

CHAPTER 4

Microprogrammed Control

LH 10 Hrs

BCA 2nd semester
MP and CA
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CONTENTS

- Basic Design of Accumulator: Control of AC register, ALU organization
- Control Memory, Address Sequencing: Conditional Branching, Mapping of Instruction, Subroutines, Microprogram: Symbolic Microprogram, Binary Microprogram, Design of Control Unit, Basic requirement of Control Unit, Structure of Control Unit, Microprogram Sequencer.

Questions:

1. Explain the Design procedure of Accumulator Logic.
2. Explain the Gate structure for controlling the LD, INR, and CLR of Accumulator.
3. Explain the components of ALU with their functions.
4. Define the Control Unit. Explain the organization of Microprogrammed Control unit.
5. Differentiate between Hardwired and Microprogrammed Control Design.
6. Explain the address sequencing procedure.
7. Explain the conditional branching mechanism.
8. What do you mean by mapping of instructions? Explain the procedure for mapping from instruction code to microinstruction address.
9. Define Microprogram. Differentiate between Symbolic and Binary microprogram with example.
10. Explain the basic requirements for designing control unit.
11. Explain the structure of Control Unit.
12. Write the role of microprogram sequencer in microprogrammed control unit.
13. Define following terminologies : **Control Memory, Control Word, Microoperations, Microcode and Microinstructions**

Microprogrammed vs Hardwired Control

HARDWIRED CONTROL UNIT	MICROPROGRAMMED CONTROL UNIT
The control unit whose control signals are generated by the hardware through a sequence of instructions is called a hardwired control unit.	The control unit whose control signals are generated by the data stored in control memory and constitute a program on the small scale is called a microprogrammed control unit
The control logic of a hardwired control is implemented with gates, flip flops, decoders etc.	The control logic of a micro-programmed control is the instructions that are stored in control memory to initiate the required sequence of microoperations.
Wiring changes are made in the hardwired control unit if there are any changes required in the design.	Changes in a microprogrammed control unit are done by updating the microprogram in control memory.
Hardwired control unit are faster and known to have complex structure.	Microprogrammed control unit is comparatively slow compared but are simple in structure.

Terminologies

- **Hardwired Control Unit:**

When the control signals are generated by hardware using conventional logic design techniques, the control unit is said to be hardwired.

- **Micro programmed control unit:**

A control unit whose binary control variables are stored in memory is called a microprogrammed control unit.

- **Control Memory:**

Control Memory is the storage in the microprogrammed control unit to store the microprogram.

- **Control Word:**

The control variables at any given time can be represented by a control word string of 1's and 0's called a control word.

- **Microoperations:**

Micro-operations perform basic operations on data stored in one or more registers, including transferring data between registers or between registers and external buses of the central processing unit (CPU), and performing arithmetic or logical operations on registers.

- **Microcode:**

A very low-level instruction set which is stored permanently in a computer or peripheral controller and controls the operation of the device.

- **Microinstruction:**

A single instruction in microcode. It is the most elementary instruction in the computer, such as moving the contents of a register to the arithmetic logic unit (ALU).

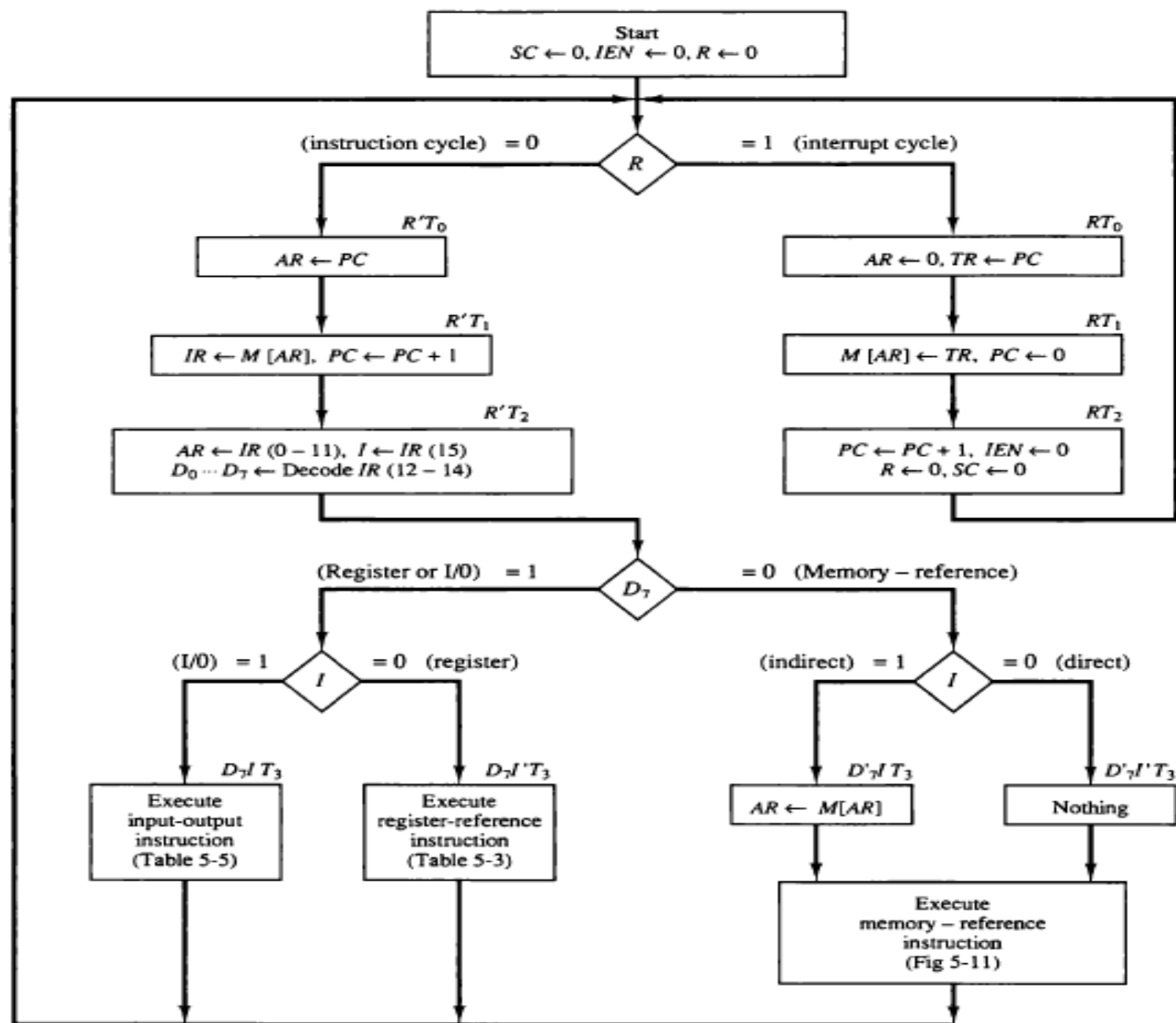
- **Microprogram:**

A set or sequence of microinstructions.

Design of Basic Computer

The basic computer consists of the following hardware components:

- A memory unit with 4096 words of 16 bits each.
- Nine registers: AR(Address Reg.), PC (Program Counter), DR(Data Reg.), AC (Accumulator), IR (Instruction Reg.), TR (Temp. Reg.),
- OUTR (Output Reg.), INPR (Input Reg.), and SC (Sequence Counter).
- Flip-flops: IEN (Interrupt Enable), FGI (Input Flag), and FGO (Output Flag).
- Two decoders: a 3 x 8 operation decoder and a 4 x 16 timing decoder
- A 16-bit common bus.
- Control logic gates.
- Adder and logic circuit connected to the input of AC.



