Chapter – 5

Control Unit

INTRODUCTION:

The control unit (CU) is a component of a computer's central processing unit (CPU) that directs the operation of the processor. It tells the computer's memory, arithmetic/logic unit and input and output devices on how to respond to a program's instructions. It controls on primitive operations (micro-operations). The micro-operations for different sub-cycles are:

A. Fetch Cycle Micro-operation:

T1: MAR ← (PC)
T2: MBR ← Memory
    PC +I; Instruction Length
T3: IR ← (MBR)

B. Indirect Cycle Micro-operation:

T1: MAR ← (IR Address)
T2: MBR ← Memory
T3: IR (Address) ← MBR (Address)

C. Interrupt Cycle Micro-operation:

T1: MBR ← (PC)
T2: MAR ← Save Address
    PC ← Routine Address
T3: Memory ← (MBR)

D. Execute Cycle Micro-operation:

    Add R1, X
    R1 ← R1 + X
T1: MAR ← (IR (Address))
T2: MBR ← Memory
T3: R_1 ← (R_1) + (MBR)

CONTROL OF PROCESSOR/CPU:

❖ Responsibilities:

The basic responsibilities of control unit is to control various operations of CPU such as:

1. Data Exchange Of CPU With Memory Or Input/output Module:
2. Internal Operations Of CPU Such As:
   a. Moving data between Registers.
   b. Making ALU to perform particular operation on data.
   c. Regulating internal operations.

❖ Functional Requirement:

In order to define the functions of a control unit that it must perform, we have to know what resources and means the control unit need to perform those operations. A control unit must have following three requirements:

1. **Defining Basic Elements of Processor:**

The basic functional units of processor are ALU, Registers, Internal Data Path, External Data Path and Control Unit itself.

2. **Describe The Micro-Operations That The Processor Performs:**
   a. Transfer data from one register to another.
   b. Transfer data from external interface to register.
   c. Performing arithmetic logical and shift micro-operations.

3. **Determine The Functions That The CPU Must Perform To Cause Micro-Operation To Be Performed:**
   a. **Execution:** The control unit cause each micro-operation to be performed.
   b. **Sequencing:** It enables the CPU to execute proper sequence of micro-operations.

STRUCTURE OF CONTROL UNIT WITH CONTROL SIGNALS:

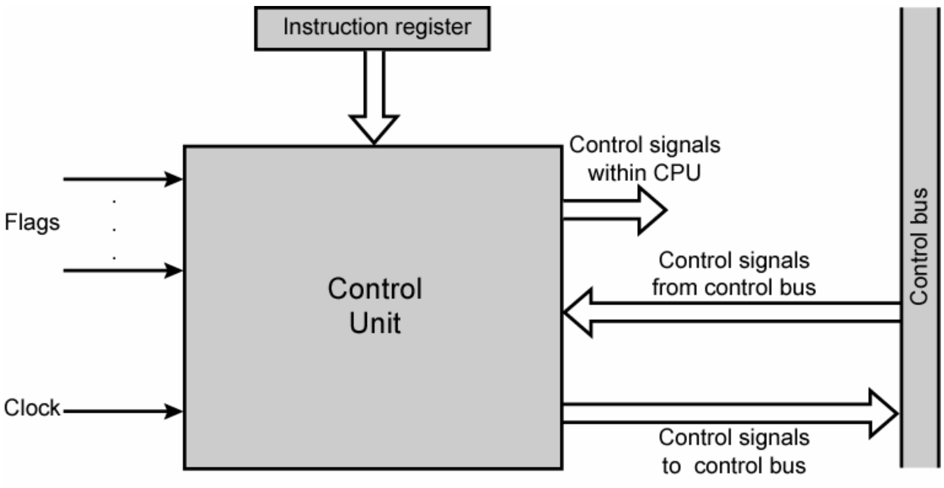

Fig: Block Diagram of Control Unit

For the control unit to perform its function it must have input that allows it to determine the state of system. These are the external specification of control unit. Internally control unit must have logics that is required to perform its sequencing and execution function. The input control unit are:

1. Clock:

This is how a control unit keeps time. The control unit cause one micro-operation or a set of simultaneous micro-operations to be performed for each clock pulse or system clock cycle time.

