Міністерство освіти і науки України

Національний університет «Львівська політехніка»

Кафедра ЕОМ

Звіт

до лабораторної роботи № 3

з дисципліни «Моделювання комп’ютерних систем»
на тему:

«Поведінковий опис цифрового автомата Перевірка роботи автомата за допомогою стенда Elbert V2 – Spartan 3A FPGA»

Варіант №21

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Львів 2024

Мета роботи: На базі стенда реалізувати цифровий автомат для обчислення значення виразів.

Виконання роботи:

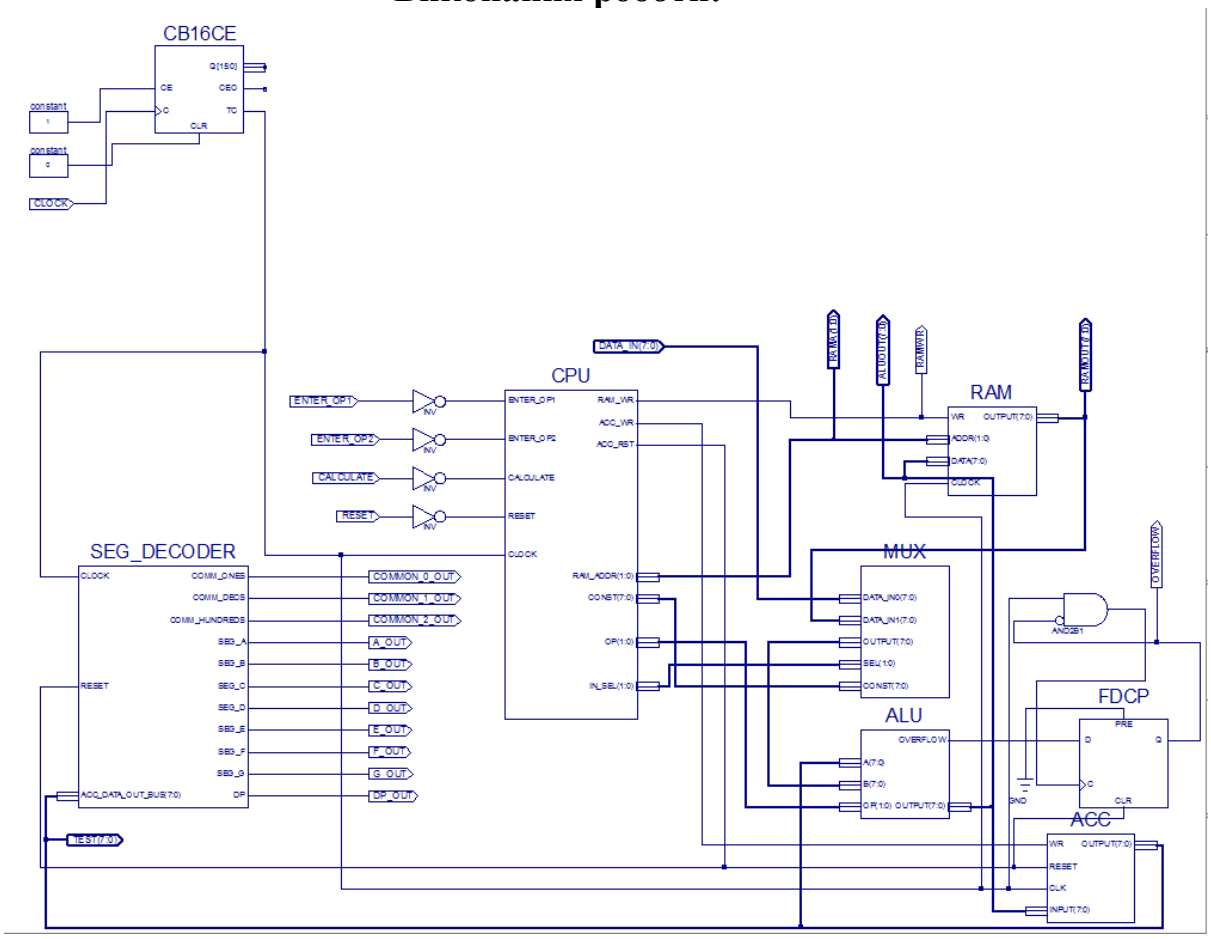

Рис. 1 – Top Level

Файл ACC.vhd

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

entity ACC is
    Port ( WR   : in  STD_LOGIC;
           RESET  : in  STD_LOGIC;
           CLK  : in  STD_LOGIC;
           INPUT : in  STD_LOGIC_VECTOR (7 downto 0);
           OUTPUT : out  STD_LOGIC_VECTOR (7 downto 0));
end ACC;

architecture ACC_arch of ACC is
    signal DATA : STD_LOGIC_VECTOR (7 downto 0);
```

```
begin
   process (CLK)
   begin
      if rising_edge(CLK) then
         if RESET = '1' then
            DATA <= (others => '0');
         elsif WR = '1' then
            DATA <= INPUT;
         end if;
      end if;
   end process;


