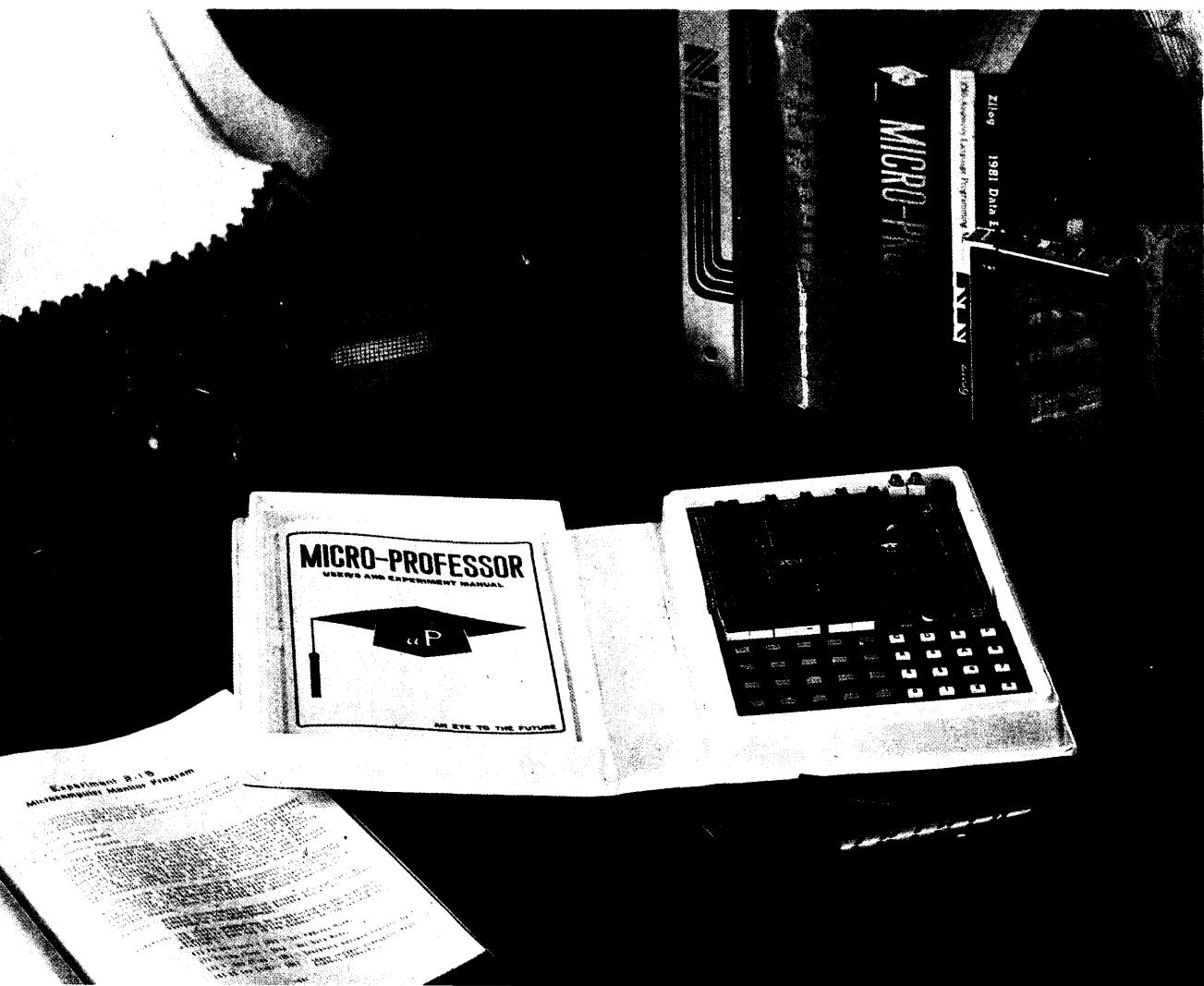


MPF-I

EXPERIMENT

MANUAL

(SOFTWARE / HARDWARE)



MULTITECH INDUSTRIAL CORP.

MPF-I
EXPERIMENT
MANUAL
(SOFTWARE/HARDWARE)

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PREFACE

The first 50 years of the 20th century witnessed the invention of the internal combustion engine, which greatly extended the physical strength of the human body.

In the second half of the century, the birth of the microprocessor further extended our mental capabilities. Applications of this amazing product in various industries have introduced so much impact on our lives, hence, it is called the second Industrial Revolution.

Microcomputers represent a total change in designing systems. Both industrial and academic institutions are active in the development and search for new applications for microcomputers.

This book is designed to be used in conjunction with the "multitech" MPF-1 Microcomputer as part of a one-year laboratory class on microcomputers. With the aid of this book, students will be able to learn the fundamentals of microcomputers, from basic CPU instructions to practical applications.

The first part of this book is an introduction to the basic concepts of microcomputer programming. It lays the foundation for later studies, the second part of this book is the source list of monitor program, the third part begins with a series of experiments using microcomputer instructions, such as, data transfers, arithmetic and logic operations, jump and subroutine and memory address allocation in simple programs. Experiments involving more complicated arithmetic operations, such as, binary to decimal conversion, decimal to binary conversion, multiplication, division and square root are presented.

There are two experiments in this book which are designed to familiarize the student with the fundamentals of input/output programming. These programs are centered around the keyboard and display. These experiments establish the foundation for later experiments involving a simple monitor program, which leads to more complicated MPF-1 programs.

MPF-I EXPERIMENT MANUAL

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Preparations

Introduction To Designing Microcomputer Programs

A computer program is an organized series of instructions. The central processing unit will perform a series of logical actions to obtain the desired result.

Before a program is executed by CPU it must be stored in memory in binary form. This type of program is called a "machine language program". This is the only type of language the computer understands. The machine language program is usually represented by Hexadecimal digits. For example, the 8-bit instruction 1010 1111B (B represents binary) in the Z80 CPU it can be replaced by OAFH (H indicates Hexadecimal). Interpreting a machine language program is extremely difficult and time consuming for the User. The microprocessor manufacturer divides the CPU instructions into several categories according to their functions. The CPU instructions and registers are usually represented by symbols called "mnemonics". For example, the Z80 CPU instruction 70H can be represented by the mnemonic code LD A,L (Load Data into register A from register L). A program written in mnemonic codes is called an "assembly language program." Before an assembly language program can be executed by the CPU, it must be translated into machine language by a special software program called an "Assembler".

Normally a program is written in assembly language. The main advantage of assembly language program over machine language programming is that assembly language programming is much faster to code, the mnemonics makes it much easier for the User to remember the instruction set, and normally the assembler will contain a self-diagnostic package for debugging programs. The main disadvantage of assembly language programs is that it requires an assembler and microcomputer development system. These two items are very costly. With the MPF-I microcomputer the User has to translate assembly programs into machine level programs by hand before executing programs

A. Problem Analysis

The software program of a simple problem may be easily designed with a well-defined flowchart. It may also be obtained by revising some existing programs or combining some simple routines. The design of more complicated programs, such as monitor programs, system control programs or a special purpose program, are usually started after some detailed analysis of the problem has been made. Problem analysis and solution requires a good understanding of the following:

See page (III-3)

- (1) Characteristic and requirements of the problem
 - (2) Conditions which are known
 - (3) Input information format and how it is converted
 - (4) Output data format and how it is converted
 - (5) Type of data and how precise it is
 - (6) Execution speed required
 - (7) CPU instructions and performance
 - (8) Memory size
 - (9) The possibility that the problem can be solved
 - (10) Methods to solve the problem
 - (11) Evaluation of the program
 - (12) How the resultant program will be disposed