2. Flags:

These are needed by control unit to determine the status of processor and outcome of previous ALU operation.

3. Instruction Register:

The Opcode of current instruction is used to determine, which micro-operation is to be performed.

4. Control Signals from System Bus:

The control bus portion of system bus provides signal to control unit such as interrupt signal, acknowledgement signal, etc.

5. Control Signals within CPU:

These control signals cause two types of micro-operation such as data transfer from one register to another and performing various ALU operations using input/output and register.

6. Control Signals to System Bus:

The basic purpose of these control signals is to bring or transfer data from CPU register to memory or input/output module.

TYPES OF DESIGN ISSUES IN CONTROL UNIT:

1. Hardwired Control Unit:

In a hardwired organization control logic is implemented with logic gates, flip-flop, decoder and other digital circuits with control bus signal. On the basis of these input the output signals are generated. Therefore, output control signals are the functions of input signals.

Advantages:

- It can be optimized to produce fast mode of operations.

Disadvantages:

- It is inflexible in design because of which it is more difficult to modify.
- It is quite difficult to test and implement because there are hundreds of control lines in the computer.

Two Main Issues in Hardwired Implementation:

a. Control Unit Input:

The main key inputs for control unit are instruction register, clock signals or time generator, flags and decoded instructions.

For flags and control bus signals, each bit has a typical meaning but in other two keys, instruction register and time generator extra circuit is required i.e. decoder.

The function of decoder is to produce more output from less number of input bits.

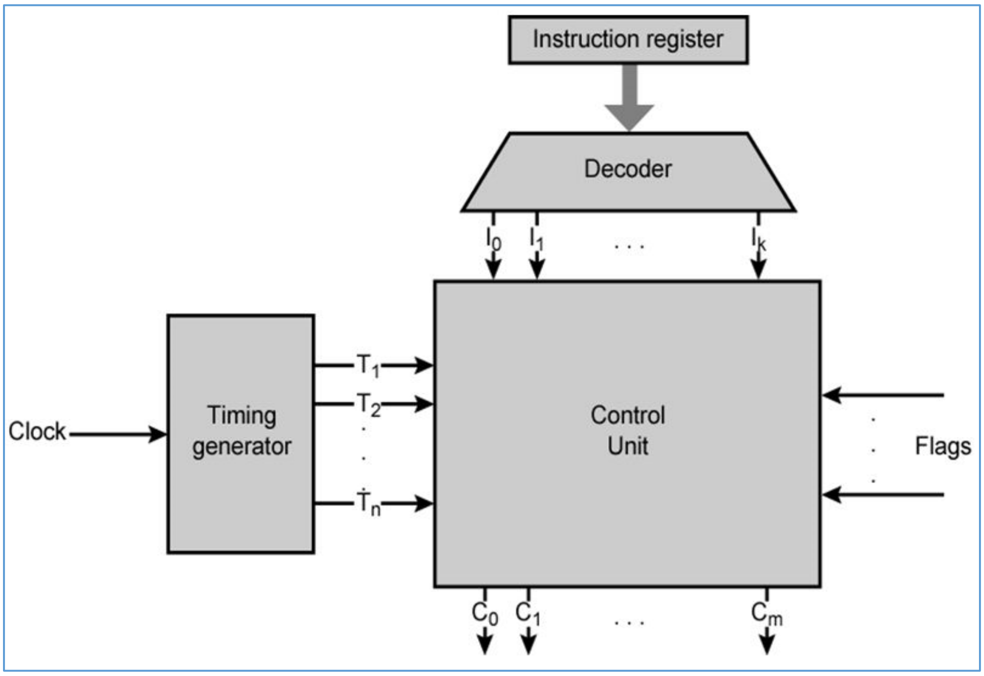

Fig: Control Unit with Decoded Input

b. <u>Control Unit Logic:</u>

Here each expression can be expressed (written) in the form of Boolean expression for each operation. The output control signals are as the function of input signals. Let us consider two control signals P and Q, which may be expressed as:

PQ = 00; Fetch Cycle
PQ = 01; Indirect Cycle
PQ = 10; Execute Cycle
PQ = 11; Interrupt Cycle

2. Micro-programmed Control Unit:

An alternative way to implement control unit is micro-program control unit. In which the logic of control unit is specified by micro-program. A micro-program consist of sequence of micro-instructions in a micro-programming language.

On executing these micro-instructions, they are responsible for execution of one or more micro-operation and sequencing through micro-operation.

A micro-program is also known as firmware or mid-way between hardware and software. In comparison to hardware, it is easier to design where as in comparison to software it is difficult to write. A micro-instruction is made responsible for generating control signal for desired control lines to implement a desired micro-operation.

A set of control signals with each bit representing a single control line is called control word. The micro-programs are stored in Read Only Memory (ROM) known as control memory.

Advantages:

- It is easy to design. So it is both cheaper and less error prone to implement.

- Since, micro-program can be changed relatively easily so, it is very flexible in comparison to hardwired control unit.

Disadvantages:

- It is slower than hardwired control unit because micro-instructions are to be fetched from control memory which is time consuming.

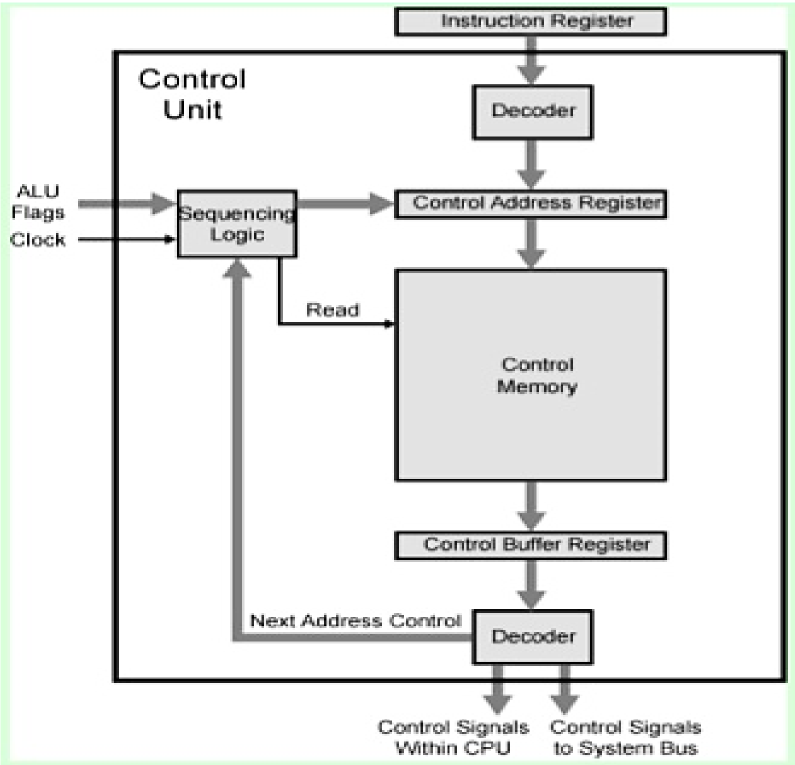

Fig: Micro programmed Control Unit

MICRO-INSTRUCTION FORMAT:

The format of micro-instruction must include following fields:

- Micro-instruction address
- Jump condition, unconditional, zero, overflow, etc.
- System bus control signals
- Internal CPU control signals

Types of Micro-instruction Format:

1. **Horizontal Micro-instruction Format:**

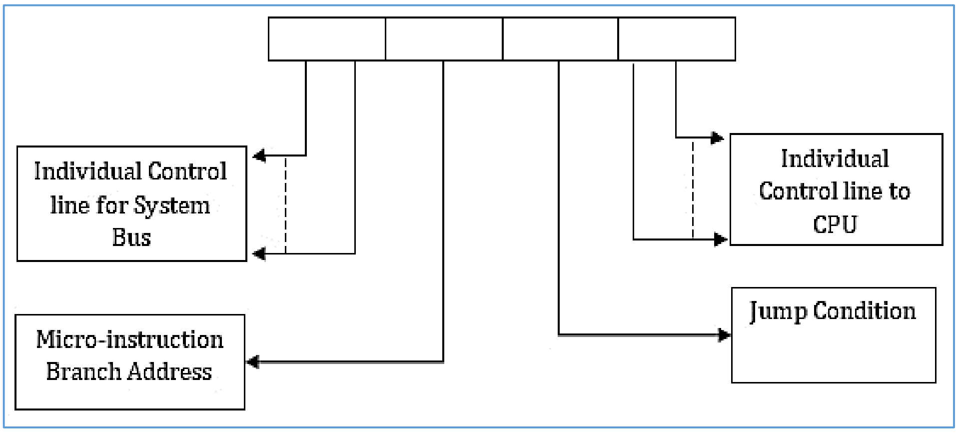

Fig: Horizontal Micro-instruction

In horizontal micro-instruction there is one bit for each internal processor control line and one bit for each system bus control line, therefore length of such microinstruction may be 100 of bits. Such micro-instructions may be executed as follows:

a. To execute micro-instruction turn ON all the control lines indicated by 1 and leave OFF all the control lines indicated by 0 bit. The resulting control signal will cause one or more micro-operations to be performed.
b. If the condition indicated by condition bit is FALSE execute next instruction in sequence.
c. If the condition indicated by condition bit is TRUE the next micro-instruction to be executed is indicated in address field.

2. **Vertical Micro-instruction Format:**

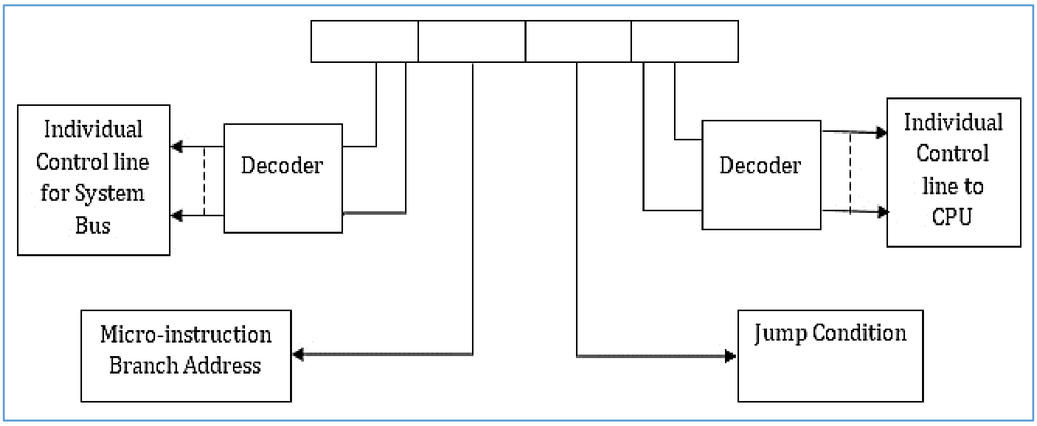

Fig: Vertical Micro-instruction

In vertical micro-instruction a code is used for each action to be performed and a decoder is used for translation of these codes into individual control signals. The advantages of vertical micro-instruction is that they are more complex and compact than horizontal microinstruction.