Control Functions and Microoperations of Basic Computer

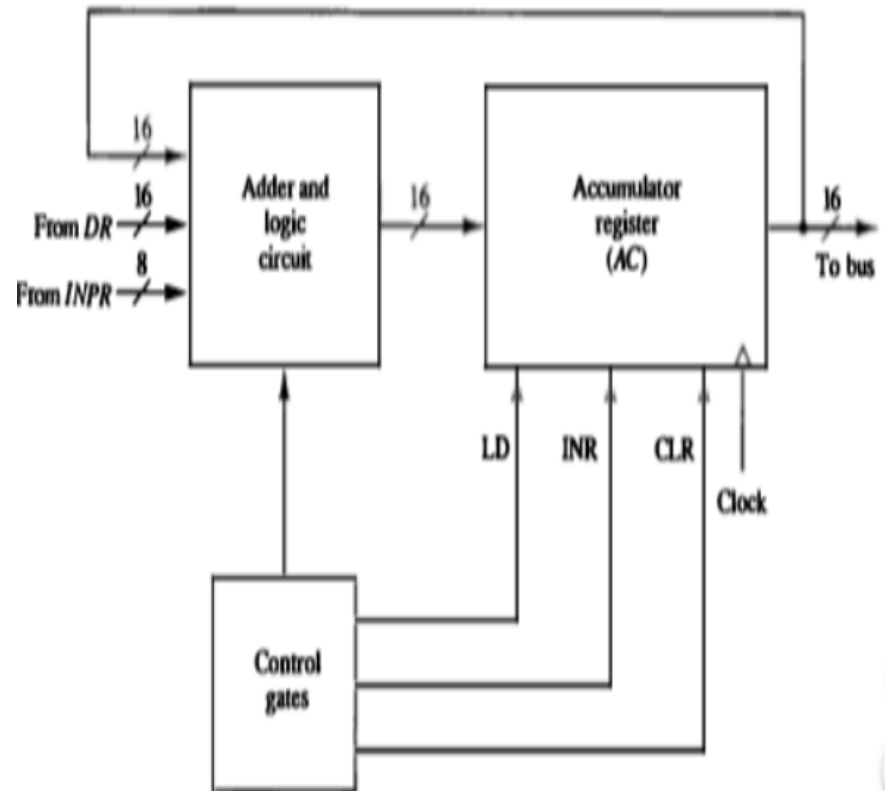
TABLE 5-6 Control Functions and Microoperations for the Basic Computer

Fetch	$R'T_0$:	$AR \leftarrow PC$
	$R'T_1$:	$IR \leftarrow M[AR], \quad PC \leftarrow PC + 1$
Decode	$R'T_2$:	$D_0, \dots, D_7 \leftarrow \text{Decode } IR(12-14),$ $AR \leftarrow IR(0-11), \quad I \leftarrow IR(15)$
Indirect	D_5IT_2 :	$AR \leftarrow M[AR]$
Interrupt:		
	$T_0T_1T_2(IEN)(FGI + FGO)$:	$R \leftarrow 1$
	RT_0 :	$AR \leftarrow 0, \quad TR \leftarrow PC$
	RT_1 :	$M[AR] \leftarrow TR, \quad PC \leftarrow 0$
	RT_2 :	$PC \leftarrow PC + 1, \quad IEN \leftarrow 0, \quad R \leftarrow 0, \quad SC \leftarrow 0$
Memory-reference:		
AND	D_0T_4 :	$DR \leftarrow M[AR]$
	D_0T_5 :	$AC \leftarrow AC \wedge DR, \quad SC \leftarrow 0$
ADD	D_1T_4 :	$DR \leftarrow M[AR]$
	D_1T_5 :	$AC \leftarrow AC + DR, \quad E \leftarrow C_{out}, \quad SC \leftarrow 0$
LDA	D_2T_4 :	$DR \leftarrow M[AR]$
	D_2T_5 :	$AC \leftarrow DR, \quad SC \leftarrow 0$
STA	D_3T_4 :	$M[AR] \leftarrow AC, \quad SC \leftarrow 0$
BUN	D_4T_4 :	$PC \leftarrow AR, \quad SC \leftarrow 0$
BSA	D_5T_4 :	$M[AR] \leftarrow PC, \quad AR \leftarrow AR + 1$
	D_5T_5 :	$PC \leftarrow AR, \quad SC \leftarrow 0$
ISZ	D_6T_4 :	$DR \leftarrow M[AR]$
	D_6T_5 :	$DR \leftarrow DR + 1$
	D_6T_6 :	$M[AR] \leftarrow DR, \quad \text{if } (DR = 0) \text{ then } (PC \leftarrow PC + 1), \quad SC \leftarrow 0$
Register-reference:		
	$D_3I'T_3 = r$ (common to all register-reference instructions)	
	$IR(i) = B_i$ ($i = 0, 1, 2, \dots, 11$)	
	r :	$SC \leftarrow 0$
CLA	rB_{11} :	$AC \leftarrow 0$
CLE	rB_{10} :	$E \leftarrow 0$
CMA	rB_9 :	$AC \leftarrow \overline{AC}$
CME	rB_8 :	$E \leftarrow \overline{E}$
CIR	rB_7 :	$AC \leftarrow \text{shr } AC, \quad AC(15) \leftarrow E, \quad E \leftarrow AC(0)$
CIL	rB_6 :	$AC \leftarrow \text{shl } AC, \quad AC(0) \leftarrow E, \quad E \leftarrow AC(15)$
INC	rB_5 :	$AC \leftarrow AC + 1$
SPA	rB_4 :	If $(AC(15) = 0)$ then $(PC \leftarrow PC + 1)$
SNA	rB_3 :	If $(AC(15) = 1)$ then $(PC \leftarrow PC + 1)$
SZA	rB_2 :	If $(AC = 0)$ then $PC \leftarrow PC + 1$
SZE	rB_1 :	If $(E = 0)$ then $(PC \leftarrow PC + 1)$
HLT	rB_0 :	$S \leftarrow 0$
Input-output:		
	$D_3IT_3 = p$ (common to all input-output instructions)	
	$IR(i) = B_i$ ($i = 6, 7, 8, 9, 10, 11$)	
	p :	$SC \leftarrow 0$
INP	pB_{11} :	$AC(0-7) \leftarrow INPR, \quad FGI \leftarrow 0$
OUT	pB_{10} :	$OUTR \leftarrow AC(0-7), \quad FGO \leftarrow 0$
SKI	pB_9 :	If $(FGI = 1)$ then $(PC \leftarrow PC + 1)$
SKO	pB_8 :	If $(FGO = 1)$ then $(PC \leftarrow PC + 1)$
ION	pB_7 :	$IEN \leftarrow 1$
IOF	pB_6 :	$IEN \leftarrow 0$

Design of Accumulator Logic

- The circuits associated with the AC register are shown in Fig. The adder and logic circuit has three sets of inputs.
- One set of 16 inputs comes from the outputs of AC.
- Another set of 16 inputs comes from the data register DR.
- A third set of eight inputs comes from the input register INPR.
- The outputs of the adder and logic circuit provide the data inputs for the register. In addition, it is necessary to include logic gates for controlling the LD, INR, and CLR in the register and for controlling the operation of the adder and logic circuit.

Figure 5-19 Circuits associated with AC.