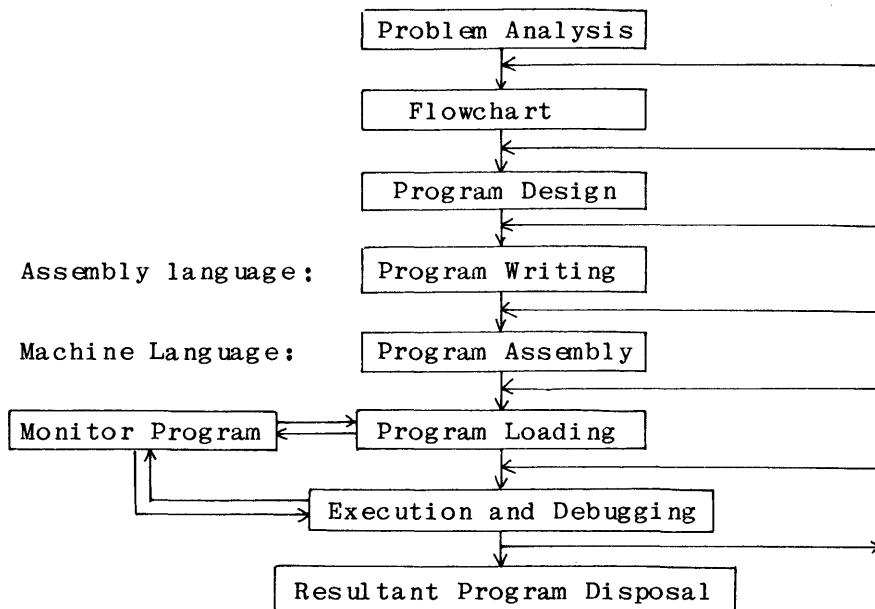


Figure 2-A-1

B. Flowchart

A flowchart can be used to indicate the behavior of algorithms by suitable graphs. Once the complete flowchart has been completed, a full picture of the programmer's thought processes in reaching a solution to the problem may be followed. Flowcharts are especially important in program-debugging. It is an important part of the finished program. It may help other people to understand the exact algorithm used by the programmer.

Two levels of flowcharts are often desirable:

System flowchart -- showing the general flow of the program

Detailed flowchart -- providing details that are of interest mainly to the programmer.

Usually, a complicated program is introduced using a system flowchart outlining the program, and then a detailed flowchart is presented. The advantage of a flowchart is that it emphasizes the sequential nature of steps by using arrows pointing from each step to its successor. Various symbols are used to indicate the operation that is to be performed at each step. Figure 3-A-2 gives some standard symbols used in flowcharts:

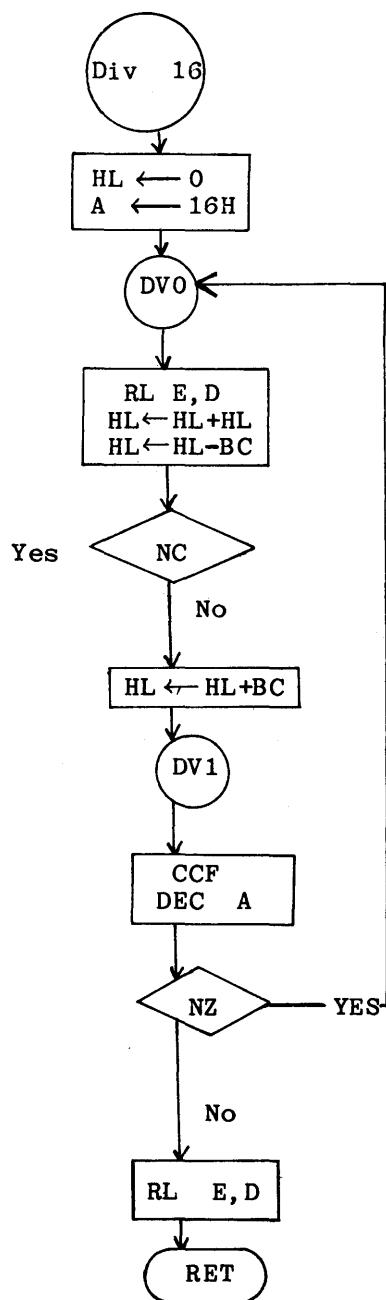
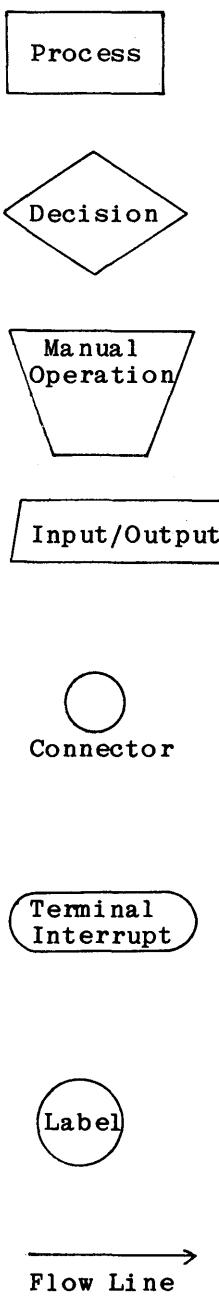


Figure 2-A-2

C Program Design

There are many types of programs. Programs for mathematical equations, conversion of input and output signals, coding and decoding of the program data, peripheral device drives, etc. are example of simple programs. Assembler, monitor and system control programs or special purpose applications are examples of more complicated programs. The following items are usually considered in program design:

- (1) Acquisition of input signals or data
- (2) Generation or conversion of output signals and data
- (3) Logical analysis and calculations in the main program
- (4) Relation between the main program and subroutines
- (5) Use of internal registers
- (6) Memory allocation of the main program
- (7) Memory allocation of subroutines
- (8) Memory allocation of data tables and indexed addressing method
- (9) System initialization and constants in the program
- (10) Definition of the variables in the program
- (11) Consideration of timing sequences and program execution speed
- (12) Limitations of memory size
- (13) Length and precision of data
- (14) Availability of documents and references
- (15) Other special items

D. Program Writing

In this book, the programs are written mainly in assembly language. Here only the format of the assembly language program is given.

A statement in the program is composed of four parts : Label, Opcode, Operand and Comment. An example is shown below

LABEL	OPCODE & OPERAND	COMMENT
DTB4	LD B,16	
DB3	SRL H	
	RR L	
	RR D	
	RR E	; ROTATE HL DE RIGHT
	LD A,H	
	CALL DB1	
	LD H,A	; CORRECT H
	LD A,L	
	CALL DB4	
	LD L,A	; BINARY CORRECT L
	DJNZ DB3	
	RET	
BINARY CORRECT ROUTINE		
DB4	BIT 7,A	
	JR Z,DB1	; IF BIT 7 OF A = 1, SUB FROM 30H
	SUB 30H	
DB1	BIT 3,A	
	JR Z,DB2	; IF BIT 3 OF A = 1, SUB FROM 03H
	SUB 3	
DB2	RET	

Sometimes, a program statement without a comment is not easy to understand. The comments in the statements are very important especially for a complicated program. Statements with a label and comment field are more convenient for calling and debugging.

E. Program Assembly

Using the resident assembler in a microcomputer system is an effective way to assemble the source program. However, a beginner or a program designer not familiar with the microcomputer development system must assemble his/her program by hand. The usual procedure for hand assembly is:

- (1) Translate each instruction (mnemonic) into the machine code by looking it up in the conversion table. The comment field of each statement is ignored.
- (2) After deciding the starting address of the program. Assign an appropriate address to the first byte of each instruction. The exact number of bytes needed must be reserved including space for instructions such as JR, DJNZ, and destination addresses of instructions JP, CALL, etc.
- (3) Calculate the relative displacement and put it in the assembled program. A simple formula for calculating the relative displacement is:

$$\text{displacement} = (\text{destination address}) - (\text{next instruction address})$$

If the calculated result is positive, then it is the desired value. If the calculated result is negative, then subtract the result from 100H (i.e. take its 2's complement) and the final result is taken as the operand of this instruction. For instance, in the program listed above, the instruction DJNZ DB3 at address 0014H is first translated into 10xx and then the xx value is calculated.

$$\begin{aligned} \text{xx} &= 0002H \text{ (destination address)} - 1016H \text{ (next instruction's address)} \\ &= -14H \text{ (negative value)} \\ \text{xx} &= 100H - 14H = 0ECH \end{aligned}$$

Therefore, the instruction DJNZ DB3 must be translated into 10EC. In addition, the instruction JR Z, DB 1 at address 0019H is first translated into 28xx, and then the xx value is calculated.

$$\begin{aligned} \text{xx} &= 001DH \text{ (destination address)} - 001BH \text{ (next instruction's address)} \\ &= 2 H \end{aligned}$$

The instruction JR Z, DB 1 must be translated into 2802.