   OUTPUT <= DATA;

end ACC_arch;
```

Файл ALU.vhd

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;


use IEEE.NUMERIC_STD.ALL;
use IEEE.STD_LOGIC_UNSIGNED.ALL;


entity ALU is
   Port ( A : in  STD_LOGIC_VECTOR(7 downto 0);
          B : in  STD_LOGIC_VECTOR(7 downto 0);
          OP : in  STD_LOGIC_VECTOR(1 downto 0);
          OUTPUT : out  STD_LOGIC_VECTOR(7 downto 0);
                        OVERFLOW: out STD_LOGIC);
end ALU;


architecture ALU_Behavioral of ALU is
         signal ALUR: STD_LOGIC_VECTOR(15 downto 0) := (others => '0');
         signal Carry: STD_LOGIC := '0';
begin
         process(A, B, OP)
         begin
                  case (OP) is
```

```
                        when "01" => ALUR <= ("00000000" & A) +
("00000000" & B);
                        when "10" => ALUR <= ("00000000" & A) +
("11111111" & not B) + "0000000000000001";
                        when "11" => ALUR <= ("00000000" & A) or
("00000000" & B);
                        when others => ALUR <= ("00000000" & B);
                end case;
        end process;
        OUTPUT <= ALUR(7 downto 0);
        OVERFLOW <= ALUR(8) OR ALUR(9) OR ALUR(10) OR
ALUR(11) OR ALUR(12) OR ALUR(13) OR ALUR(14) OR ALUR(15);
end ALU_Behavioral;
```

```
Файл CPU.vhd
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;


entity CPU is
        port( ENTER_OP1 : IN STD_LOGIC;
                        ENTER_OP2 : IN STD_LOGIC;
                        CALCULATE : IN STD_LOGIC;
                        RESET : IN STD_LOGIC;
                        CLOCK : IN STD_LOGIC;
                        RAM_WR : OUT STD_LOGIC;
                        RAM_ADDR : OUT STD_LOGIC_VECTOR(1
DOWNTO 0);
                        CONST : OUT STD_LOGIC_VECTOR(7 DOWNTO 0);
                        ACC_WR : OUT STD_LOGIC;
                        ACC_RST : OUT STD_LOGIC;
                        IN_SEL : OUT STD_LOGIC_VECTOR(1 downto 0);
                        OP : OUT STD_LOGIC_VECTOR(1 DOWNTO 0));
end CPU;

architecture CPU_arch of CPU is

type   STATE_TYPE is (RST, IDLE, LOAD_OP1, LOAD_OP2,
RUN_CALC0, RUN_CALC1, RUN_CALC2, RUN_CALC3, RUN_CALC4,
FINISH);
signal CUR_STATE  : STATE_TYPE;
signal NEXT_STATE : STATE_TYPE;
```

```
begin
        SYNC_PROC: process (CLOCK)
   begin
     if (rising_edge(CLOCK)) then
       if (RESET = '1') then
         CUR_STATE <= RST;
       else
         CUR_STATE <= NEXT_STATE;
       end if;
     end if;
   end process;


        NEXT_STATE_DECODE: process (CLOCK, ENTER_OP1,
ENTER_OP2, CALCULATE)
   begin
     NEXT_STATE <= CUR_STATE;

                case(CUR_STATE) is
                        when RST =>
                                NEXT_STATE <= IDLE;
                        when IDLE          =>
                                if (ENTER_OP1 = '1') then
                                        NEXT_STATE <= LOAD_OP1;
                                elsif (ENTER_OP2 = '1') then
                                        NEXT_STATE <= LOAD_OP2;
                                elsif (CALCULATE = '1') then
                                        NEXT_STATE <= RUN_CALC0;
                                else
                                        NEXT_STATE <= IDLE;
                                end if;
                        when LOAD_OP1         =>
                                NEXT_STATE <= IDLE;
                        when LOAD_OP2         =>
                                NEXT_STATE <= IDLE;
                        when RUN_CALC0 =>
                                NEXT_STATE <= RUN_CALC1;
                        when RUN_CALC1 =>
                                NEXT_STATE <= RUN_CALC2;
                        when RUN_CALC2 =>
                                NEXT_STATE <= RUN_CALC3;
                        when RUN_CALC3 =>
```

```
                        NEXT_STATE <= RUN_CALC4;
                when RUN_CALC4 =>
                        NEXT_STATE <= FINISH;
                when FINISH     =>
                        NEXT_STATE <= FINISH;
                when others             =>
                        NEXT_STATE <= IDLE;
        end case;
end process;

    OUTPUT_DECODE: process (CUR_STATE)
    begin
        case (CUR_STATE) is
            when RST =>
                RAM_WR <= '0';
                RAM_ADDR <= "00";
                CONST <= "00000000";
                ACC_WR <= '0';
                ACC_RST <= '1';
                IN_SEL <= "00";
                OP <= "00";
            when LOAD_OP1 =>
                RAM_WR <= '1';
                RAM_ADDR <= "00";
                CONST <= "00000000";
                ACC_WR <= '0';
                ACC_RST <= '1';
                IN_SEL <= "00";
                OP <= "00";
            when LOAD_OP2 =>
                RAM_WR <= '1';
                RAM_ADDR <= "01";
                CONST <= "00000000";
                ACC_WR <= '0';
                ACC_RST <= '1';
                IN_SEL <= "00";
                OP <= "00";
            when RUN_CALC0 =>
                RAM_WR <= '0';
                RAM_ADDR <= "01";
                CONST <= "00000000";
                ACC_WR <= '1';
                ACC_RST <= '0';
```

```
                IN_SEL <= "01";
                OP <= "00";
            when RUN_CALC1 =>
                RAM_WR <= '0';
                RAM_ADDR <= "01";
                CONST <= "00000100";
                ACC_WR <= '1';
                ACC_RST <= '0';
                IN_SEL <= "10";
                OP <= "11";
            when RUN_CALC2 =>
                RAM_WR <= '0';
                RAM_ADDR <= "00";
                CONST <= "00000000";
                ACC_WR <= '1';
                ACC_RST <= '0';
                IN_SEL <= "01";
                OP <= "01";
            when RUN_CALC3 =>
                RAM_WR <= '0';
                RAM_ADDR <= "00";
                CONST <= "00001010";
                ACC_WR <= '1';
                ACC_RST <= '0';
                IN_SEL <= "10";
                OP <= "01";
            when RUN_CALC4 =>
                RAM_WR <= '0';
                RAM_ADDR <= "00";
                CONST <= "00000010";
                ACC_WR <= '1';
                ACC_RST <= '0';
                IN_SEL <= "10";
                OP <= "10";
            when IDLE =>
                RAM_WR <= '0';
                RAM_ADDR <= "00";
                CONST <= "00000000";
                ACC_WR <= '0';
                ACC_RST <= '0';
                IN_SEL <= "00";
                OP <= "00";
            when others =>
```

```
                        RAM_WR <= '0';
                        RAM_ADDR <= "00";
                        CONST <= "00000000";
                        ACC_WR <= '0';
                        ACC_RST <= '0';
                        IN_SEL <= "00";
                        OP <= "00";
                end case;
  end process;
end CPU_arch;
```