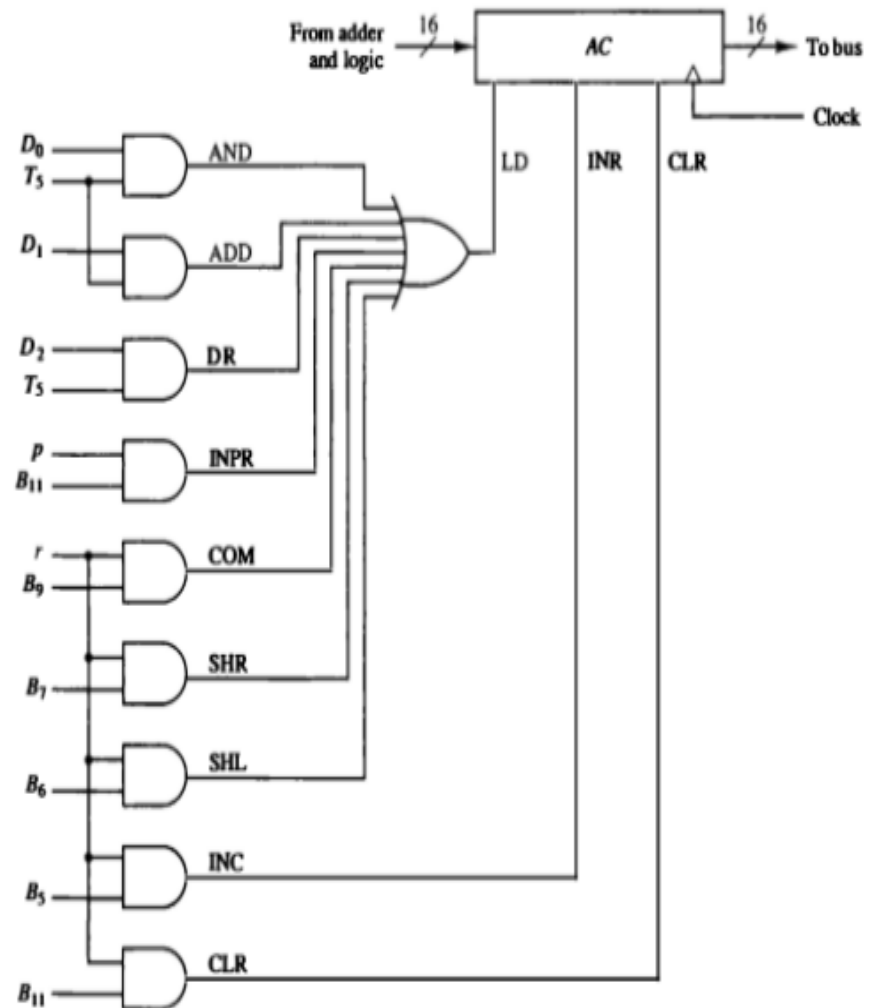
In order to design the logic associated with AC , it is necessary to go over the register transfer statements in Table and extract all the statements that change the content of AC .

$D_0T_5:$	$AC \leftarrow AC \wedge DR$	AND with DR
$D_1T_5:$	$AC \leftarrow AC + DR$	Add with DR
$D_2T_5:$	$AC \leftarrow DR$	Transfer from DR
$pB_{11}:$	$AC(0-7) \leftarrow INPR$	Transfer from $INPR$
$rB_9:$	$AC \leftarrow \overline{AC}$	Complement
$rB_7:$	$AC \leftarrow shr\ AC, \quad AC(15) \leftarrow E$	Shift right
$rB_6:$	$AC \leftarrow shl\ AC, \quad AC(0) \leftarrow E$	Shift left
$rB_{11}:$	$AC \leftarrow 0$	Clear
$rB_5:$	$AC \leftarrow AC + 1$	Increment

Control of AC Register – Gate Structure

- The gate structure that controls the LD, INR, and CLR inputs of AC is shown in Fig.
- The output of the AND gate that generates this control function is connected to the CLR input of the register.
- Similarly, the output of the gate that implements the increment micro operation is connected to the INR input of the register.
- The other seven micro operations are generated in the adder and logic circuit and are loaded into AC at the proper time.
- The outputs of the gates for each control function is marked with a symbolic name. These outputs are used in the design of the adder and logic circuit.

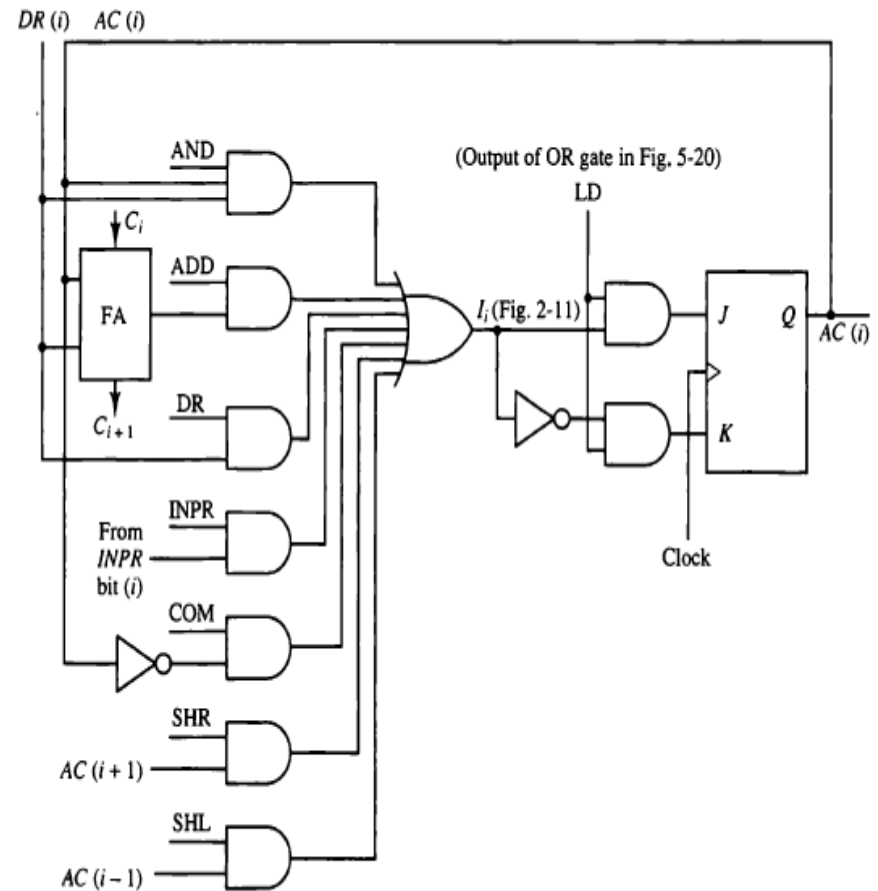
Figure 5-20 Gate structure for controlling the LD, INR, and CLR of AC.



Adder and Logic Circuit

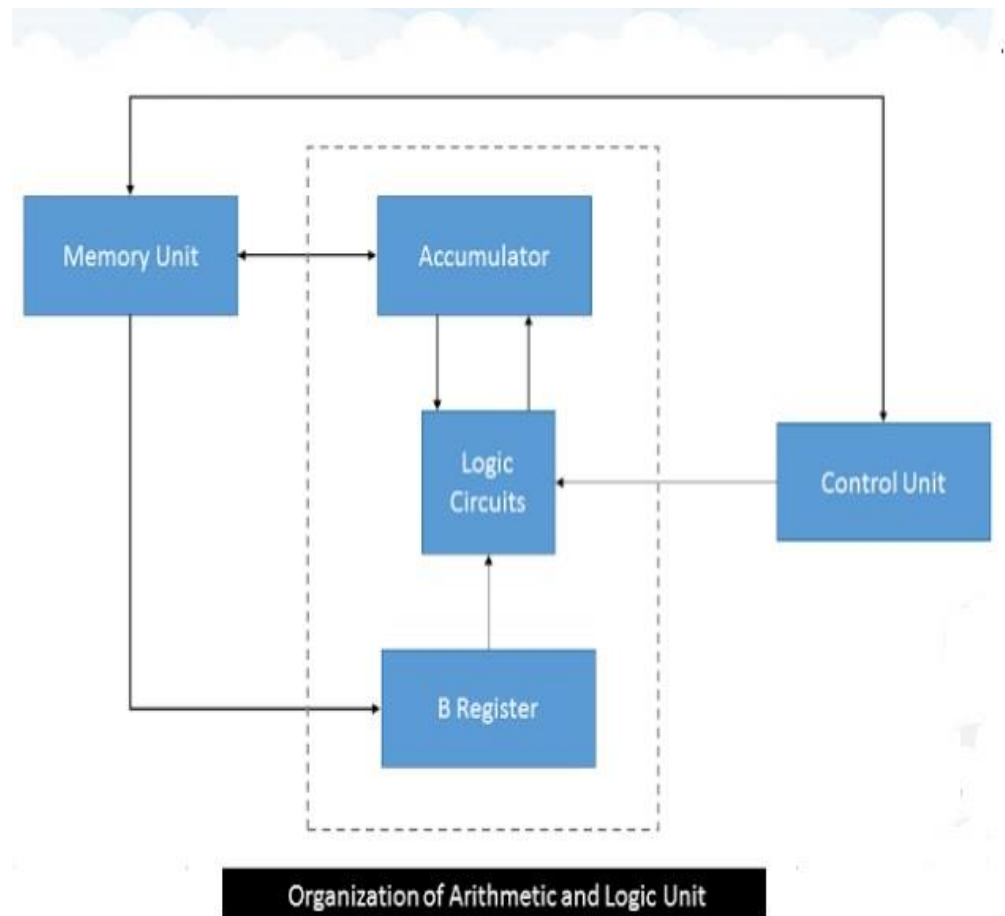
The adder and logic circuit can be sub-divided into 16 stages with each stage corresponding to one bit of AC. The load (LD) input is connected to the inputs of the AND gate.