The translated machine language is given below:

Address	Machine Language	Label	Opcode & Operand	Comment
			; ** 4 DIGIT BCD TO BINARY CONVERSION ROUTINE ** ; EXTRY : BCD DATA IN HL ; EXIT : BINARY DATA IN DE ; REGISTER CHANGED : AF BC DE HL	

```
0000 0610 DTB4 LD B,16 ; B = BIT COUNT
0002 CB3C DB3 SRL H
0004 CB1D RR L
0006 CB1A RR D
0008 CB1B RR E ; ROTATE HL DE RIGHT
000A 7C LD A,H
000B CD1D00 CALL DB1
000E 67 LD H,A ; CORRECT H
000F 7D LD A,L
0010 CD1700 CALL DB4
0013 6F LD L,A ; BINARY CORRECT L
0014 10EC DJNZ DB3
0016 C9 RET

;
; BINARY CORRECT ROUNTINE
0017 CB7F DB4 BIT 7,A
0019 2802 JR Z,DB1 ; IF BIT 7 OF A = 1, SUB FROM 30H
001B D630 SUB 30H
001D CB5F DB1 BIT 3,A
001F 2802 JR Z,DB2 ; IF BIT 3 OF A = 1, SUB FROM 03H
0021 D603 SUB 3
0023 C9 DB2 RET
```

F. Program Loading

The monitor program can be used to assist the user in loading the program into the reserved memory address in MPF-I. The program can be inputted from the keyboard or read from a magnetic tape. After the program is loaded into MPF-I RAM, an error-checking process is required to eliminate any errors. Redundant instructions or data may be replaced by an "NOP" instruction. Missed instructions or data are inserted into the desired addresses by using the Block Data Transfer method or simply by reloading the program. While revising the program, it is very important to check whether Jump instructions (JP, JR, DJNZ, CALL, etc.) are affected by the change in memory addresses. If this happens, then make the necessary correction(s) immediately.

G. Program Execution and Debugging

Before executing a program, it is necessary to set the initialization parameters and set the program counter at the starting address of the program. Pressing the GO key will start the program execution. After the program execution is completed, check the result. If there is any error, the program must be checked step by step with the aid of the monitor program. After the program is revised, execute it again and check the result again.

Experiment I

Data-Transfer Experiment

Purposes:

1. To familiarize the user with the function of data-transfer instruction
2. To practise setting the initial value of data
3. To practise assembling, loading and executing a program

Time required: 4 hours

I. Theorectical Background:

1. Most of the data-transfer operation is accomplished by using LD (load) instructions. Data can be transferred in units of 8 bits or 16 bits. Also, instructions such as EX, EXX, PUSH and POP can be used to transfer 16-bit data. Instructions such as LDI and LDIR can be used to transfer blocks of data by moving a series of bytes.
2. A LD instruction must include two operands. The first operand represents the location where data will be stored (register or memory section). This is called its "destination". The second operand represents the original location of the data to be transferred. This is called the "source". For instance, LD A,B indicates that data in register B will be transferred to register A. Register A is the "destination" and Register B is the "source".
3. The direction of data transfer may be:
 - (1) register <- register e.g. LD A,B ; LD HL,BC
 - (2) register <- memory e.g. LD A,(HL) ; POP AF
 - (3) register <- immediate data e.g. LD A,25H ; LD HL,125AH
 - (4) memory <- register e.g. LD (HL),A ; PUSH BC
 - (5) memory <- memory e.g. LDD ; LDIR
 - (6) memory <- immediate data e.g. LD (HL),5BH

II. Experiment 1-1

Write an assembly language program to set the contents of the registers as follows : A=0, B=1, C=2, D=3, E=4, H=5, L=6 (use 8-bit LD instructions to transfer one byte of data each time).

Step 1 Write the assembly language program in the following blank form. The last instruction is RST 38H which returns control of the MPF-I to the monitor program after executing the whole program.

-
- Step 2 Using the table of 8-bit LD instructions, translate the program into machine language with the starting address at 1800H. Assign the proper address to each instruction.
- Step 3 Prepare the MPF-I microcomputer. Key in the program from the keyboard. Check the program stored in memory. Set the PC (program counter) to the starting address 1800H and execute the program.
- Step 4 Press the REG key and check if the content of each register is correct. If there is any error then return to step 1 and recheck.

<u>Memory Address</u>	<u>Machine Language</u>	<u>Assembly Language</u>
1800H	3E00	LD A, 0
.	.	.
.	.	.
FF		RST 38H

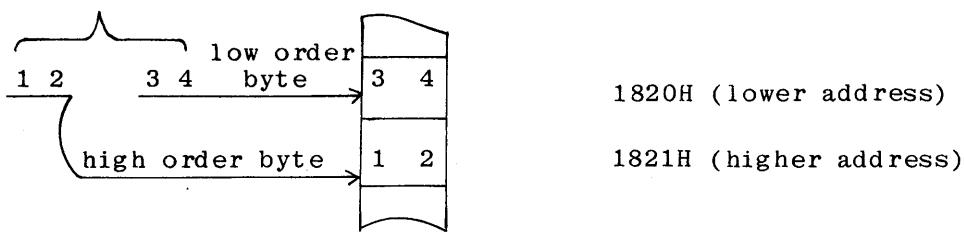
III. Experiment 1-2

Write an assembly language program to set the contents of registers as follows: B=12, C=34, D=56, E=78, H=9, L=A (use 16-bit LD instruction to transfer two bytes of data each time).

- Step 1 Same as in Experiment 2-1-1 (Write an assembly language program).
- Step 2 Using the 16-bit LD instruction table, translate the program into machine language with starting address at 1820H. Assign the proper address to each instruction.
- Step 3 Load the program (same as Experiment 2-1-1). Set the PC to 1820H and execute the program.
- Step 4 Check contents of each register same as Experiment 2-1-1.

Note A 16-bit piece of data is composed of two bytes of data. The high-order byte is in the higher memory address and the low-order byte is in the lower memory address. For instance, the 16-bit data 1234H is stored in addresses 1820H - 1821H in the following way:

16-bit data · memory contents memory address



Address	Machine Language	Assembly Language
1820H	013412	LD BC, 1234H
1823H		
	F	RST 38H

Example :

Write a program to clear the contents of memory addresses 1850H - 186FH.

Explanation:

- (1) If we use an 8-bit LD instruction to transfer the data to each destination, then 32 (20H) executions of data-transfer is required. It is more convenient to use the loop method in the program.
- (2) Use register B as a loop counter. Set register B equal to 20H before the loop program is executed. Use HL as the memory address pointer and set HL to the starting address 1850H. HL is incremented by one and B is decremented by one for each loop. If B=0, then all loops have been executed; otherwise, run the loop again.

(3) The program is given below:

Address	Machine Language	Label	Opcode & Operand	Comment
1800			LD B, 20H	; Set loop counter equal to 32
			LD HL, 1850H	; Set HL equal to the starting address of memory to be cleared
			XOR A	; Set A=0
		LOOP	LD (HL), A	; Load 0 into the memory address pointed to by HL
			INC HL	; Increment HL by 1
			DEC B	; Decrement B by 1
			JR NZ, LOOP	; If B not = 0, return to LOOP
FF			RST 38H	; Return to the monitor program

IV. Experiment 1-3

Translate the program in Example 1-1 into machine language and load it into MPF-I RAM. Then, execute the program and check if the contents of 1850H - 186FH have been cleared. If not, correct the program and execute it again.

V. Experiment 1-4

Write an assembly language program to set the contents of memory address 1840H - 184FH as follows: 0, 1, 2, 3,F.