Difference between Horizontal and Vertical Micro-instruction Format:

Horizontal Micro-instruction Format	Vertical Micro-instruction Format
In a horizontal microinstruction every bit in the control field attaches to a control line.	In a vertical microinstruction, a code is used for each action to be performed and the decoder translates this code into individual control signals.
They do not have decoder.	They have decoder.
They need higher bits or wider bits.	They need fewer bits but higher number of decoder.
They are faster.	They are slower.
They are not complex and compact.	They are complex and compact.
They are easy to design.	They are hard to design.

Difference between Hardwired and Micro-programmed Control Unit:

Hardwired Control Unit	Micro-programmed Control Unit
It uses flags, decoder, logic gates and other digital circuits.	It uses sequence of micro-instruction in micro programming language.
As name implies it is a hardware control unit.	It is mid-way between Hardware and Software.
On the basis of input Signal output is generated.	It generates a set of control signal on the basis of control line.
Difficult to design, test and implement.	Easy to design, test and implement.
Inflexible to modify.	Flexible to modify.
Faster mode of operation.	Slower mode of operation.
Expensive and high error.	Cheaper and less error.
Used in RISC processor.	Used in CISC processor.

MICROINSTRUCTION SEQUENCING:

Sequencing means getting next microinstruction from control memory. Two consequences are involved in design of microinstruction sequencing techniques and they are:

a. Size Of Microinstruction
b. Address Generation Time

The first issues try to minimize the size of control memory to reduce the cost of control memory component. Similarly, the second issues is used to develop or design a microinstruction that can be executed as fast as possible.

In executing a microinstruction the address of next microinstruction to be executed is one of the following categories:

a. Determine by instruction register
b. Next sequential address
c. Branch address

Microinstruction Sequencing Techniques:

Based on the current microinstruction condition (content of flag and content of instruction register). A control memory address must be generated for next microinstruction. In general three techniques based on the number of address field in microinstruction is utilized for sequencing.

1. **Two Address Field Microinstruction:**

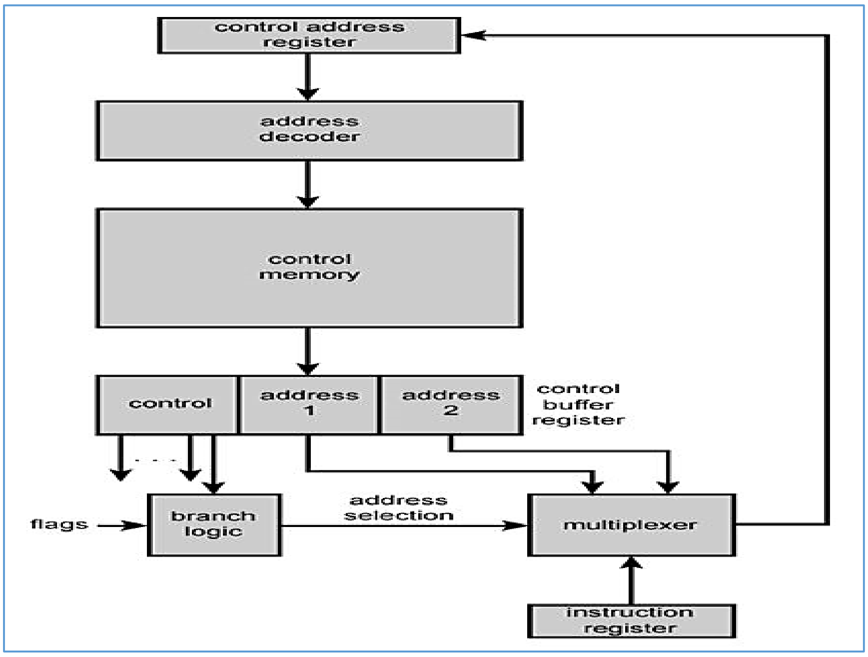

Fig: Branch Control Logic: Two Address Fields

The simplest approach is to provide two address field in each microinstruction. Above figure suggest how these information is to be used. A multiplexer is provided that serves as a destination for both address fields plus the instruction register. On the basis of address selection input, the multiplexor transmits either the Opcode or one of the two address to Control Address Register (CAR).

