

**ISTANBUL TECHNICAL UNIVERSITY**  
**COMPUTER ENGINEERING DEPARTMENT**

**BLG 222E**  
**Computer Organization**  
**Project 1**

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**GROUP MEMBERS:**

150220762 : Muhammed Yusuf Mermer (Group Representative)  
150210071 : Emre Çamlıca  
150200091 : Hakan Duran

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# 1 INTRODUCTION

In this project our purpose was to design a hardwired control unit. To achieve this we divided it into parts. Yusuf did the fetch and decode parts, Hakan did the instructions without memory reference and Emre did the instructions with memory reference parts. Yusuf also wrote the test bench and tested the system with Hakan.

We used the ALU System module to determine the paths we should go through in order to implement the operations determined by the instruction register. Then we designed the operations, using the selectors and multiplexers to choose the right values. After that, we tested the general project and made corrections in order to make it work properly, according to the example memory cycle given.

## 2 IMPLEMENTATIONS AND EXPLANATIONS

### 2.1 Fetch Cycle, Counter and Decoding

In our implementations, we made only counter module separated from the combined system. It could have also been designed inside of overall combined system as a register, but this was our design choice. It takes clock as input, because at every positive edge we increase our timing signal by 1. However, to prevent unexpected result in the current positive edge we wait for 0.25 ns in our implementation.

Not only clock, but also reset signal taken as input for this module to return initial value for the timing signal. When it reset, it returns value 4 bit binary 1111 which is equal to -0001, this is been made because reset signal does not depend on clock; therefore, after the reset we wait for new clock signal to start new operations. New operations will be started with timing signal 0.

Inside of initial block, we make all register values 0 for use in the operations. Then to prevent further changes we closed rsel and tsel values.

We have 3 always block inside of our implementations. Our very first always block works at every new instruction. It closes all rsels and tsels and also closes IR enable. Also after resetting signal, we need to make reset command 0 to prevent always 0 problem of counter.

2nd always block, works similar to 1st one but it doesn't reset at every time, because this operation doesn't needed. In here our purpose is to close all registers from changing their values with the incoming new timing signal.

After making all necessary connections, in 3rd always block, when timing signal 0 arrives to our combined system, it starts to fetch cycle. Our fetch cycle is totally takes 3 cycles. It has been made 3 cycles to prevent changes unintended changes on the PC and

IR.

At first (0th) cycle of the fetch, we just pushed values of  $M[PC]$  to the IR's LS 8 bits. This because memory can only give 8 bit output at once. To do this operation, we give PC as address to memory.

At second (1st) cycle, we only increased PC value by one. To do this, we just opened PC's register for input changes and send increment by one signal to funnel of arf.

At last (2nd) cycle, we do combined operations of 0th and 1st cycles, but different than 0th, this time high bits of IR will be changed.

For decoding part (3th cycle), for the opcodes that addressing mode doesn't required, we made a simple output opener. In other words, our module looks at here to decide where to take sreg's. It depends on the where register resits. If [2] bit is 0 it means that it will be RF, if 1 it will be ARF. The pattern of RF same for [1:0], so we did not make a change and send them directly. However for ARF, we used switch case for manipulation.

At the end of every instruction, we need to send a reset signal, so depending on the opcode type, we will send request for reset. When all operations are finished for a instruction, this operations occurs in the next clock cycle.

## 2.2 Instructions With Address Reference

Instructions that have address references either write something on memory or execute a task coming from the chosen memory address.

### 2.2.1 BRA

In this operation, the address block of the instruction register is directly written into the program counter.

To do this, the MUX B is selected as "10" to choose the input coming from the IR. The Regsel input of the ARF is chosen as "0001" which activates only the PC and the Funnel input of the ARF is "01" indicating the load mode.

### 2.2.2 BNE

This operation is exactly the same as the "BRA" operation except that it checks zero flag of the ALU. If it is zero, the condition is met and the operation is done.

### 2.2.3 LD

This operation is implemented differently, depending on the addressing mode of the instruction.

If the addressing mode is immediate addressing, indicated by "0", the address in the IR is written into a register chosen by the register selection bits of the instruction. To do this, MUX A is selected as "10" to choose the input coming from the IR. The Funsel of RF is chosen as "01", indicating the load mode. The register to load is selected using a case statement, depending on the value of the register selection bit of the instruction.

If the addressing mode is direct addressing firstly, the value of the address register is given as address to the memory which is indicated by the outDsel of the ARF being "00". Then, MUX A is selected as "01" to choose the input coming from the memory. The Funsel of RF is chosen as "01", indicating the load mode. The register to load is selected using a case statement, depending on the value of the register selection bit of the instruction.

#### **2.2.4 ST**

In this operation, the value in a register selected by the register selection bits of the IR is written to the memory location determined by the address register.

First, the D output of the ARF is selected as "00", so that the AR is given as address to memory. The register that will write to the memory is again chosen by the register selection bits of the instruction, using a case statement. Then, the MUX C is selected as "0" to give the chosen register as the input to ALU. The ALU directly transfers the value in the selected register to the memory, as the funsel is "0000". Then, the value is written into the desired memory location.

#### **2.2.5 PUL**

In this operation, the value in the memory address determined by the stack pointer is written into a register. Then, the value of the SP is incremented.