(HINT: Change the loop counter and the value of the starting address. register A is incremented by '1' in the next loop)

ADDRESS	MACHINE LANGUAGE	LABEL	OPCODE & OPERAND
-----	-----	-----	-----
-----	-----	-----	-----
-----	-----	-----	-----
-----	-----	-----	-----
-----	-----	-----	-----
-----	-----	-----	-----

Experiment 2

Basic Applications of Arithmetic and Logic Operation Instructions

Purposes:

1. To familiarize the user with the arithmetic and logic operation instructions
2. To understand the memory addressing mode
3. To understand the meaning of the register status flag
4. To practise arranging data for CPU registers and memory sections

Time Required: 4 hours

I. Theoretical Background:

1. 8-bit arithmetic and logic operation instructions:

The 8-bit arithmetic and logic operations in the Z80 CPU are performed in register A (accumulator). Registers A, B, C, D, E, H, and L can be used as operands in conjunction with register A in the LD instructions. If data are transferred between memory and register A, the memory address can be pointed to by HL, IX or IY registers. The meaning of the following instructions are given in the right-side comment field:

- (1) ADD A ; Data in register A is added to itself, i.e. the data is doubled shifted left one bit.
- (2) ADC B ; Register B and the carry flag are added to register A.
- (3) SUB C ; Data in register C is subtracted from register A.
- (4) SBC (HL) ; Subtract the data in the memory address pointed to by HL and the contents of the carry flag from register A.
- (5) AND D ; Logical "AND" of register D and register A.
- (6) OR OFH ; Logical "OR" of data OFH and register A .
- (7) XOR A ; Exclusive "OR" register A and itself. (Since register A is equal to register A, the result is zero).
- (8) INC H ; Increment the contents of register H by 1.
- (9) INC (IX) ; Increment the contents of the memory address pointed to by register IX by 1.
- (10) DEC C ; Decrement the contents of register C by 1.

(11) DEC (IY+3)

; The sum of the contents of register IY and
3 is used as the memory address pointer.
Decrement the contents of memory address
IY +3.

2. Data Addressing Mode

In the above assembly language instructions, the addressing modes used can be summarized below. Other addressing modes can be found in the Z80 CPU technical manual.

(1) Register Addressing

Example: In the instruction ADC A,B , ADC is the opcode which represents what kind of operation will be performed. The character A in the right means that the data will be added to A. The character B at the far right means that the data to be added to A is taken from register B.

(2) Register Indirect Addressing

A 16-bit register is used to store the memory address.
Example: In the instruction SBC A,(HL) , (HL) does not mean that HL will be subtracted from register A. Instead, the CPU takes the 16-bit data contained in HL as the memory address and then accesses the 8-bit data stored in this memory address. The 8-bit data pointed to by HL is finally subtracted from register A. IX and IY are called index registers. When a memory address is pointed to by IX or IY, an 8-bit byte which is less than +127 but larger than -128 can be added to this register.

For instance, the following two instructions can be used to add the data stored in the memory address pointed to by IX to the 8-bit data stored in the memory address pointed to by IX+2. The result is stored in register A.

LD A,(IX)
ADD A,(IX+2)

(3) Immediate Addressing

Example : OR OFH. On the right-hand side of the opcode OR, a hexadecimal number, OFH, is given. It means that the number OFH is logically ORed with the contents of register A. Therefore, the data is part of the instruction which is stored in memory. The CPU fetches the data by using the program counter (PC) as a reference address. The following instructions are examples of immediate addressing.

```
LD      B,8
ADD    A,44H
SUB    A,0A4H
```

3. Status Flags

After a logical or arithmetic operation is finished, the result will be stored in register A and some of the status flags (Carry, Overflow, Change Sign, Zero Result, Parity) will also be affected. These status flags will be stored in the flip flops in the Z-80 CPU. These flip flops form a register called the Flag Register. The data in this register can be moved to memory, like data in other registers, by specific instructions (PUSH instruction). Some of the status flags are given below.

(1) Carry Flag

This flag is the carry from highest order bit of the Accumulator. The carry flag will be set in either a signed or unsigned addition where the result is larger than an 8-bit number. This flag is also set if a borrow is generated during a subtraction instruction. The carry flag can be used as a condition for jump, call, or return instructions. The carry flag also serves as an important linkage in multi-byte arithmetic operations. Three 8-bit data can be connected as a 24-bit data by using carry flag and four 8-bit data can be connected as a 32-bit data.

(2) Overflow/Parity Flag

When signed two's complement arithmetic operations are performed, this flag represents overflow. The Z-80 overflow flag indicates that the signed two's complement number in the accumulator has exceeded the maximum possible (+127) or is less than minimum possible (-128).

When an arithmetic operation is performed in the Z80-CPU, the number in register A can be assumed to be unsigned data (0 - 255) or signed data (-128 ~ +127). Thus, either the carry flag or the overflow flag can be affected by the arithmetic operation. The programmer decides which interpretation is desired. The following arithmetic operations are described on the right-hand side.

10101100	<- unsigned number 172 or signed number -84
+) 11101000	<- unsigned number 232 or signed number -24
<hr/>	
1 <- 10010100	<- unsigned number 148 with carry or signed number -108 but no overflow

```

01001010      <- signed or unsigned number 74
+) 01000010    <- signed or unsigned number 66
-----
0 <- 10001100  <- unsigned number 140 but no carry, or
                  signed number -116 but overflow has
                  occurred and the result becomes negative

change sign

```

For logical operations in the Z80-CPU, this flag is set if the parity of the 8-bit result in the accumulator is even. This flag is very useful in checking for parity errors occurring during data transmission. Since carry and overflow will never occur in logical operations, the parity and overflow status can be stored in the same flip flop. This flip flop is called the P/V flag. By testing this flip flop the programmer can check overflow after arithmetic operations and check parity after logical operations.

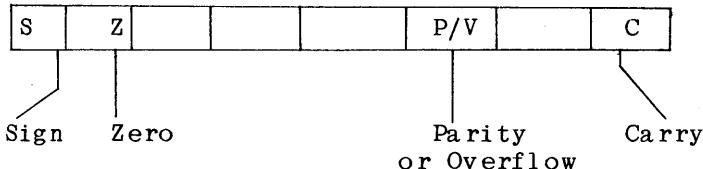
(3) Zero Flag

If register A is zero after a logical or arithmetic operation, this status will be registered in a flip flop called zero flag. The zero flag can be used as a condition for branch instructions. It is very useful in program looping.

(4) Sign Flag

If the leftmost bit (bit 7) of register A is 1 after a logical or arithmetic operation, the number in register A is interpreted as a negative number. The sign flag is then set to 1. This flag will be ignored if the programmer has assigned the data as unsigned numbers.

(5) The other flags designed for BCD arithmetic are not important for the programmer. The bit positions of the flags discussed above are shown below:



In microcomputers, it is usual to represent the contents of the flag register by two hexadecimal digits. The reader reader has to express this two-digit data with an 8-bit binary number. By referring to the bit positions in the flag register, the reader can obtain the status of the flag. For instance, if the flag register is 3CH, then the sign is positive, the value is non-zero, the parity is even or there is overflow has occurred but there is no carry. To know which flags will

be affected by an instruction, the reader has to refer to the assembly language manual. Not all instructions will affect the status flags.