Figure 5-21 One stage of adder and logic circuit.



ALU Organization

- Various circuits are required to process data or perform arithmetical operations which are connected to microprocessor's ALU.
- Accumulator and Data Buffer stores data temporarily. These data are processed as per control instructions to solve problems. Such problems are addition, multiplication etc.



Functions of ALU:

Functions of ALU or Arithmetic & Logic Unit can be categorized into following 3 categories:

1. **Arithmetic Operations:** Additions, multiplications etc. are example of arithmetic operations. Finding greater than or smaller than or equality between two numbers by using subtraction is also a form of arithmetic operations.
2. **Logical Operations:** Operations like AND, OR, NOR, NOT etc. using logical circuitry are examples of logical operations.
3. **Data Manipulations:** Operations such as flushing a register is an example of data manipulation. Shifting binary numbers are also example of data manipulation.

Control Memory

- A computer that employs a microprogrammed control unit will have two separate memories: **a main memory and a control memory**.
- The **main memory** is available to the user for storing the programs. The contents of main memory may alter when the data are manipulated and every time that the program is changed. The user's program in main memory consists of machine instructions and data.
- In contrast, the **control memory** holds a fixed microprogram that cannot be altered by the occasional user. The microprogram consists of microinstructions that specify various internal control signals for execution of register microoperations.
- Each machine instruction initiates a series of microinstructions in control memory. These microinstructions generate the microoperations to fetch the instruction from main memory; to evaluate the effective address, to execute the operation specified by the instruction, and to return control to the fetch phase in order to repeat the cycle for the next instruction.

- The control unit initiates a series of sequential steps of microoperations. During any given time, certain microoperations are to be initiated, while others remain idle. The control variables at any given time can be represented by a string of 1's and 0's called a **control word**.
- As such, control words can be programmed to perform various operations on the components of the system.
- The microinstruction specifies one or more microoperations for the system. A sequence of microinstructions constitutes a microprogram.

Microprogrammed Control Organization

- The general configuration of a microprogrammed control unit is demonstrated in the block diagram of Fig. The control memory is assumed to be a ROM, within which all control information is permanently stored.

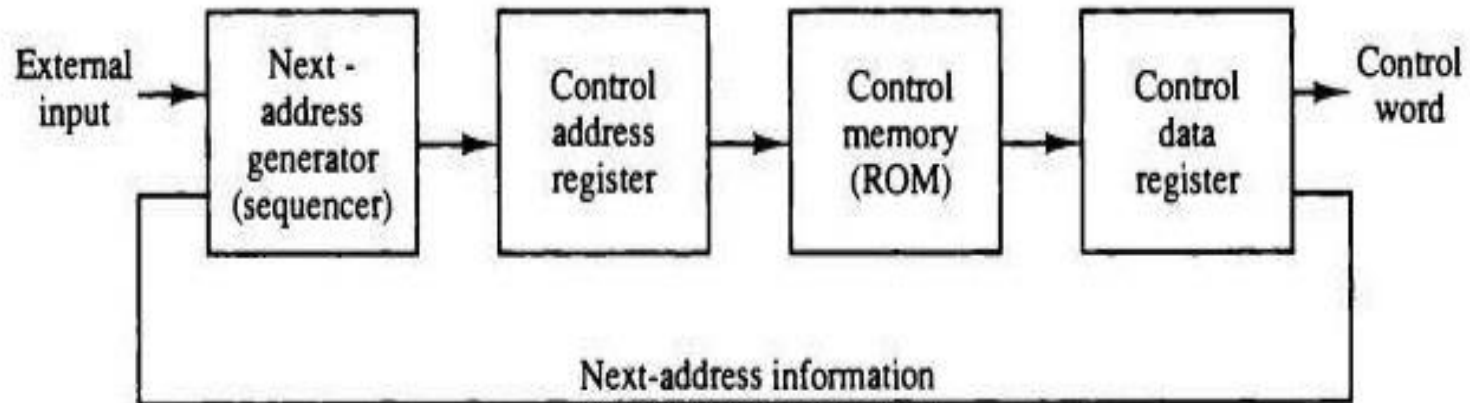


Fig: Microprogrammed control organization

- **Sequencer (Next address generator):** The device or program that generates address of next microinstruction to be executed is called sequencer. While the microoperations are being executed, the next address is computed in the next address generator circuit and then transferred into the control address register to read the next microinstruction.
- **Control Address Register:** CAR contains address of microinstruction.
- **Control Data Register:** CDR contains microinstruction read from memory. The microinstruction contains a control word that specifies one or more microoperations. The data register is sometimes called a *pipeline register*.

It allows the execution of the microoperations specified by the control word simultaneously with the generation of the next microinstruction. This configuration requires a two-phase clock, with one clock applied to the address register and the other to the data register.

Address Sequencing

- Microinstructions are stored in control memory in groups, with each group specifying a routine.
- Each computer instruction has its own microprogram routine in control memory to generate the microoperations that execute the instruction.
- To appreciate the address sequencing in a microprogram control unit, let us enumerate the steps that the control must undergo during the execution of a single computer instruction.
- An **initial address** is loaded into the control address register when power is turned on in the computer. This address is usually the address of the first microinstruction that activates the instruction fetch routine. At the end of the fetch routine, the instruction is in the instruction register of the computer.
- The control memory next must go through the routine that determines the effective address of the operand. When the effective address computation routine is completed, the address of the operand is available in the memory address register.

- The next step is to generate the microoperations that execute the instruction fetched from memory. The microoperation steps to be generated in processor registers depend on the operation code part of the instruction.
- When the execution of the instruction is completed, control must return to the fetch routine. This is accomplished by executing an unconditional branch microinstruction to the first address of the fetch routine.
- In summary, the address sequencing capabilities required in a control memory are:
 1. Incrementing of the control address register.
 2. Unconditional branch or conditional branch, depending on status bit conditions.
 3. A mapping process from the bits of the instruction to an address for control memory.
 4. A facility for subroutine call and return.