First, the D output of ARF is selected as "01" to give the SP as an address to the memory. Then, MUX A is selected as "01" in order for it to take the input coming from the memory. The Funsel of RF is chosen as "01", indicating the load mode. The register to load is selected using a case statement, depending on the value of the register selection bit of the instruction. In the next cycle, the value of SP is incremented using the ARF registers increment operation.

#### **2.2.6 PSH**

In this operation, the value in a register is written into the memory location determined by the stack pointer. Then, the value of the SP is decremented.

First, the D output of ARF is selected as "01" to give the SP as an address to the

memory. Then, the register is selected depending on the value of the register selection bit of the instruction, that will be given as input to ALU. The MUX C is selected as "0" to take the input from the RF. The ALU directly conveys the value in the register with the "0000" coded operation, so that the value in the register is written into the memory. In the next cycle, the value of SP is incremented using the ARF registers increment operation.

## **2.3 Instructions Without Address Reference**

Instructions without address references have four separate fields whose functionalities differ. Each one has 4 bits. Opcode determines which operation will be carrying out. DSTREG means destination register, SREG1 and SREG2 are source registers. There are 10 instruction types.

### **2.3.1 AND**

AND operation's opcode is 0x00. It carries out by determining ALU Funsel as 0111.

### **2.3.2 OR**

OR operation's opcode is 0x01. It carries out by determining ALU Funsel as 1000.

### **2.3.3 NOT**

NOT operation's opcode is 0x02. It carries out by determining ALU Funsel as 0010.

### **2.3.4 ADD**

ADD operation's opcode is 0x03. It carries out by determining ALU Funsel as 0100.

### **2.3.5 SUB**

SUB operation's opcode is 0x04, it is responsible for subtract operations. It carries out by determining ALU Funsel as 0101.

### **2.3.6 LSR**

LSR operation's opcode is 0x05, it is responsible for logical shift right operations. It carries out by determining ALU Funsel as 1100.

### **2.3.7 LSL**

LSL operation's opcode is 0x06, it is responsible for logical shift left operations. It carries out by determining ALU Funsel as 1011.

### 2.3.8 INC

INC operation's opcode is 0x07, it is responsible for increment operations. It carries out by determining ALU Funsel as 0100. It takes 3 cycles because in order to increment and then send to ALU, we should first create a register which has value 1. Making it takes 2 cycle, first cycle for using a temporary register which has value 0. Then in second cycle, we make it 0001 with incrementing and use it in ALU.

### 2.3.9 DEC

DEC operation's opcode is 0x08, it is responsible for decrement operations. It carries out by determining ALU Funsel as 0101. It takes 3 cycles because in order to decrement and then send to ALU, we should first create a register which has value 1. Making it takes 2 cycle, first cycle for using a temporary register which has value 0. Then in second cycle, we make it 0001 with incrementing and use it in ALU.

### 2.3.10 MOV

MOV operation's opcode is 0x0B. It carries out by determining ALU Funsel as 0000.

## 3 OVERALL DESIGN PHOTO

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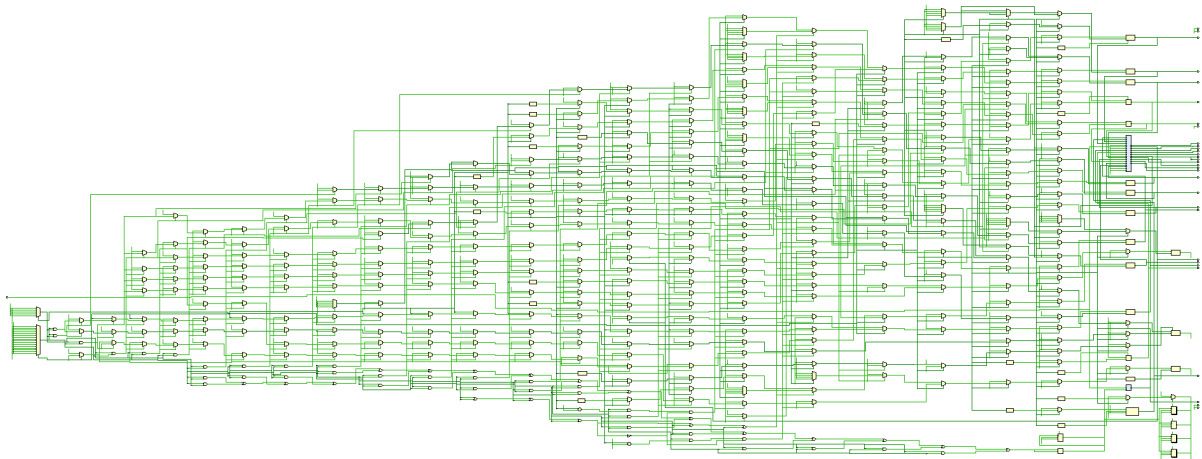