II. Example of Experiments

1. The following program can be used to add the contents of register D and register E together. The result will be stored in the pair register HL. Load the program into MPF-I and then execute it. Record the result.

```
ORG    1800H ; Starting Address <- 1800H
LD     A,E    ; A <- E
ADD    A,D    ; A <- A + D
LD     L,A    ; L <- A
LD     A,0    ; A <- 0
ADC    A,0    ; A <- A + 0 + Carry
LD     H,A    ; H <- A
RST    38H    ; Return to Monitor
```

Preset Value		Result of Program Execution				
Register		Register	Flag			
D	E	HL	Sign	Zero	P/V	Carry
5AH	A6H					
46H	77H					

2. The following program can be used to add the 16-bit data in memory addresses 1A00H - 1A01H to the 16-bit value in the register pair DE. The result will be stored in the register pair HL. Load the program into MPF-I and execute it. Discuss the result obtained.

preset values of memory: (1A01H) = _____, (1A00H) = _____
preset value of register DE pair = _____, _____

```
ORG    1800H ; Starting address <- 1800H
LD     A,(1A00H) ; A <- (1A00H)
ADD    A,E    ; A <- A + E
LD     L,A    ; L <- A
LD     A,(1A01H) ; A <- (1A01H)
ADC    A,D    ; A <- A + D + Carry
LD     H,A    ; H <- A
RST    38H    ; Return to monitor.
```

Result :

result	HL	= _____ ,	_____
	Carry	= _____ ,	_____
	Zero	= _____ ,	_____
	Overflow	= _____ ,	_____
	Sign	= _____ ,	_____

3. Revise the above program for a subtraction operation.

4. The following program can be used to add the 32-bit data in memory addresses 1A00H - 1A03H to the 32-bit data in memory addresses 1A04H - 1A07H. The result will be stored in memory addresses 1A08H - 1A0BH. The higher-order byte is stored in a higher address (This is conventional in microcomputer programming)

preset memory contents: (1A03H - 1A00H) = _____
 (1A07H - 1A04H) = _____

```
ORG        1800H
LD        B,4
LD        IX,1A00H
AND       A
LOOP     LD       A,(IX)
        ADC      A,(IX+4)
        LD       (IX+8),A
        INC       IX
        DEC       B
        JP       NZ,LOOP
        RST      38H
```

Result of program testing:

results of program execution: (1A0BH - 1A08H) = _____
Flag Register = _____

5. If the instruction ADC A,(IX+4) is replaced by SBC A, (IX+4), then the above program can be used for a subtraction operation. If the instruction DAA is inserted immediately after the ADC or SBC instruction, then the program becomes a program for decimal addition or subtraction. Load the revised program to MPF-I and test it.

Experiment 3

Binary Addition and Subtraction

Purposes:

1. To understand how an addition or subtraction operation is performed on a microcomputer.
2. To familiarize the reader with software programming techniques.

Time Required: 4 hours

I. Theoretical Background:

1. In this experiment, we only discuss unsigned binary integer addition and subtraction. For a N-bit binary number, its range is $< 0, 2^N - 1 >$. For instance, if $N = 8$, the range is $< 0, 255 >$; if $N = 16$, the range is $< 0, 65535 >$. If the range of the numbers are expressed by hexadecimal digits, the ranges are $< 0, FFH >$ and $< 0, FFFFH >$, respectively. If the sum of an addition operation is larger than the maximum value that can be represented by N bits, then carry is generated and the carry flag is set. In the subtraction operation, if the subtrahend is more than the minuend, a borrow is generated and the carry flag is set in the high order byte. The set carry bit indicates an incorrect result.

Example 3-1:

Single byte addition and subtraction.

Addition: $7FH + ADH = 12CH$

$$\begin{array}{r} 01111111 \rightarrow 7FH \\ +) 10101101 \rightarrow ADH \\ \hline 100101100 \rightarrow 12CH \end{array}$$

↑
Carry

Subtraction: 7FH - ADH Subtraction: ADH - 7FH = 2EH

$\begin{array}{r} 01111111 \\ -) 10101101 \\ \hline 111010010 \end{array}$ <p>Borrow The answer is incorrect (CY = 1)</p>	$\begin{array}{r} 10101101 \\ -) 01111111 \\ \hline 000101110 \end{array}$ <p>Borrow The answer is correct (CY = 0)</p>
---	---

Example 3-2

Three-byte addition and subtraction

Addition: 6A7CBDH + 4B65ACH = B5E269H

$\begin{array}{r} 6A \\ 4B \\ + 0 \end{array}$ <p>0 B5 Carry</p>	$\begin{array}{r} 7C \\ 65 \\ + 1 \end{array}$ <p>0 E2 Carry</p>	$\begin{array}{r} BD \\ AC \\ + 0 \end{array}$ <p>1 69 Carry</p>
← Carry		

Subtraction: 854372H - 69ACBFH =

$\begin{array}{r} 85 \\ - 69 \\ \hline 0 1B \end{array}$	$\begin{array}{r} 43 \\ - AC \\ \hline 1 97 \end{array}$	$\begin{array}{r} 72 \\ - BF \\ \hline 1 B3 \end{array}$
← Borrow		
$\begin{array}{r} - 1 \\ 0 1A \end{array}$	$\begin{array}{r} - 1 \\ 1 96 \end{array}$	$\begin{array}{r} - 0 \\ 1 B3 \end{array}$

The borrow of the highest-order byte is 0, thus the answer is correct. In multi-byte subtraction, the correctness of the result depends upon the borrow of the highest-order byte. If the borrow is 1, then the result is incorrect.

2. Order of data stored in memory:

The conventional way of storing multi-byte data in memory is: the lowest order byte is stored in the lowest address and the highest order byte is stored in the highest address. The address of the multi-byte data is usually expressed by its lowest address. For beginning at instance, the number 7325H is stored beginning at memory address A in the following way:

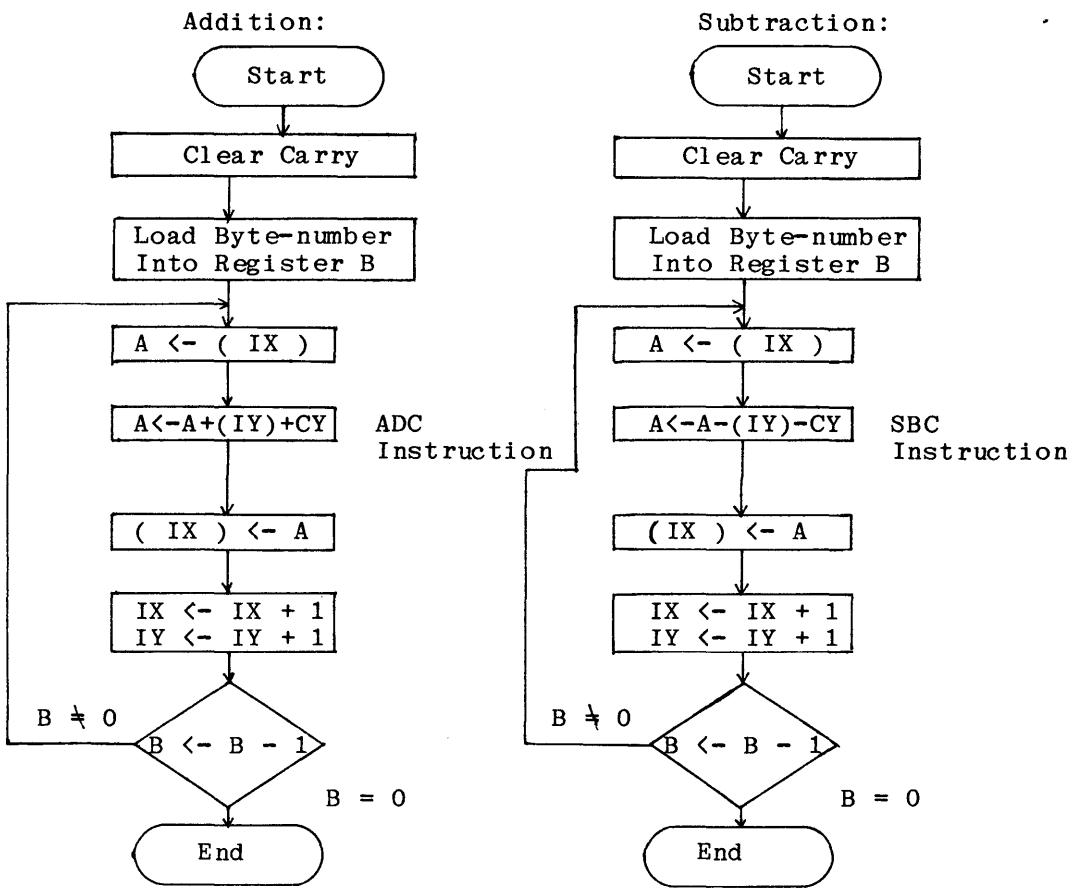
address A	25	<- low-order byte
A + 1	73	<- high-order byte

If the starting address of 4 three-byte numbers stored in memory is A, the data and their addresses can be shown as follows :