Файл MUX.vhd

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

entity MUX is
        PORT(
                SEL: in STD_LOGIC_VECTOR(1 downto 0);
                CONST: in STD_LOGIC_VECTOR(7 downto 0);
                --CONST1: in STD_LOGIC_VECTOR()
                DATA_IN0: in STD_LOGIC_VECTOR(7 downto 0);
                DATA_IN1: in STD_LOGIC_VECTOR(7 downto 0);
                OUTPUT: out STD_LOGIC_VECTOR(7 downto 0)
        );
end MUX;

architecture Behavioral of MUX is
begin
        process (SEL, DATA_IN0, DATA_IN1, CONST)
        begin
                if (SEL = "00") then
                        OUTPUT <= DATA_IN0;
                elsif (SEL = "01") then
                        OUTPUT <= DATA_IN1;
                else
                        OUTPUT <= CONST;
                end if;
        end process;
end Behavioral;
```

Файл RAM.vhd

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
use IEEE.NUMERIC_STD.ALL;
use IEEE.STD_LOGIC_UNSIGNED.ALL;


entity RAM is
	port(
			WR : IN STD_LOGIC;
			ADDR : IN STD_LOGIC_VECTOR(1 DOWNTO 0);
			DATA : IN STD_LOGIC_VECTOR(7 DOWNTO 0);
			CLOCK: IN STD_LOGIC;
			OUTPUT : OUT STD_LOGIC_VECTOR(7 DOWNTO 0)
			);
end RAM;

architecture RAM_arch of RAM is
	type ram_type is array (3 downto 0) of STD_LOGIC_VECTOR(7
downto 0);
	signal UNIT : ram_type;

begin
	process(ADDR, CLOCK, UNIT)
	 begin
		if(rising_edge(CLOCK)) then
			if (WR = '1') then
				UNIT(conv_integer(ADDR)) <= DATA;
			end if;
		end if;
		OUTPUT <= UNIT(conv_integer(ADDR));
	end process;
end RAM_arch;
```

Файл SEG_DECODER.vhd

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
use IEEE.STD_LOGIC_ARITH.ALL;
use IEEE.STD_LOGIC_UNSIGNED.ALL;


entity SEG_DECODER is
```

```
        port( CLOCK : IN STD_LOGIC;
                      RESET : IN STD_LOGIC;
                      ACC_DATA_OUT_BUS : IN STD_LOGIC_VECTOR(7
DOWNTO 0);
                      COMM_ONES                    : OUT STD_LOGIC;
                      COMM_DECS            : OUT STD_LOGIC;
                      COMM_HUNDREDS   : OUT STD_LOGIC;
                      SEG_A        : OUT STD_LOGIC;
                      SEG_B        : OUT STD_LOGIC;
                      SEG_C        : OUT STD_LOGIC;
                      SEG_D        : OUT STD_LOGIC;
                      SEG_E        : OUT STD_LOGIC;
                      SEG_F        : OUT STD_LOGIC;
                      SEG_G        : OUT STD_LOGIC;
                      DP           : OUT STD_LOGIC);
end SEG_DECODER;

architecture Behavioral of SEG_DECODER is

        signal ONES_BUS : STD_LOGIC_VECTOR(3 downto 0) := "0000";
        signal DECS_BUS : STD_LOGIC_VECTOR(3 downto 0) := "0001";
        signal HONDREDS_BUS : STD_LOGIC_VECTOR(3 downto 0) :=
"0000";