Figure 1: overall design photo

## 4 SIMULATION RESULTS

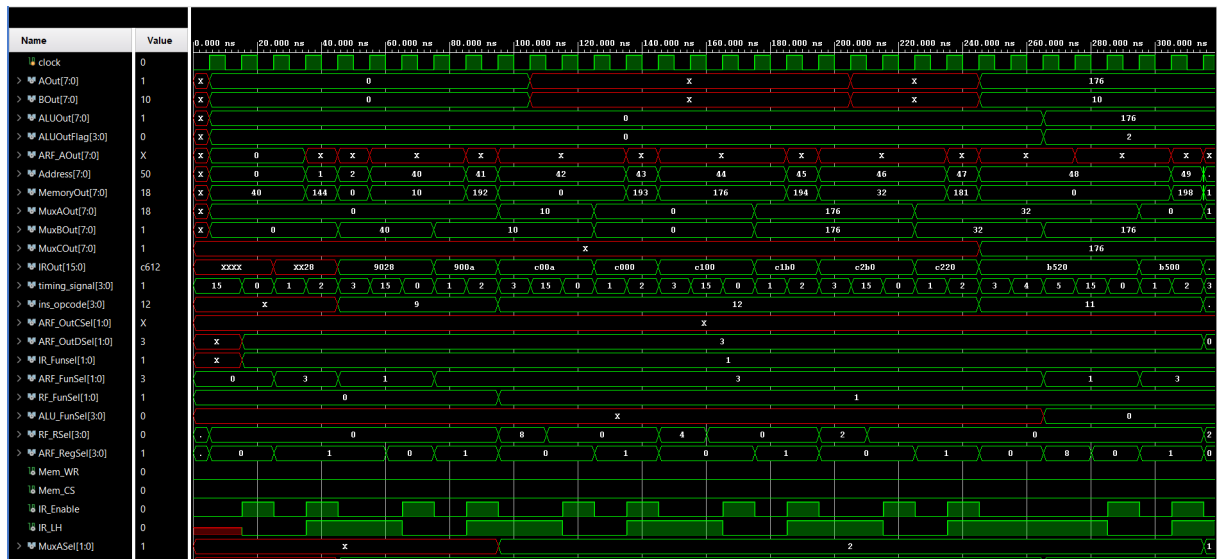


Figure 2: simulation of system

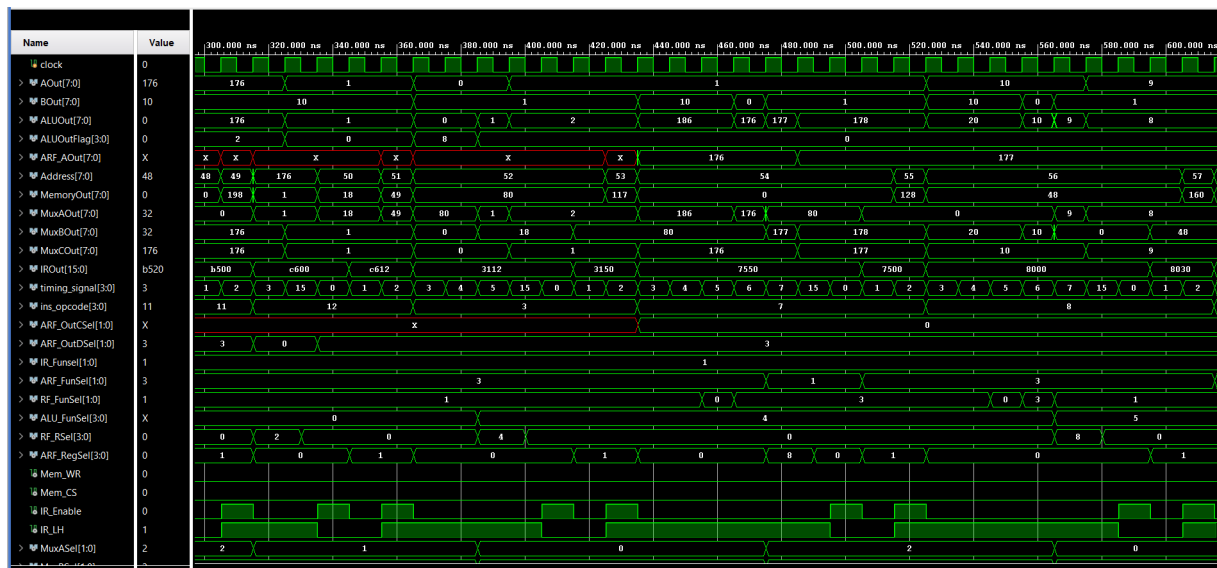


Figure 3: simulation of system



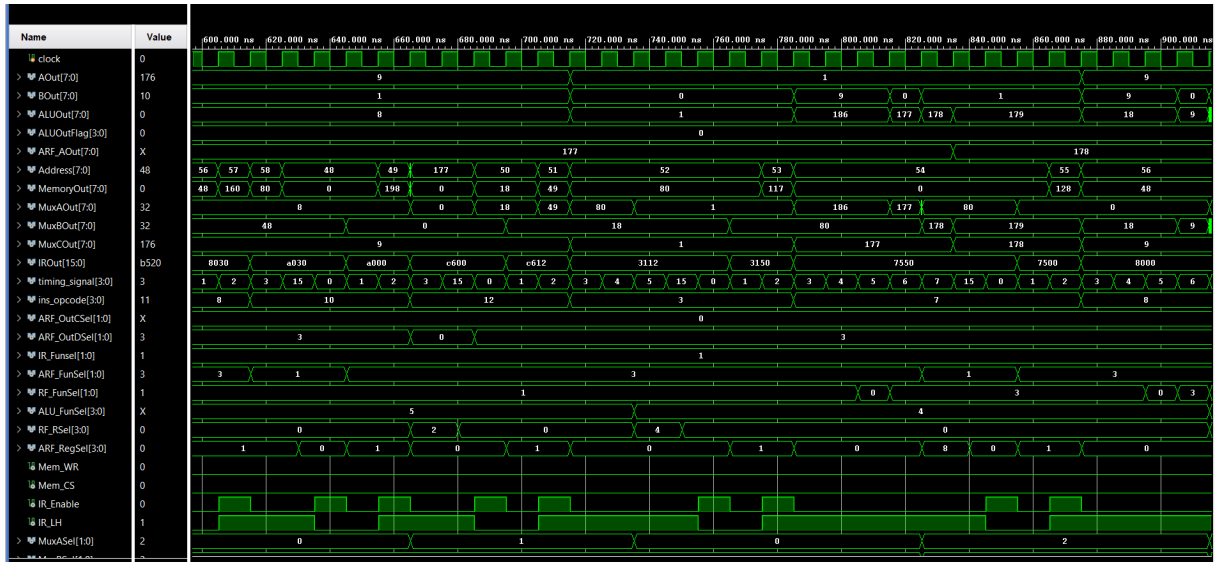


Figure 4: simulation of system

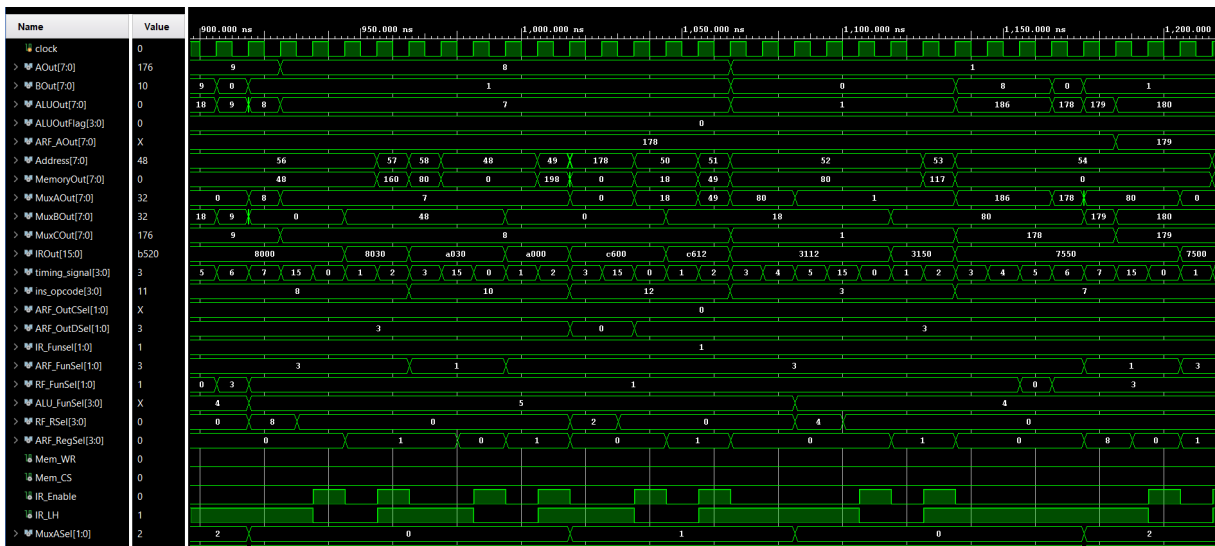


Figure 5: simulation of system

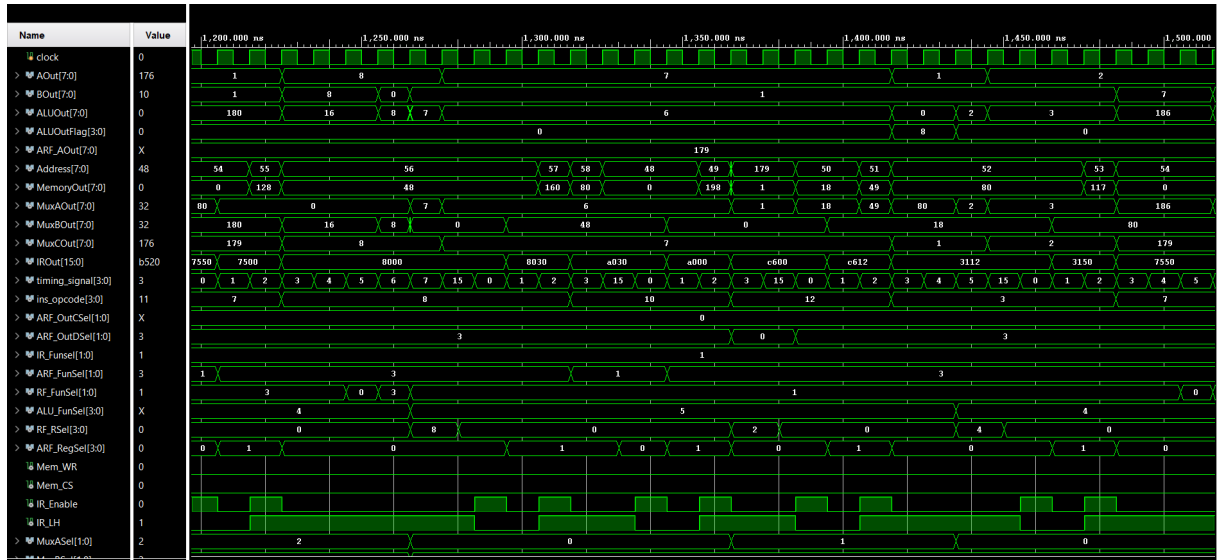


Figure 6: simulation of system

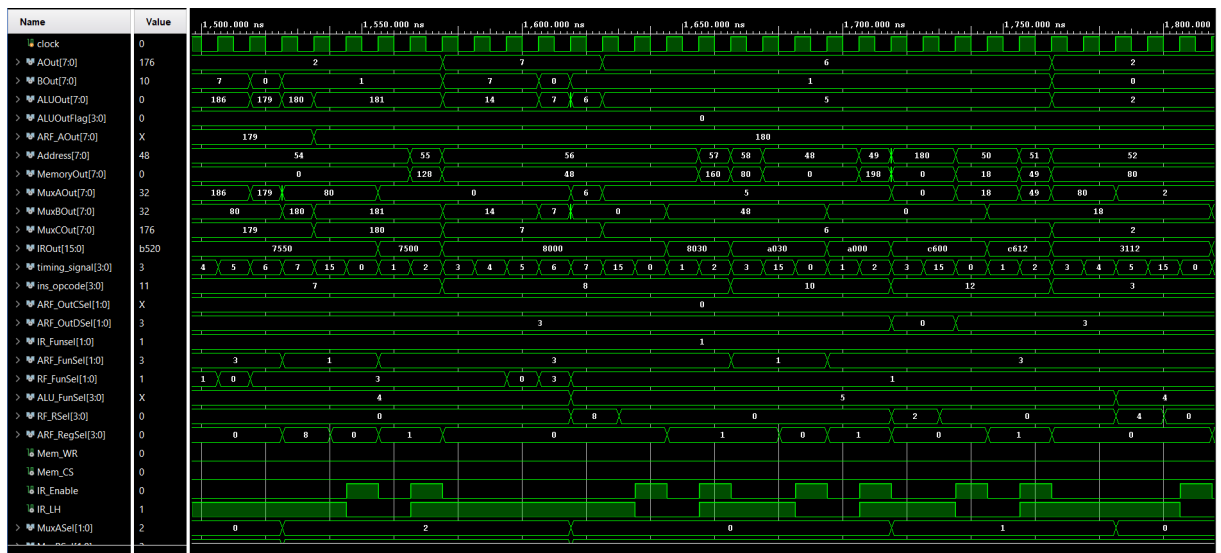


Figure 7: simulation of system

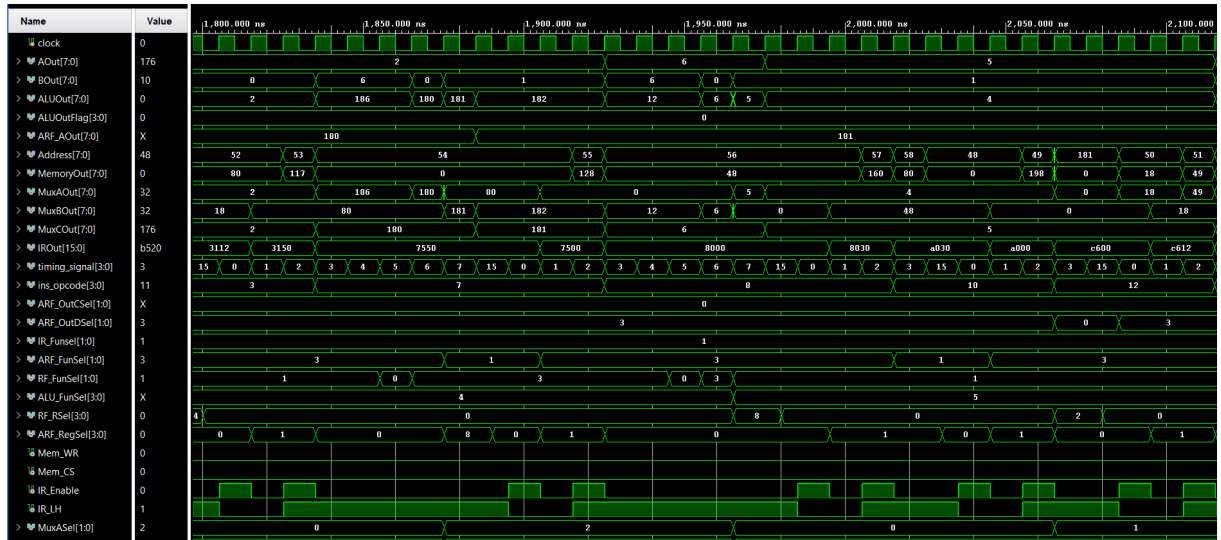


Figure 8: simulation of system

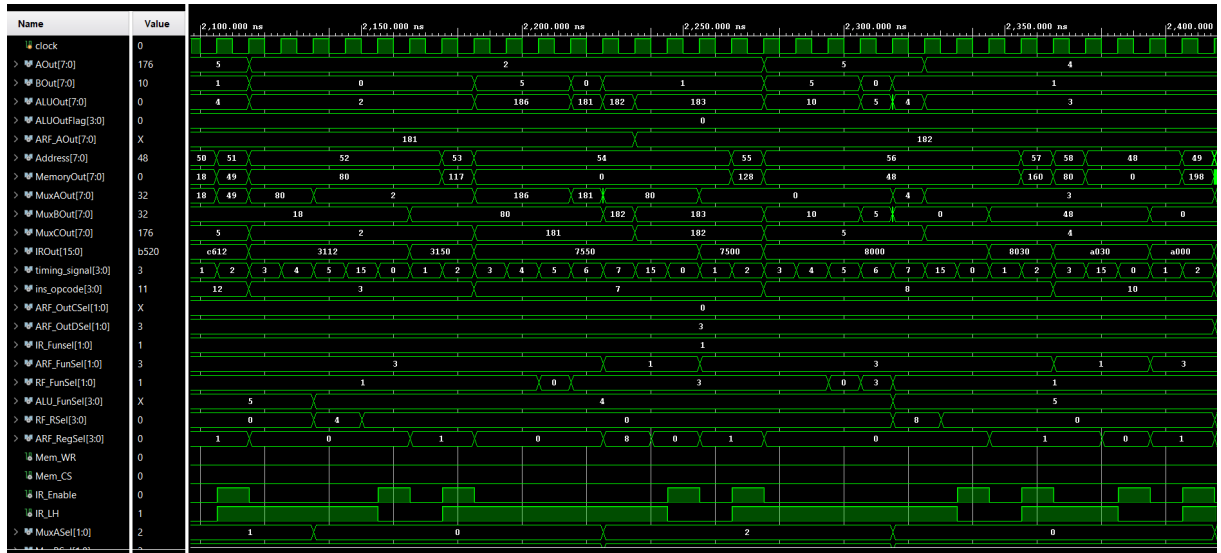