Address selection signals are provided by branch logic module whose input consist of control unit flags plus bits from control portion of microinstruction. Although two address approach is simple, it requires more bits in microinstruction than other approach.

2. **<u>Single Address Field Microinstruction:</u>**

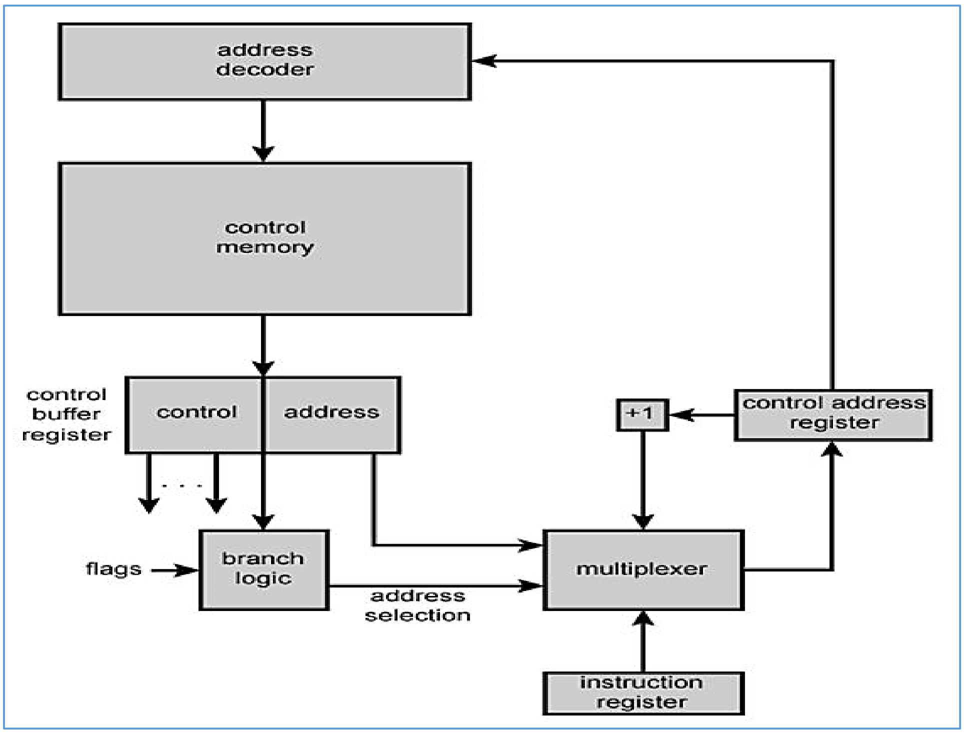

Fig: Branch Control Logic: Single Address Field

Single Address Field approach is common approach in which option for next address will be one of the following address:

a. Address Field
b. Instruction Register Code
c. Next Sequential Address

The address selection signal determine which option is selected. The approach reduces the number of address field to one.

3. **<u>Variable Format Microinstruction:</u>**

In variable format branch control logic one bit designates which format is being used. In one format, the remaining bits are used to active control signals. In the other format, some bits drive the branch logic module, and the remaining bits provide the address. With the first format, the next address is either the next sequential address or an address derived from the instruction register. With the second format, either a conditional or unconditional branch is being specified.

One disadvantage of this approach is that one entire cycle is consumed with each branch microinstruction.

