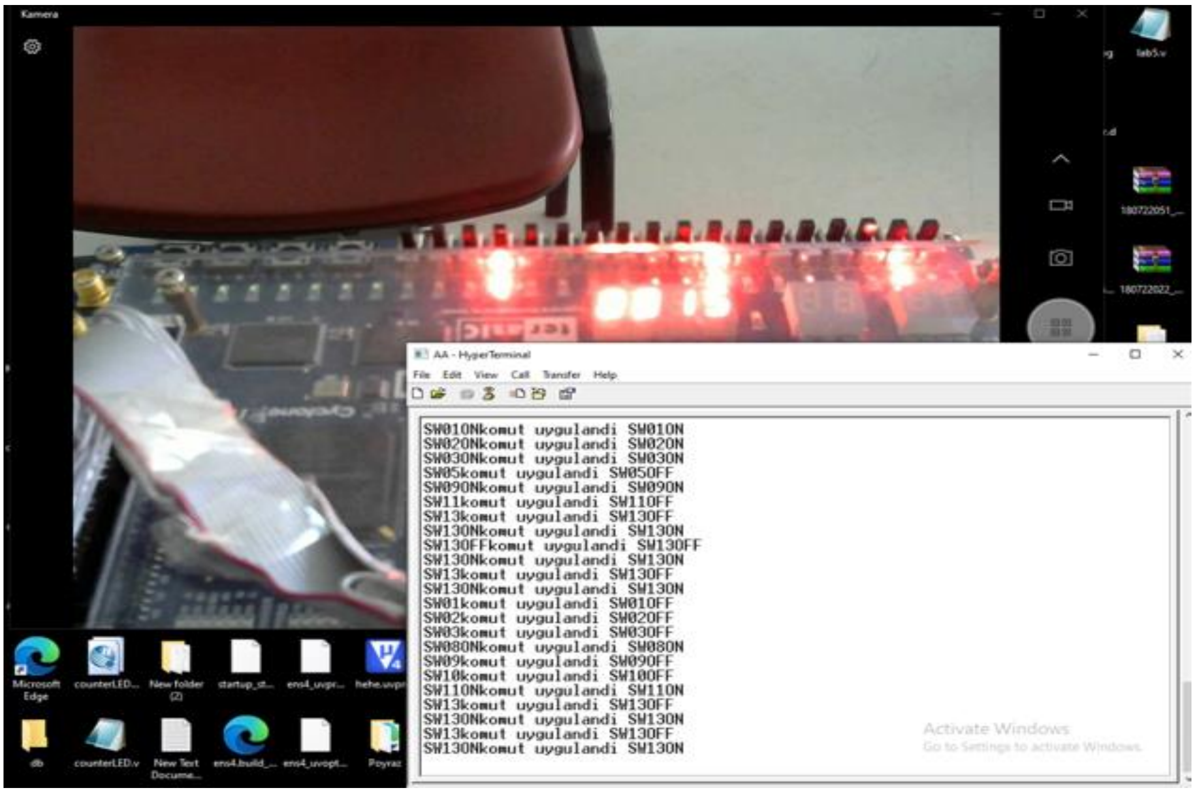
For this operation, we opened the 8th and 11th switches and closed the 1st, 2nd, 3rd, 9th and 10th switches. Then, we give the Control Unit a new clock, so that the decode state is completed and thus the new input is taken to IR.



```
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW01ONkomut uygulandi SW01ON
SW02ONkomut uygulandi SW02ON
SW03ONkomut uygulandi SW03ON
SW05komut uygulandi SW05OFF
SW09ONkomut uygulandi SW09ON
SW11komut uygulandi SW11OFF
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13OFFkomut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
SW01komut uygulandi SW01OFF
SW02komut uygulandi SW02OFF
SW03komut uygulandi SW03OFF
SW08ONkomut uygulandi SW08ON
SW09komut uygulandi SW09OFF
SW10komut uygulandi SW10OFF
SW11ONkomut uygulandi SW11ON
SW13komut uygulandi SW13OFF
SW13ONkomut uygulandi SW13ON
_
```

Figure-26:

Current State: Execute - Completed State: Decode - PC:8 - Flags: 0000 - ACC:15
7-Segment: 15