Figure 9: simulation of system

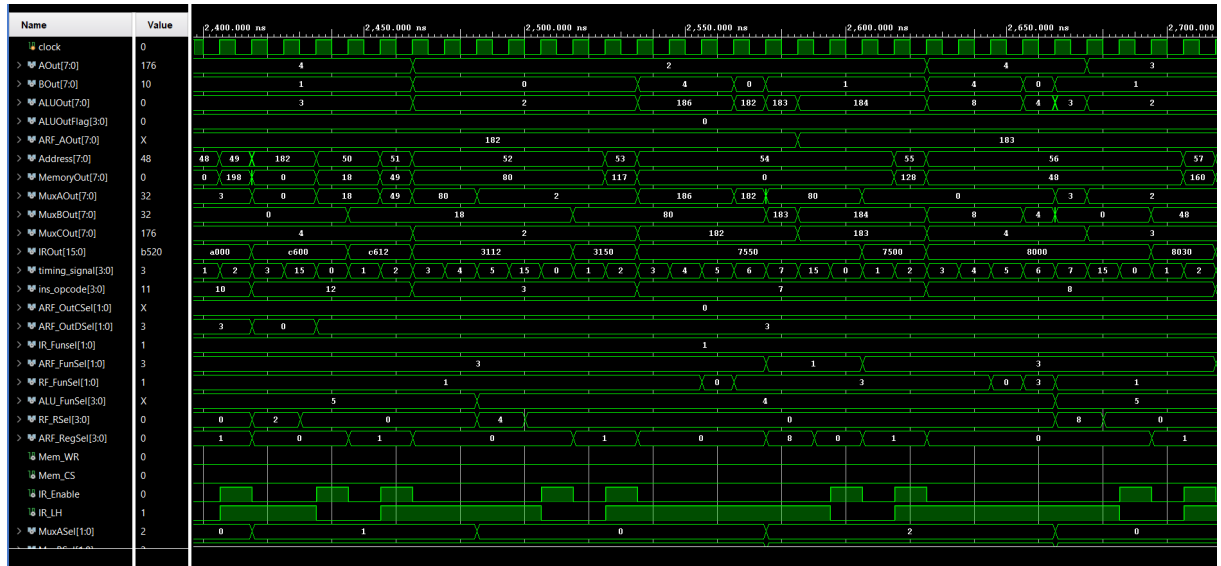


Figure 10: simulation of system

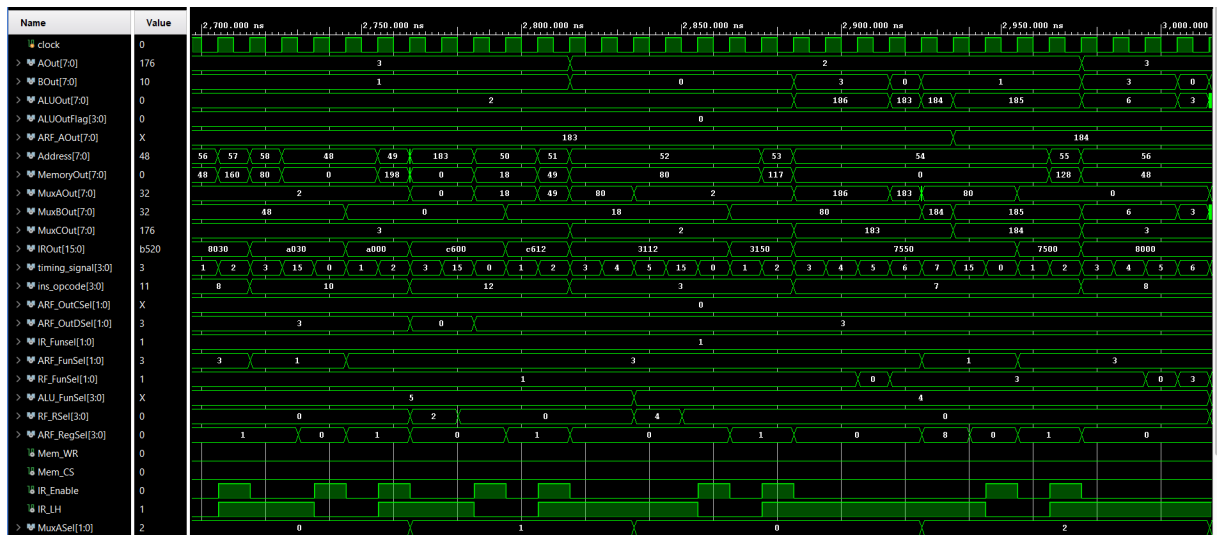


Figure 11: simulation of system

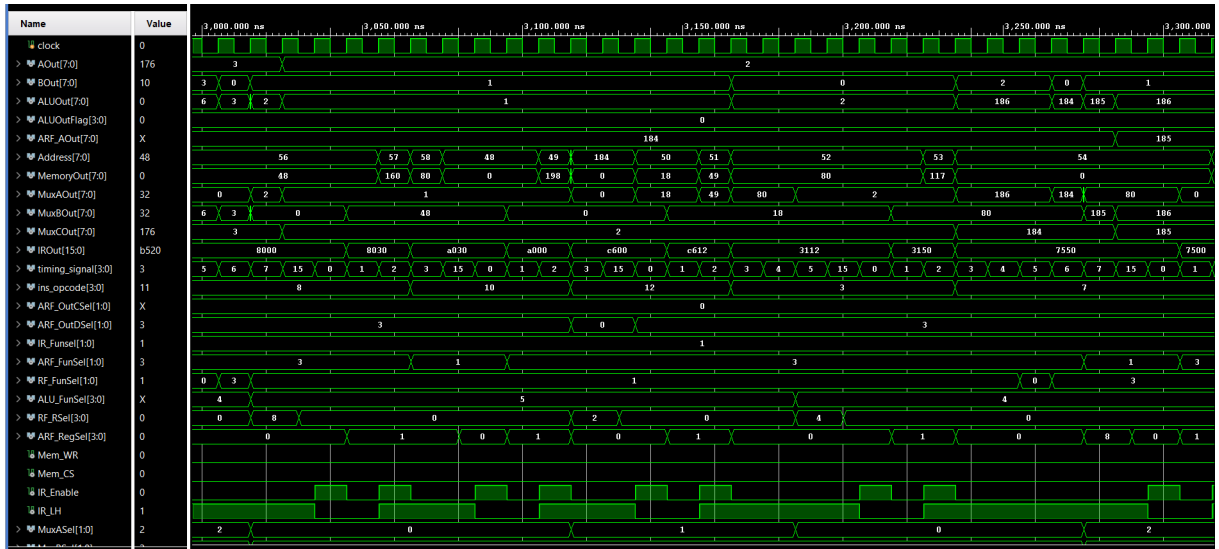


Figure 12: simulation of system

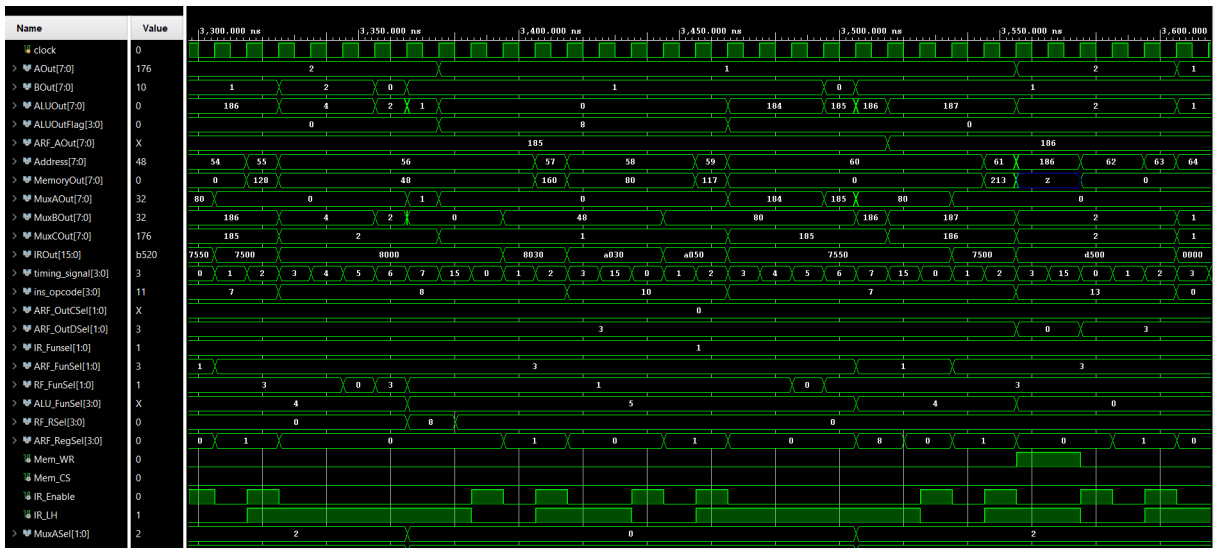


Figure 13: simulation of system

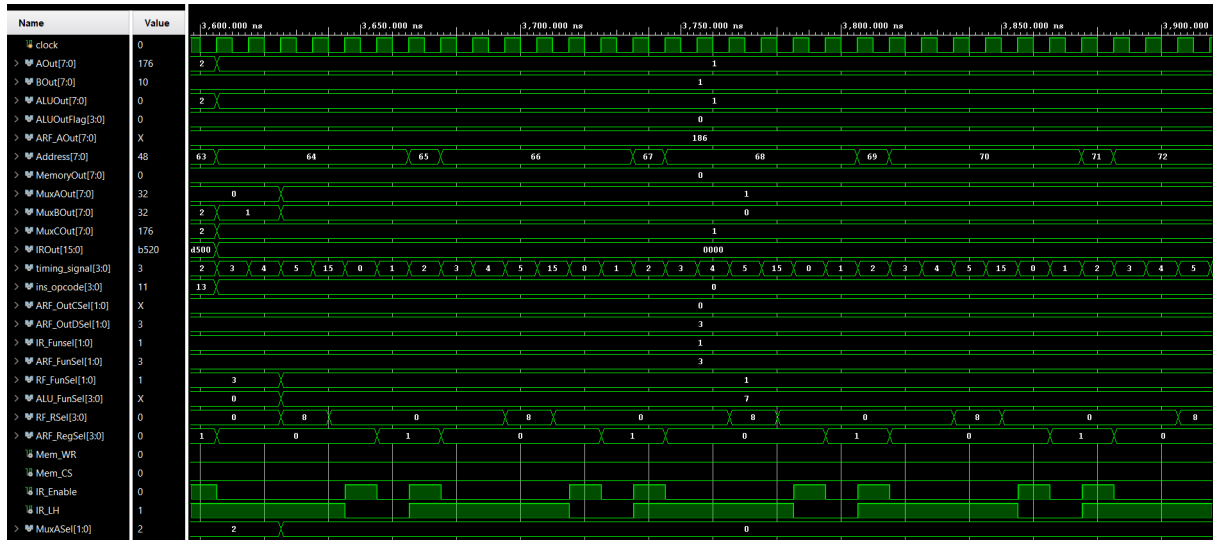


Figure 14: simulation of system

## 5 DISCUSSION

In this project, we have implemented an ALU system which can take instructions defined in Instruction Format. In order to achieve that, we have implemented a counter and by using counter's timing signal output, we have implemented