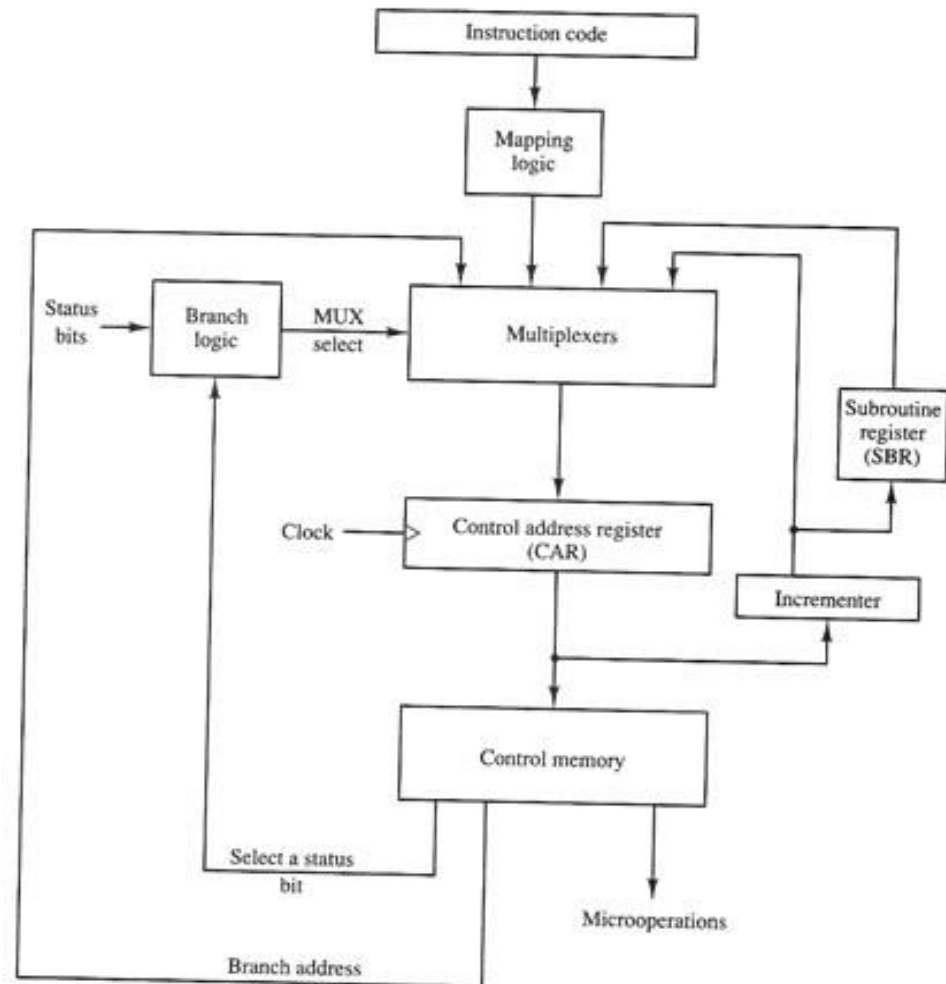


Fig: Block diagram of address sequencer.

The diagram shows four different paths from which the control address register (CAR) receives the address. The incrementer increments the content of the control address register by one, to select the next microinstruction in sequence. Branching is achieved by specifying the branch address in one of the fields of the microinstruction. Conditional branching is obtained by using part of the microinstruction to select a specific status bit in order to determine its condition. An external address is transferred into control memory via a mapping logic circuit. The return address for a subroutine is stored in a special register whose value is then used when the microprogram wishes to return from the subroutine.

Control address register receives address of next microinstruction from different sources.

- a) Incrementer simply increments the address by one
- b) In case of branching, branch address is specified in one of the field of microinstruction.
- c) In case of subroutine call, return address is stored in the register SBR which is used when returning from called subroutine.

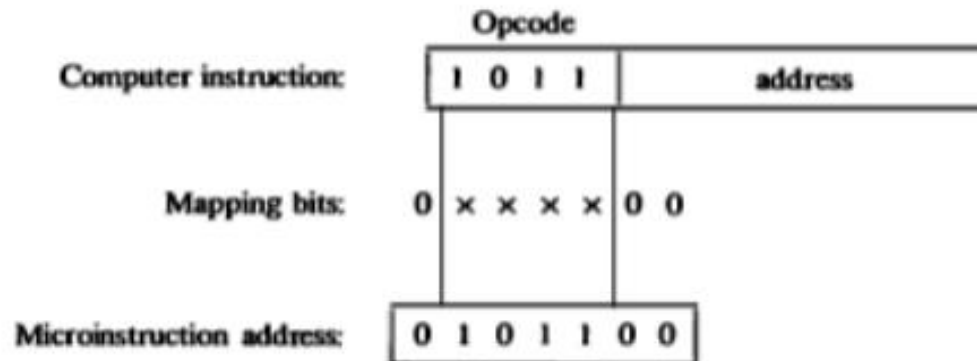
Conditional Branching

- The branch logic provides decision-making capabilities in the control unit.
- The status conditions are special bits in the system that provide parameter information such as the carry-out of an adder, the sign bit of a number, the mode bits of an instruction, and input or output status conditions.
- Information in these bits can be tested and actions initiated based on their condition: whether their value is 1 or 0.
- The status bits, together with the field in the microinstruction that specifies a branch address, control the conditional branch decisions generated in the branch logic.
- The branch logic hardware may be implemented in a variety of ways. The simplest way is to test the specified condition and branch to the indicated address if the condition is met; otherwise, the address register is incremented.

Mapping of Instruction

- Each instruction has its own microprogram routine stored in a given location of control memory. The transformation from the instruction code bits to an address in control memory where the routine is located is referred to as a mapping process.
- A mapping procedure is a rule that transforms the instruction code into a control memory address.
- For example, a computer with a simple instruction format as shown in Fig. has an operation code of four bits. Assume further that the control memory has 128 words, requiring an address of seven bits. For each operation code there exists a microprogram routine in control memory that executes the instruction.

Figure 7-3 Mapping from instruction code to microinstruction address.



- One simple mapping process that converts the 4- bit operation code to a 7-bit address for control memory.
- This mapping consists of placing a 0 in the most significant bit of the address, transferring the four operation code bits, and clearing the two least significant bits of the control address register. This provides for each computer instruction a microprogram routine with a capacity of four microinstructions.
- If the routine needs more than four microinstructions, it can use addresses 1000000 through 1111111.
- If it uses fewer than four microinstructions, the unused memory locations would be available for other routines.

Subroutines

- Subroutines are programs that are used by other routines to accomplish a particular task.
- A subroutine can be called from any point within the main body of the microprogram.
- Frequently, many microprograms contain identical sections of code. Microinstructions can be saved by employing subroutines that use common sections of microcode.
- For example, the sequence of microoperations needed to generate the effective address of the operand for an instruction is common to all memory reference instructions. This sequence could be a subroutine that is called from within many other routines to execute the effective address computation.
- Microprograms that use subroutines must have a provision for storing the return address during a subroutine call and restoring the address during a subroutine return. This may be accomplished by placing the incremented output from the control address register into a subroutine register and branching to the beginning of the subroutine. The subroutine register can then become the source for transferring the address for the return to the main routine.

Microprogram Example

Once the configuration of a computer and its microprogrammed control unit is established, the designer's task is to generate the microcode for the control memory. This code generation is called microprogramming and is a process similar to conventional machine language programming.

Computer Configuration:

- It consists of two memory units: a main memory for storing instructions and data, and a control memory for storing the microprogram
- Four registers are associated with the processor unit and two with the control unit. The processor registers are PC, AR, DR and AC. The control registers are CAR and SBR.
- The control unit has control address register CAR and subroutine register SBR.
- The transfer of information among the registers in processor is done through multiplexer rather than a common bus. DR can receive information from AC, PC or memory. AR can receive information from PC or DR. PC can receive information only from AR.
- The arithmetic, logic and shift unit performs microoperations with data from AC and DR and places the result in AC. Note that memory receives its address from AR. Input data written to memory come from DR, and data read from memory can go only to DR.
- The computer instruction format has three fields: a 1-bit field for indirect addressing symbolized by I, a 4-bit operation code (op-code), and an 11-bit address field. The figure below lists four of the 16 possible memory reference instructions.