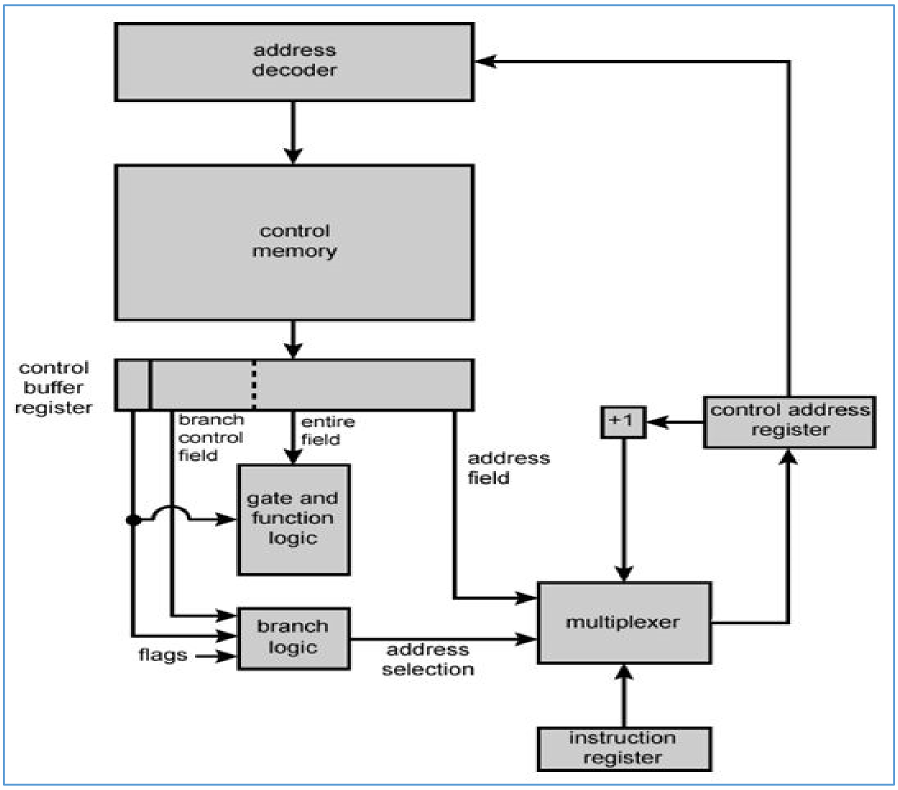

Fig: Branch Control Logic: Variable Format

MICRO-INSTRUCTION EXECUTION:

The microinstruction cycle is the basic event on a micro-programmed processor. Each cycle is made up the two parts: fetch and execute. This section deals with the execution of microinstruction. The effect of the execution of a microinstruction is to generate control signals for both the internal control to processor and the external control to processor.

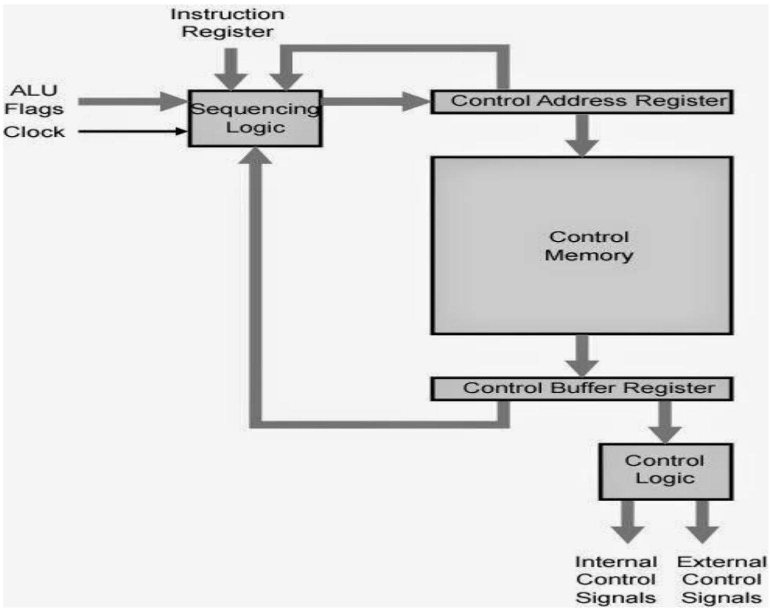

Fig: Control Unit Organization