fetch-decode operations and instructions' actual operations on registers in register file and address register file.

We think we greatly achieve what we wanted. We successfully implemented fetch-decode operations and instructions' actual operations defined in their OPCODE part. We've loaded our memory to instruction register and used it in ALUSystem's components. While our code has worked, we couldn't run the last ST operation successfully. While we achieve the adding numbers in memory from 0xB0 to 0xBA, we couldn't store it in memory. It is because we couldn't find a way to write value into the memory. But our success can be seen from the simulation bar.

While doing this homework, we have encountered with a lot of difficulties. One of them is our one teamfriend, Emre, were in another city, it maked our job difficult, but we've overcome it by giving less tasks to our teamfriend that is in another city.

Another big difficult was debugging. Finding the root of problems has caused us to lose a lot of days. We've encountered with a lot of different problems. Syncing the clock with code was the hardest task. Another big problem was ensuring the security. Without security, we have overwrite some registers and didn't realize it. Enhancing security has provided our code to be safe.

The other issue was the limited time. 5 ns clock was not enough for us to simulate all the loop. In order to overcome it, we have adjusted the simulation time in setting by changing xsim.simulation.runtime to 4000 ns. Default is 1000 ns.

We have learned how an instructor is performed in the computer, and its relates with clock cycles and ALU components.

## 6 CONCLUSION

In this project we designed a hardwired control unit with the help of the system module we created in the first project. We designed a simple fetch-decode-execute cycle which is capable of doing non addressing mode instructions such as arithmetic and logic operations on registers, as well as operations having an addressing mode such as loading a value from the memory or storing a value into the memory.

During this project, we communicated using whatsapp and we used GitHub to help each other fix some mistakes we made. Some operations took more than one cycle to complete, therefore we needed to arrange the timing accordingly. We needed to re-design the fetch cycle and conditions to increment the counters to make the system work properly. The error checking was challenging for this project as we needed to check each step over and over again to find what might be the cause of an error.