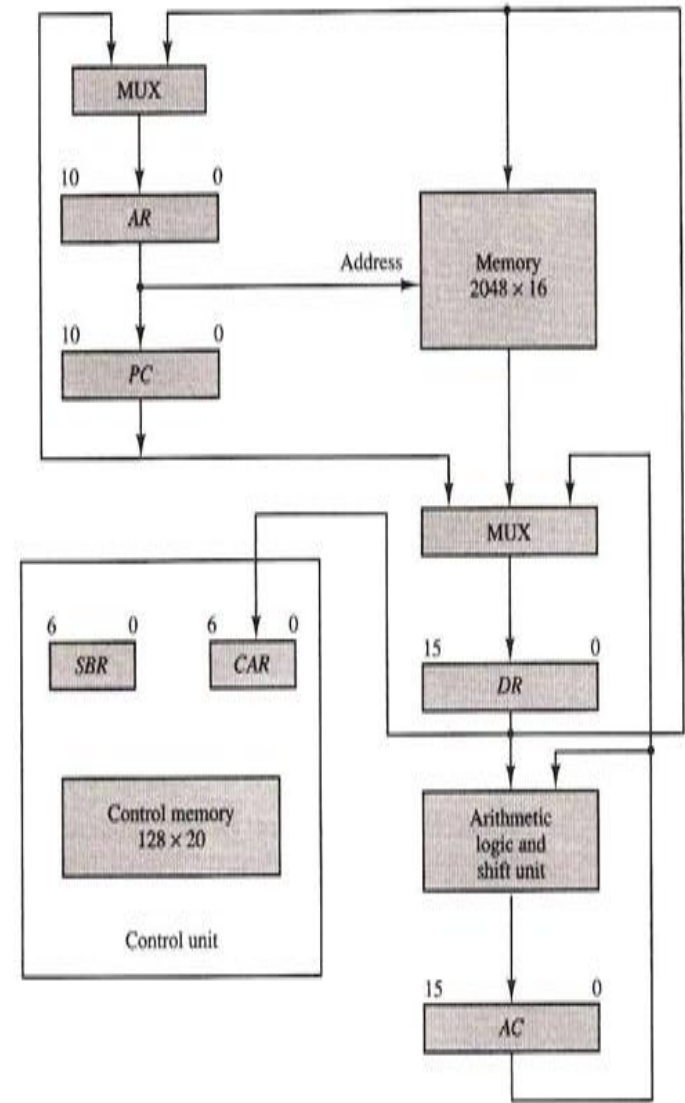


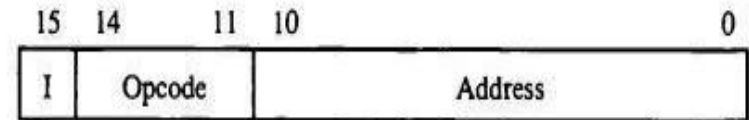
Fig: Computer hardware configuration

➤The ADD instruction adds the content of the operand found in the effective address to the content of AC.

➤The BRANCH instruction causes a branch to the effective address if the operand in AC is negative. The program proceeds with the next consecutive instruction if AC is not negative. The AC is negative if its sign bit is a 1.

➤The STORE instruction transfers the content of AC into the memory word specified by the effective address.

➤The EXCHANGE instruction swaps the data between AC and the memory word specified by the effective address.



(a) Instruction format

Symbol	Opcode	Description
ADD	0000	$AC \leftarrow AC + M[EA]$
BRANCH	0001	If $(AC < 0)$ then $(PC \leftarrow EA)$
STORE	0010	$M[EA] \leftarrow AC$
EXCHANGE	0011	$AC \leftarrow M[EA], M[EA] \leftarrow AC$

EA is the effective address

(b) Four computer instructions

Microprogram

- Microprogram is a sequence of microinstructions that controls the operation of an arithmetic and logic unit so that machine code instructions are executed.
- It is a microinstruction program that controls the functions of a central processing unit or peripheral controller of a computer.
- **Microinstruction Format**

The microinstruction format for the control memory is shown in Fig. The 20 bits of the microinstruction are divided into four functional parts. The three fields F1, F2, and F3 specify microoperations for the computer. The CD field selects status bit conditions. The BR field specifies the type of branch to be used. The AD field contains a branch address. The address field is seven bits wide, since the control memory has $128 = 2^7$ words.



Fig: Microinstruction code format (20 bits)

F1, F2, F3: Microoperation fields

CD: Condition for branching

BR: Branch field

AD: Address field

Each microoperation below is defined using register transfer statements and is assigned a symbol for use in symbolic microprogram.

Symbols & Binary Code for Microoperations

F1	Microoperation	Symbol
000	None	NOP
001	$AC \leftarrow AC + DR$	ADD
010	$AC \leftarrow 0$	CLRAC
011	$AC \leftarrow AC + 1$	INCAC
100	$AC \leftarrow DR$	DRTAC
101	$AR \leftarrow DR(0-10)$	DRTAR
110	$AR \leftarrow PC$	PCTAR
111	$M[AR] \leftarrow DR$	WRITE

F2	Microoperation	Symbol
000	None	NOP
001	$AC \leftarrow AC - DR$	SUB
010	$AC \leftarrow AC \vee DR$	OR
011	$AC \leftarrow AC \wedge DR$	AND
100	$DR \leftarrow M[AR]$	READ
101	$DR \leftarrow AC$	ACTDR
110	$DR \leftarrow DR + 1$	INCDR
111	$DR(0-10) \leftarrow PC$	PCTDR

F3	Microoperation	Symbol
000	None	NOP
001	$AC \leftarrow AC \oplus DR$	XOR
010	$AC \leftarrow \overline{AC}$	COM
011	$AC \leftarrow \text{shl } AC$	SHL
100	$AC \leftarrow \text{shr } AC$	SHR
101	$PC \leftarrow PC + 1$	INCP
110	$PC \leftarrow AR$	ARTPC
111	Reserved	

CD	Condition	Symbol	Comments
00	Always = 1	U	Unconditional branch
01	$DR(15)$	I	Indirect address bit
10	$AC(15)$	S	Sign bit of AC
11	$AC = 0$	Z	Zero value in AC

BR	Symbol	Function
00	JMP	$CAR \leftarrow AD$ if condition = 1 $CAR \leftarrow CAR + 1$ if condition = 0
01	CALL	$CAR \leftarrow AD$, $SBR \leftarrow CAR + 1$ if condition = 1 $CAR \leftarrow CAR + 1$ if condition = 0
10	RET	$CAR \leftarrow SBR$ (Return from subroutine)
11	MAP	$CAR(2-5) \leftarrow DR(11-14)$, $CAR(0,1,6) \leftarrow 0$

Description

- Each microoperation in Table is defined with a register transfer statement and is assigned a symbol for use in a symbolic microprogram. All transfer-type microoperations symbols use five letters. The first two letters designate the source register, the third letter is always a T, and the last two letters designate the destination register. For example, the microoperation that specifies the transfer $AC \leftarrow DR$ (F1 = 100) has the symbol DRTAC, which stands for a transfer from DR to AC.
- The **CD** (condition) field consists of two bits which are encoded to specify four status bit conditions as listed in Table. The first condition is always a 1, so that a reference to $CD = 00$ (or the symbol U) will always find the condition to be true. We will use the symbols U, I, S, and Z for the four status bits when we write microprograms in symbolic form.
- The **BR** (branch) field consists of two bits. It is used, in conjunction with the address field AD, to choose the address of the next microinstruction. As shown in Table, when $BR = 00$, the control performs a jump (JMP) operation (which is similar to a branch), and when $BR = 01$, it performs a call to subroutine (CALL) operation. The return from subroutine is accomplished with a BR field equal to 10. This causes the transfer of the return address from SBR to CAR. The mapping from the operation code bits of the instruction to an address for CAR is accomplished when the BR field is equal to 11.

FETCH Routine: During FETCH Read an instruction from memory and decode the instruction and update PC

- Sequence of microoperations in the *fetch cycle*:

$$AR \leftarrow PC$$

$$DR \leftarrow M[AR], \quad PC \leftarrow PC + 1$$

$$AR \leftarrow DR(0-10), \quad CAR(2-5) \leftarrow DR(11-14), \quad CAR(0,1,6) \leftarrow 0$$

The fetch routine needs three microinstructions, which are placed in control memory at address 64, 65 and 66.