begin
        BIN_TO_BCD : process (ACC_DATA_OUT_BUS)
      variable hex_src : STD_LOGIC_VECTOR(7 downto 0) ;
      variable bcd     : STD_LOGIC_VECTOR(11 downto 0) ;
   begin
      bcd           := (others => '0') ;
      hex_src        := ACC_DATA_OUT_BUS;

      for i in hex_src'range loop
         if bcd(3 downto 0) > "0100" then
            bcd(3 downto 0) := bcd(3 downto 0) + "0011" ;
         end if ;
         if bcd(7 downto 4) > "0100" then
            bcd(7 downto 4) := bcd(7 downto 4) + "0011" ;
         end if ;
         if bcd(11 downto 8) > "0100" then
            bcd(11 downto 8) := bcd(11 downto 8) + "0011" ;
         end if ;
```

```
        bcd := bcd(10 downto 0) & hex_src(hex_src'left) ; -- shift bcd + 1 new
entry
        hex_src := hex_src(hex_src'left - 1 downto hex_src'right) & '0' ; --
shift src + pad with 0
      end loop ;

      HONDREDS_BUS      <=  bcd (11 downto 8);
      DECS_BUS       <=  bcd (7 downto 4);
      ONES_BUS      <=  bcd (3 downto 0);

   end process BIN_TO_BCD;

        INDICATE : process(CLOCK)
            type DIGIT_TYPE is (ONES, DECS, HUNDREDS);

            variable CUR_DIGIT     : DIGIT_TYPE := ONES;
            variable DIGIT_VAL       : STD_LOGIC_VECTOR(3 downto 0)
:= "0000";
            variable DIGIT_CTRL     : STD_LOGIC_VECTOR(6 downto 0)
:= "0000000";
            variable COMMONS_CTRL  : STD_LOGIC_VECTOR(2
downto 0) := "000";

            begin
                if (rising_edge(CLOCK)) then
                    if(RESET = '0') then
                        case CUR_DIGIT is
                            when ONES =>
                                DIGIT_VAL := ONES_BUS;
                                CUR_DIGIT := DECS;
                                COMMONS_CTRL := "001";
                            when DECS =>
                                DIGIT_VAL := DECS_BUS;
                                CUR_DIGIT := HUNDREDS;
                                COMMONS_CTRL := "010";
                            when HUNDREDS =>
                                DIGIT_VAL :=
HONDREDS_BUS;
                                CUR_DIGIT := ONES;
                                COMMONS_CTRL := "100";
                            when others =>
                                DIGIT_VAL := ONES_BUS;
                                CUR_DIGIT := ONES;
```

```
                                        COMMONS_CTRL := "000";
                        end case;

                        case DIGIT_VAL is           --abcdefg
                                when "0000" => DIGIT_CTRL :=
"1111110";
                                when "0001" => DIGIT_CTRL :=
"0110000";
                                when "0010" => DIGIT_CTRL :=
"1101101";
                                when "0011" => DIGIT_CTRL :=
"1111001";
                                when "0100" => DIGIT_CTRL :=
"0110011";
                                when "0101" => DIGIT_CTRL :=
"1011011";
                                when "0110" => DIGIT_CTRL :=
"1011111";
                                when "0111" => DIGIT_CTRL :=
"1110000";
                                when "1000" => DIGIT_CTRL :=
"1111111";
                                when "1001" => DIGIT_CTRL :=
"1111011";
                                when others => DIGIT_CTRL :=
"0000000";
                        end case;
                else
                        DIGIT_VAL := ONES_BUS;
                        CUR_DIGIT := ONES;
                        COMMONS_CTRL := "000";
                end if;

                COMM_ONES      <= not COMMONS_CTRL(0);
                COMM_DECS      <= not COMMONS_CTRL(1);
                COMM_HUNDREDS <= not
COMMONS_CTRL(2);

                SEG_A <= not DIGIT_CTRL(6);
                SEG_B <= not DIGIT_CTRL(5);
                SEG_C <= not DIGIT_CTRL(4);
                SEG_D <= not DIGIT_CTRL(3);
                SEG_E <= not DIGIT_CTRL(2);
```

```
                        SEG_F <= not DIGIT_CTRL(1);
                        SEG_G <= not DIGIT_CTRL(0);
                        DP    <= '1';

                    end if;
        end process INDICATE;