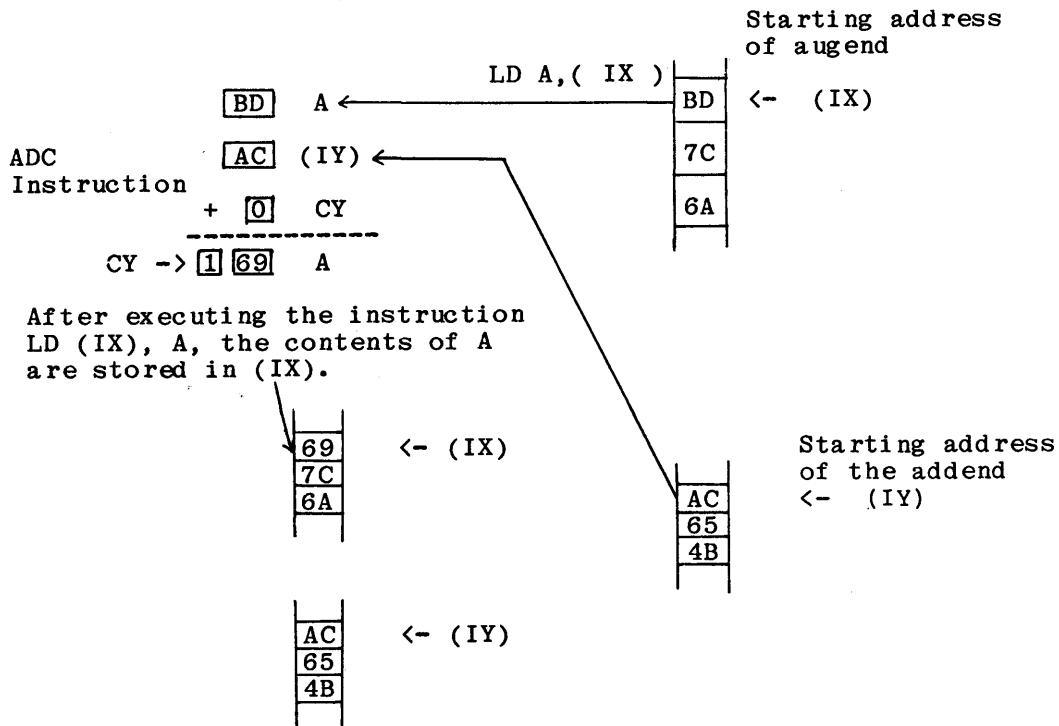
Address	A	56	}	987C56H
		7C		
		98		
A + 3	43	43	}	AD6943H
	69	69		
	AD	AD		
A + 6	BC	BC	}	2501BCH
	01	01		
	25	25		
A + 9	78	78	}	439578H
	95	95		
	43	43		
A + 12	21	21	}
	96	96		

3. Design of Addition/Subtraction Programs:

The data used in addition/subtraction operation are stored in memory according to the conventional method given above. The starting address of the augend/minuend is stored in index register IX. The starting address of addend/subtrahend is stored in index register IY. The byte-number of the data is stored in register B. First, clear CY and load the augend/minuend into the accumulator. Then, use the indexed addressing mode instruction ADC (SBC) to proceed with the addition/subtraction operation. The result is stored in the original address of the augend/minuend. Increment the index registers and compare register B with zero. Repeat the load augend, add, store increment cycle until the B register equals zero. Finally, test the carry flag to check if the result is correct. The only difference between the addition program and subtraction program is that the instruction ADC is used for addition operation and the instruction SBC is used for subtraction operation. The flowcharts and programs are given below for comparison:



The following block diagram is given to demonstrate data transfer in an addition operation.

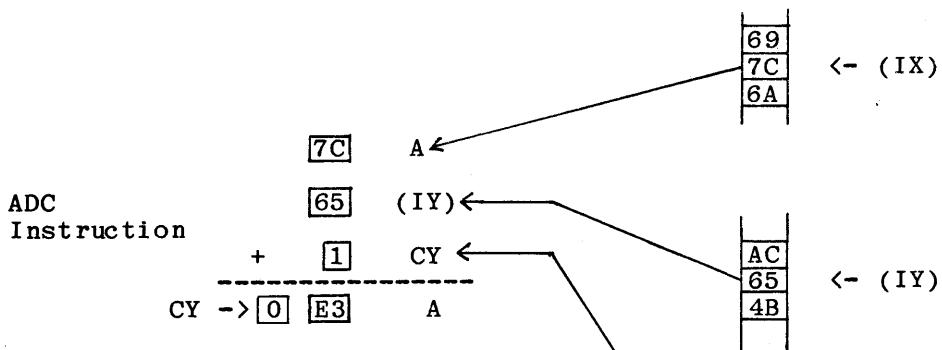


Instruction INC IX increases the value of IX by one.

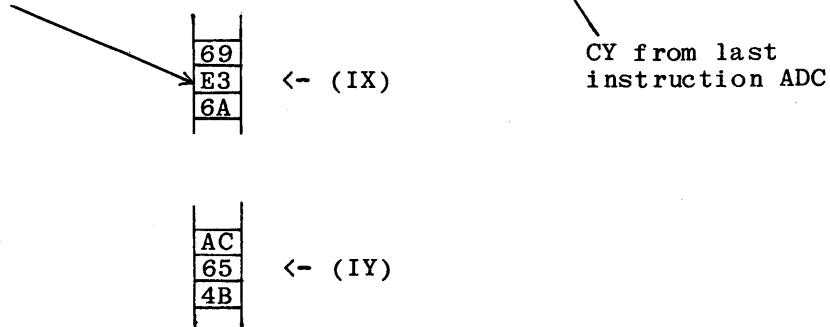
In the comment field the incrementation
of IX can be shown as $IX \rightarrow IX + 1$

INC IY leads to $IY \leftarrow IY + 1$

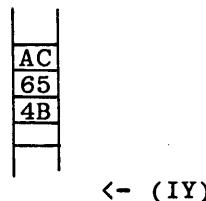
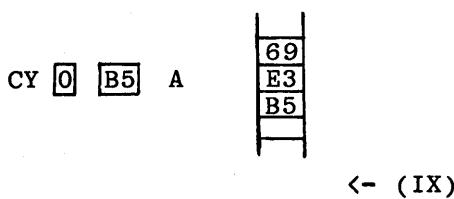
In each of frames showing the results of an instruction
step the current value pointed to by the index registers
are indicated by



After the instruction LD (IX), A is executed, the memory becomes



When B = 0, the program execution is finished and the memory becomes



The addition program is given below. By replacing the instruction ADC A, (IY) by SBC A, (IY), the addition program becomes a subtraction program.

```
1. *** MPF-I EXAMPLE PROGRAM ***
2. 3-BYTE ADDITION ( UNSIGNED INTEGER )
3. ENTRY ; AUGEND ADDRESS IN IX,
4.           ADDEND ADDRESS IN IY.
5. EXIT   : SUM IN AUGEND ADDRESS
6.
7. ADD3   : XOR A ; CLEAR CARRY FLAG
8.           LD B, 3 ; BYTE NUMBER IN B
9. ADDLP  : LD A, (IX)
10.          ADC A, (IY)
11.          LD (IX), A
12.          INC IX
13.          INC IY
14.          DJNZ ADDLP
15.          RET
```

4. Programming Technique:

From the above examples (3-1 and 3-2), we can see that the multibyte addition/subtraction operation can be accomplished by repeating the single-byte addition/subtraction operation, that is, by the loop operation of single-byte addition/subtraction. In the above program, register B is used as a loop counter. If the byte-number is 4, then 4 is loaded into B initially. Register B is decremented by 1 after each loop operation. The loop ends when B = 0. The instruction DJNZ is used for conditional jump. When B = 0, the program no longer executes the jump operation. Since ADC and SBC instructions are used in the programs, the CY is included in each addition/subtraction operation. Therefore, before the first byte addition/subtraction operation, the carry flag must be cleared (instruction XOR A). The index registers IX and IY are used as address pointers. By incrementing IX and IY, the CPU can access multibyte values stored in memory.