Symbolic microprogram for the fetch cycle:

```

FETCH:      ORG 64
            PCTAR      U      JMP      NEXT
            READ, INCPC U      JMP      NEXT
            DRTAR      U      MAP
  
```

Binary Address	F1	F2	F3	CD	BR	AD
1000000	110	000	000	00	00	1000001
1000001	000	100	101	00	00	1000010
1000010	101	000	000	00	11	0000000

Binary
Microprogram

Symbolic Vs Binary Microprogram

Symbolic Microprogram	Binary Microprogram																																																
1. It is a set of microinstructions written in a symbolic form.	1. It is a set of microinstructions written in a binary form.																																																
2. It is a convenient form for writing microprograms in a way that people can read and understand.	2. It is written in binary form so can be difficult for people to read and understand.																																																
3. To be stored in memory symbolic microprogram must be translated to binary either by means of an assembler program or by the user if the microprogram is simple enough.	3. Translation is not required for storing in memory because it is already written in binary form.																																																
4. The symbolic representation is useful for writing microprograms in an assembly language format.	4. The binary representation is the actual internal content that must be stored in control memory.																																																
5. Example: Symbolic microprogram for fetch routine: <div><table><tr><td></td><td>ORG 64</td><td></td><td></td><td></td></tr><tr><td>FETCH:</td><td>PCTAR</td><td>U</td><td>JMP</td><td>NEXT</td></tr><tr><td></td><td>READ, INCPC</td><td>U</td><td>JMP</td><td>NEXT</td></tr><tr><td></td><td>DRTAR</td><td>U</td><td>MAP</td><td></td></tr></table></div> <p>Each line of the assembly language microprogram defines a symbolic microinstruction. Each symbolic microinstruction is divided into five fields: label, microoperations, CD, BR, and AD. Here ORG 64 refers to the origin address or staring address.</p>		ORG 64				FETCH:	PCTAR	U	JMP	NEXT		READ, INCPC	U	JMP	NEXT		DRTAR	U	MAP		5. Example: Translation of symbolic microprogram to binary microprogram. <div><table><tr><th>Binary Address</th><th>F1</th><th>F2</th><th>F3</th><th>CD</th><th>BR</th><th>AD</th></tr><tr><td>1000000</td><td>110</td><td>000</td><td>000</td><td>00</td><td>00</td><td>1000001</td></tr><tr><td>1000001</td><td>000</td><td>100</td><td>101</td><td>00</td><td>00</td><td>1000010</td></tr><tr><td>1000010</td><td>101</td><td>000</td><td>000</td><td>00</td><td>11</td><td>0000000</td></tr></table></div>	Binary Address	F1	F2	F3	CD	BR	AD	1000000	110	000	000	00	00	1000001	1000001	000	100	101	00	00	1000010	1000010	101	000	000	00	11	0000000
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1000010	101	000	000	00	11	0000000																																											

Design of Control Unit/Structure of CU

- Control unit generates timing and control signals for the operations of the computer. The control unit communicates with ALU and main memory. It also controls the transmission between processor, memory and the various peripherals. It also instructs the ALU which operation has to be performed on data.
- Control unit can be designed by two methods:
 1. Hardwired control Unit
 2. Micro programmed Control Unit

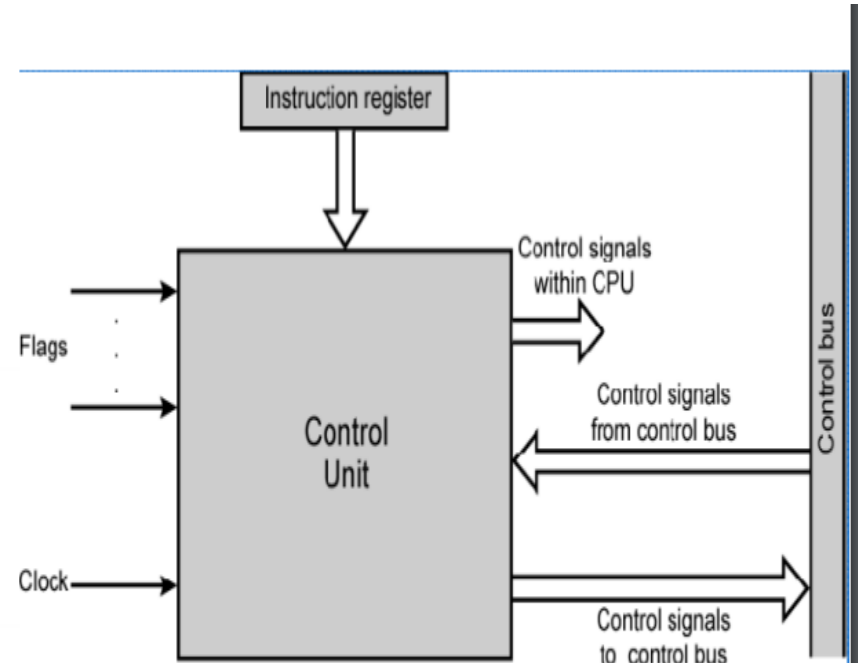


Fig: Block Diagram of Control Unit

Basic Requirement of Control Unit

- The functional requirements of control unit are those functions that the control unit must perform and these are the basis for the design and implementation of the control unit.
- A three step process that lead to the characterization of the Control Unit:
 1. Define the basis elements of the processor
 2. Describe the micro-operations that the processor performs
 3. Determine the functions that the control unit must perform to cause the microoperations to be performed.

1. Basic Elements of Processor:

The following are the basic functional elements of a CPU:

- **ALU:** is the functional essence of the computer.
- **Registers:** are used to store data internal to the CPU.

2. Types of Micro-operation:

These operations consist of a sequence of micro operations. All micro instructions fall into one of the following categories:

- Transfer data between registers
- Transfer data from register to external
- Transfer data from external to register
- Perform arithmetic or logical operations

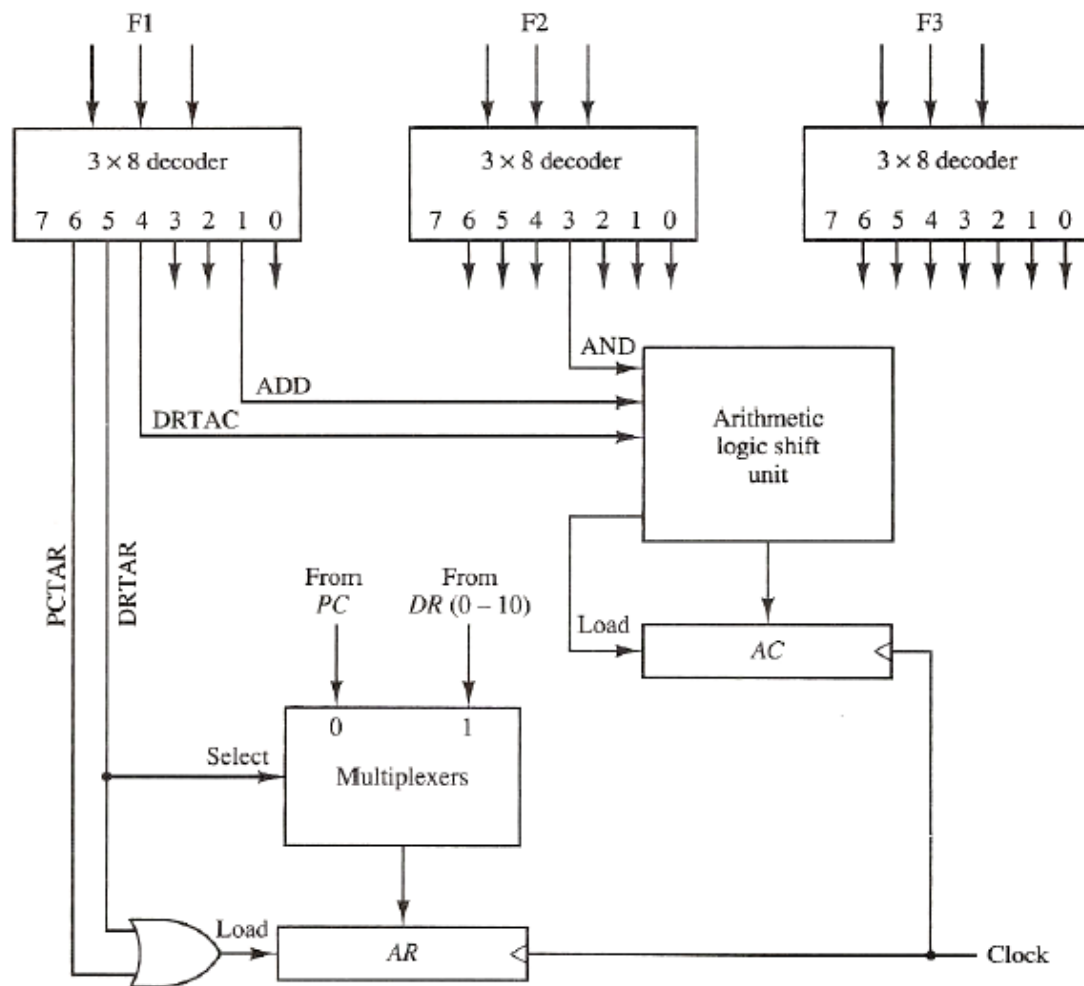
3. Functions of Control Unit:

The control unit perform two tasks:

- **Sequencing:** The control unit causes the CPU to step through a series of microoperations in proper sequence based on the program being executed.
- **Execution:** The control unit causes each micro-operation to be performed.

Decoding of Microoperation fields

- The 9-bits of the microoperation field are divided into 3 subfields of 3 bits each. The control memory output of each subfield must be decoded to provide distinct microoperations. The outputs of the decoders are connected to the appropriate inputs in the processor unit.
- Fig below shows 3 decoders and connections that must be made from their outputs.



E.g. when $F1=101$ (binary 5), next clock pulse transition transfers the content of DR(0-10) to AR (DRTAR). Similarly when $F1=110$ (6), there is a transfer from PC to AR (PCTAR). Outputs 5 & 6 of decoder F1 are connected to the load inputs of AR so that when either is active information from multiplexers is transferred to AR.

Arithmetic logic shift unit instead of using gates to generate control signals, is provided inputs with outputs of decoders (AND, ADD and ARTAC).

Fig: Decoding of microoperation fields

Microprogram Sequencer

- The basic components of a microprogrammed control unit are the control memory and the circuits that select the next address. The address selection part is called a microprogram sequencer.
- The purpose of a microprogram sequencer is to present an address to the control memory so that a microinstruction may be read and executed.
- The next-address logic of the sequencer determines the specific address source to be loaded into the control address register. The choice of the address source is guided by the next-address information bits that the sequencer receives from the present microinstruction.
- Commercial sequencers include within the unit an internal register stack used for temporary storage of addresses during microprogram looping and subroutine calls. Some sequencers provide an output register which can function as the address register for the control memory.

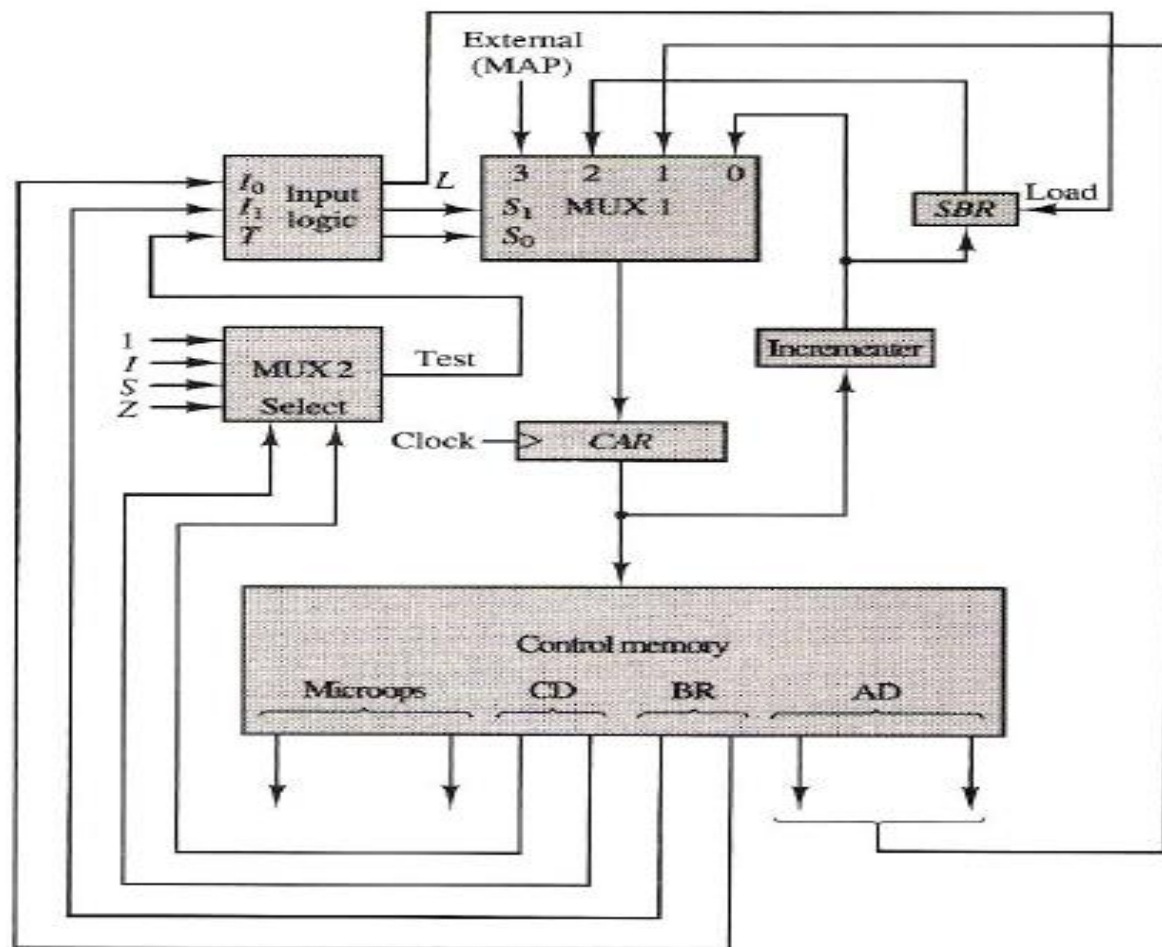


Fig: Microprogram sequencer for a control memory

- The control memory is included in the diagram to show the interaction between the sequencer and the memory attached to it.
- There are two multiplexers in the circuit.
- The first multiplexer selects an address from one of the four sources and routes it into the CAR(Control Address Register).
- The second multiplexer tests the value of a selected status bit and the result of the test is applied to an input logic circuit.
- The output from CAR provides the address for the control memory.
- The contents of CAR is incremented and applied to one of the multiplexer inputs and to the SBR.
- The other three input come from the address field of the present microinstruction, from the output of SBR(Subroutine Register) and from an external source that maps the instruction.

- MUX-1 selects an address from one of four sources and routes it into a CAR
- In-Line Sequencing - $CAR + 1$
- Branch, Subroutine Call - Take address from AD field
- Return from Subroutine - Output of SBR
- New Machine instruction - MAP
- MUX-2 Controls the condition and branching

BR Field		Input			MUX 1		Load <i>SBR</i>
		I_1	I_0	T	S_1	S_0	L
0	0	0	0	0	0	0	0
0	0	0	0	1	0	1	0
0	1	0	1	0	0	0	0
0	1	0	1	1	0	1	1
1	0	1	0	×	1	0	0
1	1	1	1	×	1	1	0

Fig: Input Logic Truth for Micro program Sequencer

- Input logic circuit has 3 inputs I0, I1 and T and 3 outputs S0, S1 and L. variables S0 and S1 select one of the source addresses for CAR. L enables load input of SBR.
- E.g. when S1S0=10, MUX input number 2 is selected and establishes a transfer path from SBR to CAR.