end Behavioral;
```

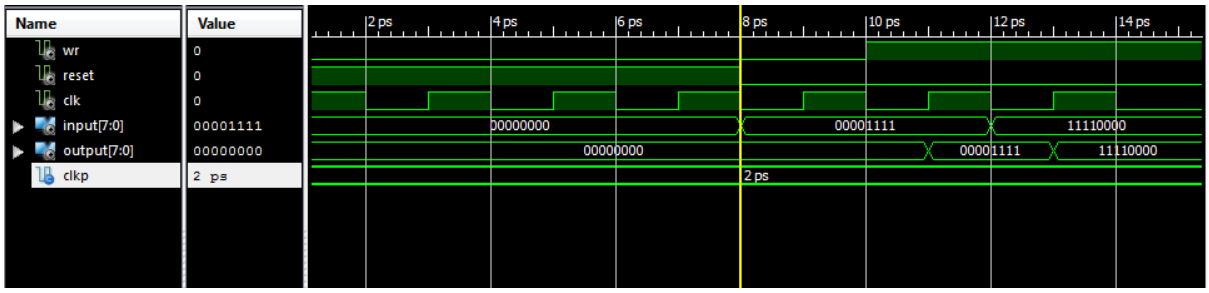

Рис. 2 – Часова діаграма ACC

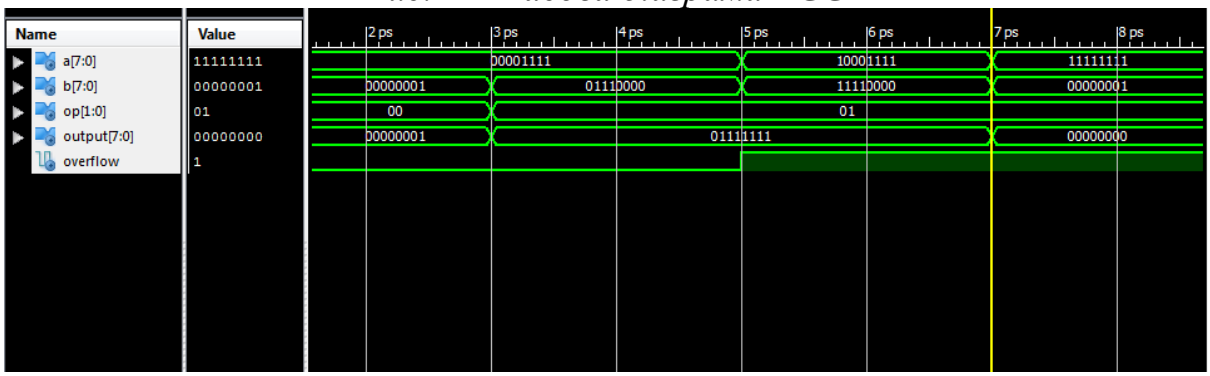

Рис. 3 – Часова діаграма ALU

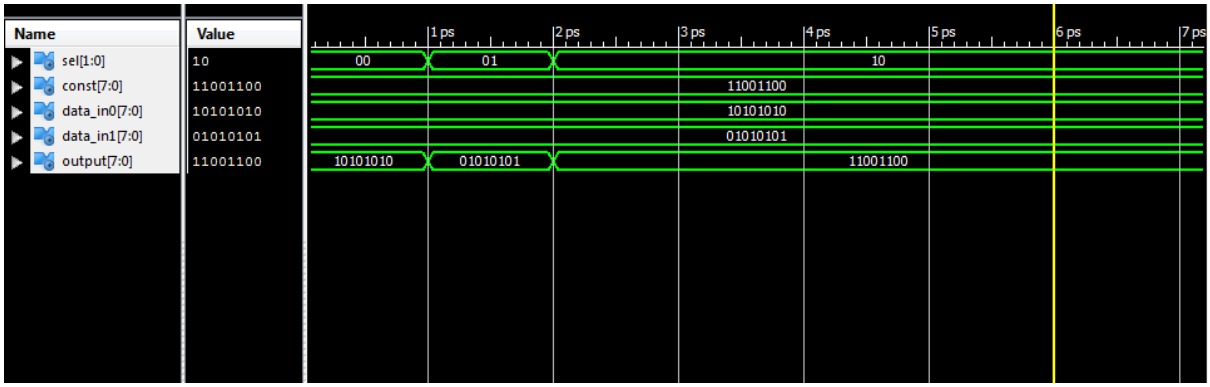

Рис. 4 – Часова діаграма MUX