II. Student Exercises:

1. Load the above addition program into MPF-I and store it on magnetic tape.
2. Replace the last instruction RET in the program by RST 38H. Load the following data into memory. The starting addresses of augend and addend are assigned as 1900H and 1A00H, respectively. Execute the program and record the result in the following table.

Augend	Addend	Answer	Check
793865H	ABCEDFH	CY =	
009543H	AB1236H	CY =	
954717H	003390H	CY =	

3. Replace the ADC instruction by the SBC instruction. Assign the starting addresses of minuend and subtrahend as 1900H and 1A00H, respectively. Execute the program and record the results obtained.

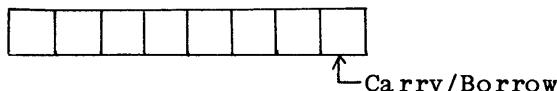
Minuend	Subtrahend	Answer	Check
683147H	336700H		
5935ABH	5877FFH		
049677H	F65B79H		

4. Express the data in the above two tables as five-byte data. Change the byte-counter to the proper value and execute the addition/subtraction program.
5. Write a program to add the 7-byte data in memory addresses 1A00H - 1A06H to the 7-byte data in memory addresses 1900H - 1906H and then subtract the 7-byte data in memory addresses 1940H - 1946H from the sum. The final result must be stored in memory with the starting address 1900H.

Experiment 3-1:

The carry/borrow flag is used to indicate whether a carry/borrow is generated during an arithmetic or logical operation. If a carry/borrow is generated, then the flag is set to 1. Otherwise, the flag is zero. The carry flag is represented by bit 0 of the flag register.

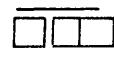
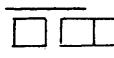
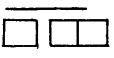
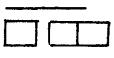
REG.F



In other words, the contents of the F register will be an even number if a carry/borrow is generated during the arithmetic or logical operation. If register F is an odd number, then no carry/borrow has been generated. Load the following program into MPF-I. Execute every instruction by using the Single Instruction method. Observe the variations of register F and record the results in the table.

Address	Machine Language		Assembly Language	
1800H	AF	1	XOR A	A, CY <-- 0
1801H	3E7F	2	LD A, 7FH	A <-- 7FH
1803H	C6 AD	3	ADD A, ADH	CY, A <-- A + ADH
1805H	C6 23	4	ADD A, 23H	CY, A <-- A + 23H
1807H	D6 13	5	SUB A, 13H	CY, A <-- A - 13H
1809H	D6 B3	6	SUB A, B3H	CY, A <-- A - B3H
180BH	D6 15	7	SUB A, 15H	CY, A <-- A - 15H
180DH	AF	8	XOR A	A, CY <-- 0
180EH	3E7F	9	LD A, 7FH	A <-- 7FH
1810H	CEAD	10	ADC A, ADH	CY, A <-- A + ADH + CY
1812H	CE23	11	ADC A, 23H	CY, A <-- A + 23H + CY
1814H	DE13	12	SBC A, 13H	CY, A <-- A - 13H - CY
1816H	DEB3	13	SBC A, B3H	CY, A <-- A - B3H - CY
1818H	DE15	14	SBC A, 15H	CY, A <-- A - 15H - CY
181AH	FF	15	RST, 38H	

INSTRUCTION (3) (4) (5) (6) (7)

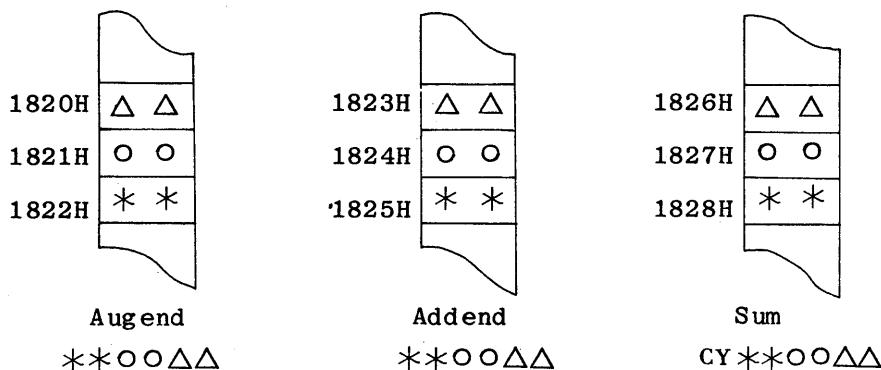
BEFORE EXECUTION					
AFTER EXECUTION	+ A D	+ 2 3	- 1 3	- B 3	- 1 5
	 CY A	 CY A	 CY A	 CY A	 CY A

(10) (11) (12) (13) (14)

CY				
A			- 1 3	- B 3
+ A D	+ 2 3	-  CY	-  CY	-  CY
 CY A	 CY A	 CY A	 CY A	 CY A

Experiment 3-2:

Referring to the operation for of 3-byte addition in example 3-3-2, write a basic addition program using only three kinds of instructions: XOR A, LD A,(nn) and ADD A,(nn). Assume that the memory addresses of the addend, augend and sum are assigned as follows:



Explanation: In the above example, we see the following rules of addition:

- (1) The addition operation moves from the low-order byte to the high-order byte, the carry generated in the low-order byte addition is added to the next higher order byte.
- (2) The addition operation is executed with the aid of the accumulator. Its result is also stored in the accumulator. Thus to add two bytes together, one byte must be loaded into the accumulator first (using the LD A,(nn) instruction). The other byte is then added to the accumulator (using the ADD A,(nn) instruction or the ADC A,(nn) instruction). The final result is stored in an assigned memory address (using the LD(nn),A instruction).

Experiment 4

Branch Instructions and Program Loops

Purposes:

1. To familiarize the reader with the applications of conditional and unconditional branch instructions.
2. To familiarize the reader with the technique of designing program loops.
3. To practice using status flags in decision-making.

Time Required: 4 hours

I. Theoretical Background:

1. Program Counter:

The program counter (PC) is an important 16-bit register in the CPU. When the voltage level of the RESET pin (pin 26) of the CPU drops to 0 and then rises to 1 (by pressing the RS key), the PC will be cleared to 0000H. The program execution is then started from address 0000H according to the clock pulses supplied by the system hardware. Once the CPU has fetched one byte of each instruction from memory, the PC will be incremented by one automatically. (The internal control circuit in the CPU determines how many bytes are contained in the instruction after the CPU has fetched the first byte of the instruction. The instruction will be executed only when the PC has been incremented by the number of bytes in the instruction). Usually, the program is fetched from the memory instruction by the instruction for execution, starting from the low memory address.

2. Branch Instructions:

At any address, the PC can be changed to another address if the programmer doesn't want the program execution to continue sequentially (For instance, when there is no memory beyond that address or the program is not stored in that area). The program then jumps to another address and continues its execution. For example, the following assembly language means that the PC will be changed to 1828H after this instruction has been executed, and the program execution continues from address 1828H.

LD PC, 1828H (This instruction is illegal in Z80 assembly language)

Actually, in assembly language, JP (Jump) is used to indicate the change in sequence of program execution. The instruction has the same meaning as:

LD PC, 1828H
JP 1828H

3. Conditional Branch Instructions:

A conditional branch instruction performs the jump operation if some specified conditions are met. These conditions are all dependent on the data in the flag register. This function makes the microcomputer capable of responding to various external conditions. It is also an indispensable tool for designing program loops. The actions of the following instructions are described in the comments to the right of the instruction:

CP 10H ; Compare the accumulator with 10H and set the proper flag.
JP Z, 1828H ; If the zero flag is set, i.e. A = 10H, then jump to address 1828H and continue the program execution.
JP C, 245AH ; If the carry flag is set, i.e. A < 10H, then jump to 245AH to execute other program.
ADD A,B ; Otherwise, i.e. A > 10, continue the program execution.