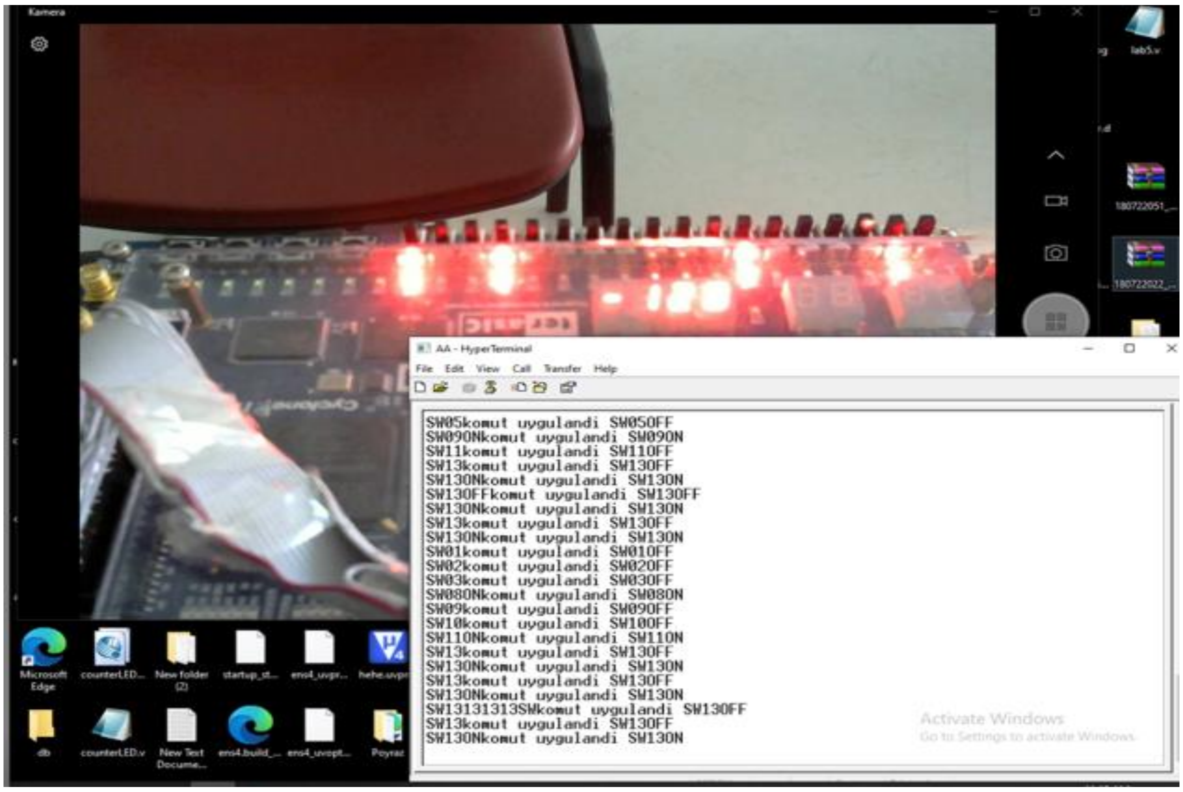

AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.

```
SW010Nkomut uygulandi SW010N
SW020Nkomut uygulandi SW020N
SW030Nkomut uygulandi SW030N
SW05komut uygulandi SW050FF
SW090Nkomut uygulandi SW090N
SW11komut uygulandi SW110FF
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW130FFkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW01komut uygulandi SW010FF
SW02komut uygulandi SW020FF
SW03komut uygulandi SW030FF
SW080Nkomut uygulandi SW080N
SW09komut uygulandi SW090FF
SW10komut uygulandi SW100FF
SW110Nkomut uygulandi SW110N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
```

Figure-27:

Current State: Fetch - Completed State: Execute - PC:8 - Flags: 0010 - ACC:-128

7-Segment: 15


AA - HyperTerminal
File Edit View Call Transfer Help
Activate Windows
Go to Settings to activate Windows.

```
SW05komut uygulandi SW050FF
SW090Nkomut uygulandi SW090N
SW11komut uygulandi SW110FF
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW130FFkomut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW01komut uygulandi SW010FF
SW02komut uygulandi SW020FF
SW03komut uygulandi SW030FF
SW080Nkomut uygulandi SW080N
SW09komut uygulandi SW090FF
SW10komut uygulandi SW100FF
SW110Nkomut uygulandi SW110N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
SW1313131 3SWkomut uygulandi SW130FF
SW13komut uygulandi SW130FF
SW130Nkomut uygulandi SW130N
```

Figure-28:

```
Current State: Decode   -   Completed State: Fetch   -    PC:9   -    Flags: 0010    -    ACC: -128
 7-Segment: -128
```