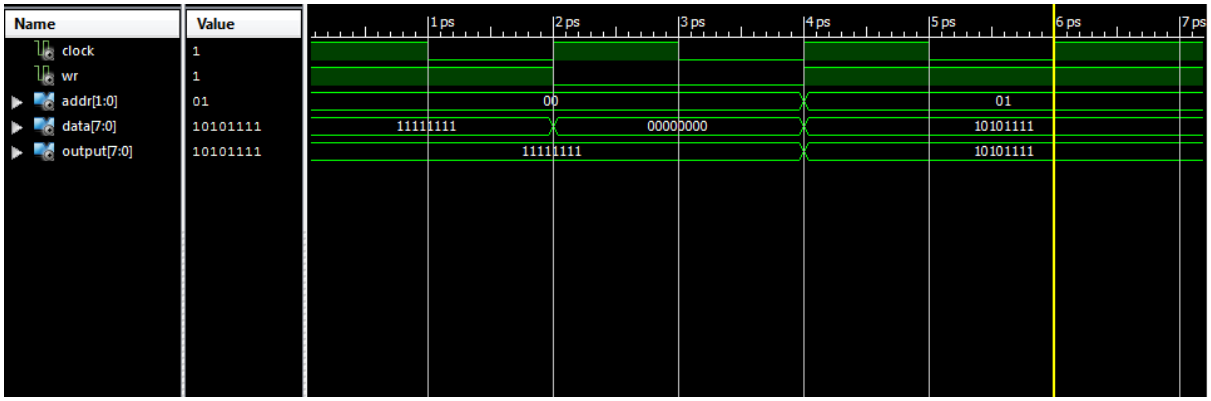

Рис. 5 – Часова діаграма RAM

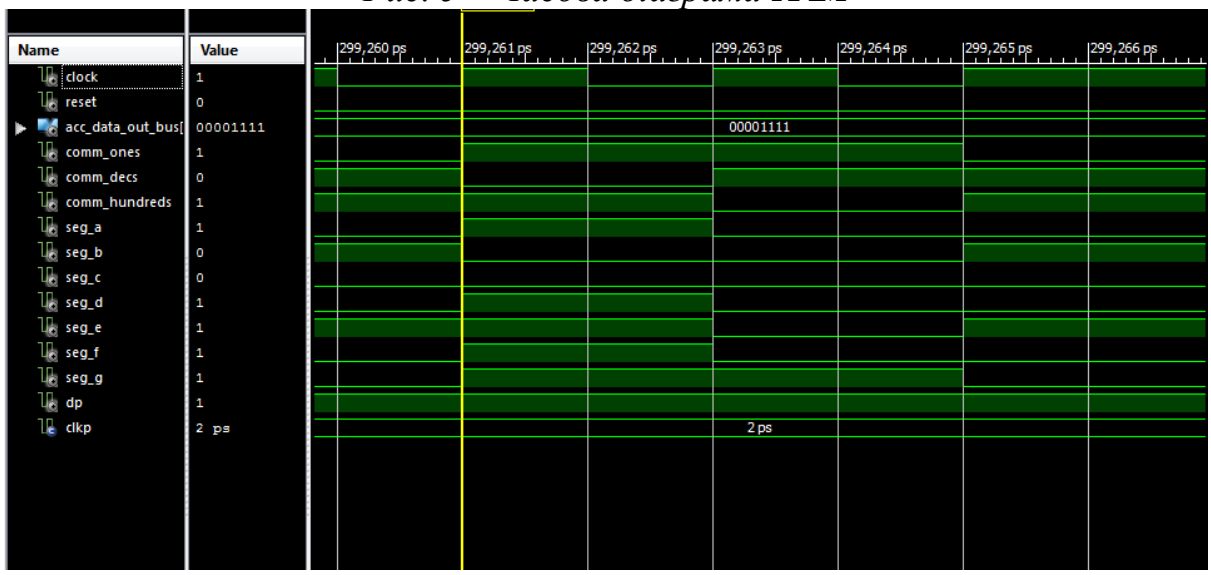

Рис 6. – Часова діграма SEG_DECODER

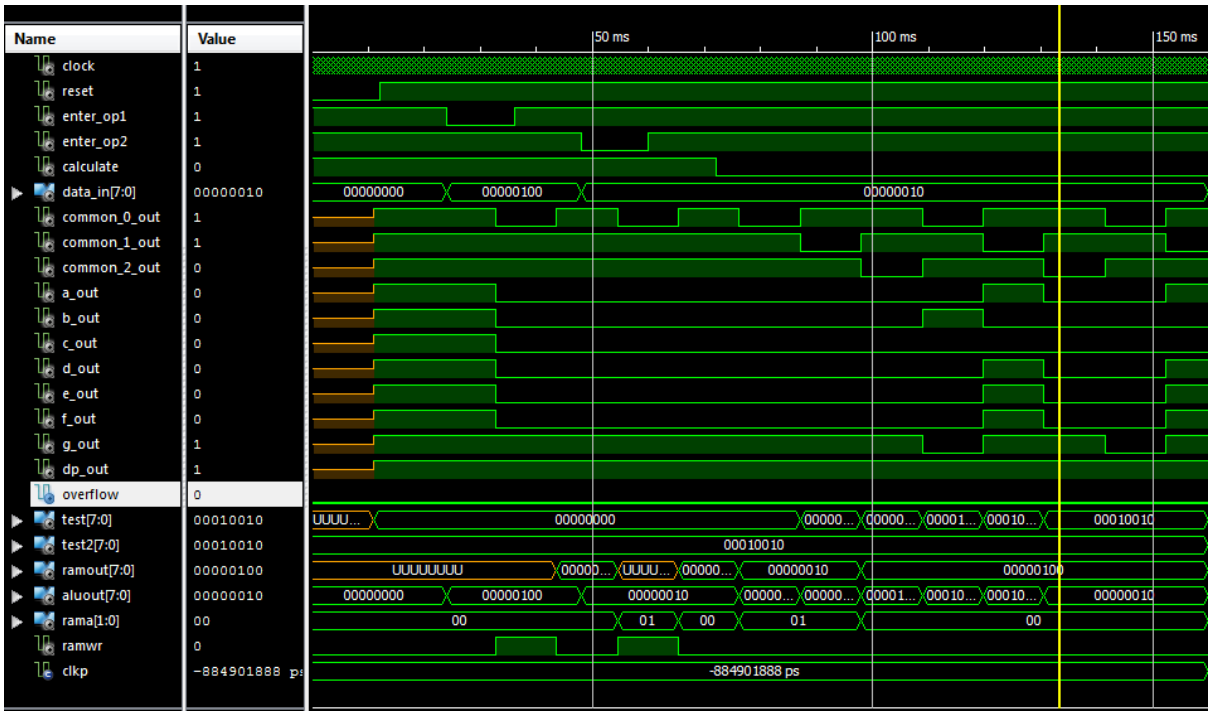

Рис 7. – Часова діграма TopLevel

```
Файл TopLevelTest.vhd
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;
USE ieee.numeric_std.ALL;
LIBRARY UNISIM;
USE UNISIM.Vcomponents.ALL;
ENTITY TopLevel_TopLevel_sch_tb IS
END TopLevel_TopLevel_sch_tb;
ARCHITECTURE behavioral OF TopLevel_TopLevel_sch_tb IS

  COMPONENT TopLevel
  PORT( CLOCK  :       IN     STD_LOGIC;
        RESET       :       IN     STD_LOGIC;
        ENTER_OP1       :       IN     STD_LOGIC;
        ENTER_OP2       :       IN     STD_LOGIC;
        CALCULATE       :       IN     STD_LOGIC;
        DATA_IN    :       IN     STD_LOGIC_VECTOR (7 DOWNTO 0);
        COMMON_0_OUT       :       OUT  STD_LOGIC;
        COMMON_1_OUT       :       OUT  STD_LOGIC;
        COMMON_2_OUT       :       OUT  STD_LOGIC;
                    TEST: OUT STD_LOGIC_VECTOR(7 downto 0);
        A_OUT       :       OUT  STD_LOGIC;
        B_OUT       :       OUT  STD_LOGIC;
        C_OUT       :       OUT  STD_LOGIC;
        D_OUT       :       OUT  STD_LOGIC;
        E_OUT       :       OUT  STD_LOGIC;
        F_OUT       :       OUT  STD_LOGIC;
        G_OUT       :       OUT  STD_LOGIC;
        DP_OUT     :       OUT  STD_LOGIC;
                    RAMOUT: OUT STD_LOGIC_VECTOR(7 downto 0);
                    ALUOUT: OUT STD_LOGIC_VECTOR(7 downto 0);
                    RAMA: OUT STD_LOGIC_VECTOR(1 downto 0);
                    RAMWR: OUT STD_LOGIC;
        OVERFLOW       :       OUT  STD_LOGIC);
  END COMPONENT;

  SIGNAL CLOCK       :       STD_LOGIC := '0';
  SIGNAL RESET :       STD_LOGIC;
  SIGNAL ENTER_OP1 :       STD_LOGIC;
  SIGNAL ENTER_OP2 :       STD_LOGIC;
  SIGNAL CALCULATE :       STD_LOGIC;
  SIGNAL DATA_IN     :       STD_LOGIC_VECTOR (7 DOWNTO 0);
```

```
  SIGNAL COMMON_0_OUT :      STD_LOGIC;
  SIGNAL COMMON_1_OUT :      STD_LOGIC;
  SIGNAL COMMON_2_OUT :      STD_LOGIC;
  SIGNAL A_OUT:      STD_LOGIC;
  SIGNAL B_OUT:      STD_LOGIC;
  SIGNAL C_OUT:      STD_LOGIC;
  SIGNAL D_OUT       :      STD_LOGIC;
  SIGNAL E_OUT:      STD_LOGIC;
  SIGNAL F_OUT:      STD_LOGIC;
  SIGNAL G_OUT       :      STD_LOGIC;
  SIGNAL DP_OUT      :      STD_LOGIC;
  SIGNAL OVERFLOW :      STD_LOGIC;
       SIGNAL TEST: STD_LOGIC_VECTOR(7 downto 0);
       SIGNAL TEST2: STD_LOGIC_VECTOR(7 downto 0);
       signal RAMOUT: STD_LOGIC_VECTOR(7 downto 0);
       signal ALUOUT: STD_LOGIC_VECTOR(7 downto 0);
       signal RAMA: STD_LOGIC_VECTOR(1 downto 0);
       signal RAMWR: STD_LOGIC;

--     constant CLOCK_period : time := 166ns;
       constant CLKP: time := 12ms;--24ms;

BEGIN

  UUT: TopLevel PORT MAP(
            CLOCK => CLOCK,
            RESET => RESET,
            ENTER_OP1 => ENTER_OP1,
            ENTER_OP2 => ENTER_OP2,
            CALCULATE => CALCULATE,
            DATA_IN => DATA_IN,
            COMMON_0_OUT => COMMON_0_OUT,
            COMMON_1_OUT => COMMON_1_OUT,
            COMMON_2_OUT => COMMON_2_OUT,
            A_OUT => A_OUT,
            B_OUT => B_OUT,
            C_OUT => C_OUT,
            D_OUT => D_OUT,
            E_OUT => E_OUT,
            F_OUT => F_OUT,
            G_OUT => G_OUT,
            DP_OUT => DP_OUT,
            OVERFLOW => OVERFLOW,
```

```
                TEST => TEST,
                RAMOUT => RAMOUT,
                ALUOUT => ALUOUT,
                RAMA => RAMA,
                RAMWR => RAMWR
  );

        CLOCK_process: process
  begin
                CLOCK <= '0';
                wait for 83ns;
                CLOCK <= '1';
                wait for 83ns;
  end process;

-- *** Test Bench - User Defined Section ***
  tb : PROCESS
  BEGIN
                lp1: for i in 4 to 4 loop
                        lp2: for j in 2 to 2 loop
                                TEST2 <=
std_logic_vector(to_unsigned(to_integer(signed(std_logic_vector(to_unsigne
d(j, 8)) or std_logic_vector(to_unsigned(4, 8)))) + i + 10 - 2, 8));
                                ENTER_OP1 <= '1';
                                ENTER_OP2 <= '1';
                                CALCULATE <= '1';
                                DATA_IN <= (others => '0');
                                RESET <= '0';
                                wait for CLKP;
                                RESET <= '1';
                                wait for CLKP;
                                DATA_IN <= std_logic_vector(to_unsigned(i, 8)); --
A
                                ENTER_OP1 <= '0';
                                wait for CLKP;
                                ENTER_OP1 <= '1';
                                wait for CLKP;
                                DATA_IN <= std_logic_vector(to_unsigned(j, 8)); --
B
                                ENTER_OP2 <= '0';
                                wait for CLKP;
                                ENTER_OP2 <= '1';
                                wait for CLKP;
```

```
                        CALCULATE <= '0'; -- START CALCULATION
                        wait for CLKP* 7;
                        assert TEST = TEST2 severity FAILURE;
                        wait for CLKP;
                    end loop;
                end loop;

    WAIT; -- will wait forever
  END PROCESS;
-- *** End Test Bench - User Defined Section ***

END;
```

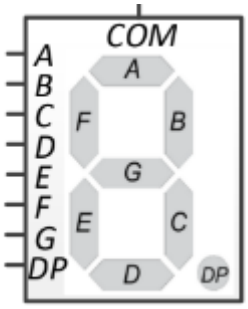

Рис.8 – 7-сегментний індикатор

Переглянемо часову діаграму 7seg decoder.
Бачимо, що для вхідного числа 00001111(2) = 15(10)
Ми отримуємо такі значення(якщо значення не вказане, вважаюмо його за одиницю):
COMM_ONES = 0: A,C,D, F, G = 0, що відповідає числу 5
COMM_DECS = 0: B,C = 0, що відповідає числу 1
COMM_HUNDREDS = 0: A,B,C,D,E,F = 0, що відповідає числу 0
Отримуємо значення 015, що збігається з даним йому.

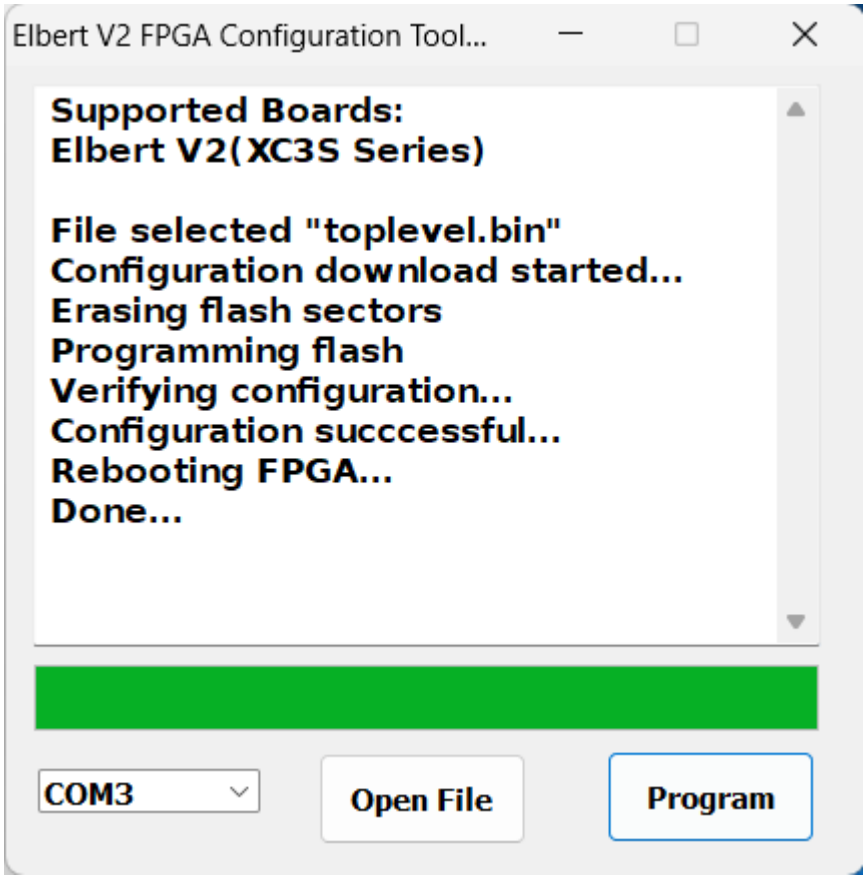

Рис.9 – Успішна прошивка

Висновок: Виконуючи дану лабораторну роботу я навчився реалізовувати цифровий автомат для обчислення значення виразів використовуючи засоби VHDL.