The condition of a conditional branch instruction is written after JP:

- (1) JP C, XXXX ; If there is a carry, or carry flag = 1, then jump to XXXX.
- (2) JP NC, XXXX ; If there is no carry, or carry flag = 0 then jump to XXXX.
- (3) JP Z, XXXX ; If zero flag = 1, or the result of previous operation is zero, then jump to XXXX.
- (4) JP NZ, XXXX ; If zero flag = 0, then jump to XXXX.
- (5) JP PE, XXXX ; If parity flag = 1 (even), or there was an overflow in the previous arithmetic operation, then jump to XXXX.
- (6) JP PO, XXXX ; If P/V flag = 0 (odd parity or no overflow) then jump to XXXX.

-
- (7) JP P, XXXX ; If sign flag = 0 (the sign of result of previous operation is positive) then jump to XXXX.
- (8) JP M, XXXX ; If sign flag = 1 (negative) then jump to XXXX.

4. Jump Relative:

To reduce the memory space occupied by the program and also reduce the cost of the microcomputer system, the Z80 microcomputer can use relative addresses to specify the displacement of a program jump. Since most displacements in a jump are within the range between +127 and -128, a one byte number can be used to indicate this displacement. One byte of memory is saved for each jump operation compared with the two-byte absolute address in JP instructions. The operations of the following instructions are described in the commands to the right of the instruction.

- JR 10H ; Jump forward 10H (16) locations from the present program counter (the address of the next instruction). Actually, the address of the next instruction to be executed is obtained by adding 10H to the present PC.
- JR C,FOH ; If carry flag = 1, then jump backward 10H (16) locations from the present program counter. Since the leftmost bit of FOH is 1, it is recognized as a negative number (its 2's complement is 10H).
- JR NC,7FH ; If carry flag = 0, than jump forward 127 locations (maximum value)
- JR Z,80H ; If zero flag = 1, i.e. the result of the previous operation is zero, then jump backward 128 locations. 80H (-128) is the minimum negative number that can be used in a relative address.

From the above examples, we can see that a positive relative address means jumping forward. The largest displacement then is 7FH (+127). A negative relative address means jumping backward. Its largest displacement is 80H (-128). The displacement is always measured from the address of the next instruction's op code. Relative jumps can be unconditional or conditional. The conditional jump depends on the status of the carry or zero flag. In the Z80 system, the data in the sign or P/V flag cannot be used as the condition of a relative jump.

5. Program Loop:

One of the important advantages of a computer is that it can repeat the steps in a repetitive task as many times as is

necessary to complete the task. This is accomplished by using a program loop. Looping is a very powerful tool in program design. A basic program loop must contain the following:

- (1) A loop's counter preset with the number of loops to be executed. Usually, a CPU register is used as a loop counter. Of course, memory can also be used as a counter.
- (2) The loop counter is decremented by 1 after one cycle of the loop has been executed. After each cycle the value of the loop counter must be checked. If the counter is not 0, then the loop repeats until the loop counter equals to 0.

The following program can be used to add the 8-bit data in memory addresses 1900H - 190FH and store the result in the DE register pair. This is a typical application of a program loop.

```
LD C,10H      ; Use register C as the loop counter. Since
                ; sixteen bytes data are to be added together,
                ; 10H is preset in C.

XOR A          ; Clear the accumulator

LD HL,1900H    ; Use the HL register pair as the address pointer.
                ; The contents of the memory pointed to by HL
                ; will be added to register A.
                ; The first address is 1900H.

LD D,A          ; Register D is used to store the carry
                ; generated during the addition operation.
                ; Clear Register D.

XX ADD A,(HL)  ; Add the contents of the memory address pointed
                ; to by HL to Register A. This instruction will
                ; be repeated 16 times. XX is assigned
                ; as the label of this instruction's address.

INC HL          ; Increment HL by 1. The new HL points to the
                ; next byte in data memory to be added to
                ; Register A.

JR NC,YY        ; If no carry is generated, jump to address
                ; YY to continue program execution.

INC D           ; If a carry is generated, add this carry to
                ; Register D.

YY DEC C        ; Decrement register C by 1.

JR NZ,XX        ; If the result is not zero (zero flag = 0),
                ; the program loop has not finished. Jump to
                ; XX to repeat the loop.
```

```
LD E,A           ; If zero flag = 1, then all data have been
                  added together. Load A into E, the answer
                  will be stored in the DE register pair.
```

END

There are various methods of designing a program loop. Try to design the program loops described in the following illustrations.

II. Example Experiments:

1. A program loop with a loop number of less than 256 : If the loop number is less than 256, register B is recommended as the loop counter. At the end of the loop, the DJNZ instruction can be used to decrement register B. If the result is not zero, jump to the assigned location using the relative jump method to continue the program execution. Try to analyze the following program and verify its function by loading it into the MPF-I and executing it.

```
ORG      1800H
LD       HL,1900H
LD       B,20H
→LOOP   LD       (HL),A
        INC     HL
        DJNZ   LOOP
        RST     38H
```

Experimental result:

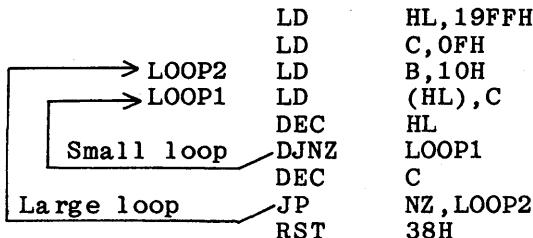
- (1) Preset register A to 0 and then execute the above program
Results:
 Contents of memory addresses 1900H - 191FH:
 Contents of memory address 1920H:
- (2) Preset register A to 55H and execute the above program.
Results:
- (3) Preset register A to 64H and replace the second instruction LD B,20H by the instruction LD B,0 . Execute the program again.
Results:
 Contents of memory addresses 1900H - 19FFH:

Discussion:

2. Nested loops:

In a more complicated program, a loop can be totally nested or embedded inside another loop. The following program can be used to divide the 256 bytes of data stored in memory into 16 groups. The starting address of the memory is 1900H. Put the contents of each group of data in the form of a hexadecimal number:

0.....(1st set), 1.....(2nd set), 2.....(3rd set),....,F.....
(16th set).



- (1) Translate the above program into machine language and then load it into the MPF-I. Execute the program.

Result :

- (2) Revise the above program such that the 16 bytes of the first group are all "F", and the 16 bytes of the last group are all "0".

3. A program loop with loop number larger than 256: If the loop number is larger than 256, a 16-bit register can be used as the loop counter. But, in the Z80 system, incrementing or decrementing a 16-bit register can not affect the status flag. Thus, some auxiliary instruction is used to determine whether the loop counter is zero. The following program is supposed to be able to set all data in RAM 1880H - 19FFH to AAH. Try to find the errors in this program and correct them. Load the correct program into the MPF-I and record the result of the program execution.

```
ORG    1800H
LD     BC,0180H
LD     HL,1880H
LOOP
LD     (HL),QAAH
INC    HL
DEC    BC
JR     NZ,LOOP
HALT
```

4. A program loop without a down counter : A program loop need not use a down counter. The function of the down counter can be replaced by using an up counter or using the method of address comparision or data comparison. Study the method used in the following program loops. Load the programs into MPF-I and execute them.

-
- (1) Move the data string in the memory (RAM) section with starting address 1B00H to the memory (RAM) section with starting address 1A00H. The movement will be terminated when data OFFH is found.

```
ORG      1800H
LD       HL, 1B00H
LD       DE, 1A00H
LOOP    LD       A,(HL)
        LD       (DE),A
        CP       OFFH
        JR       Z, EXIT
        INC      HL
        INC      DE
        JR       LOOP
EXIT    RST      38H
```

- (2) Replace all the data stored in the memory section starting from the address pointed to by HL to the address pointed to by DE with their corresponding 2's complement. In testing the program, the values of HL and DE must be preset first. The value of HL must be larger than that of DE.

```
ORG      1800H
LOOP    LD       A,(HL)
        NEG
        LD       (HL),A
        INC      HL
        AND      A
        SBC      HL, DE
        ADD      HL, DE
        JR       NZ, LOOP
```

Experiment 5

Stack and Subroutines

Purposes:

1. To understand the meaning and applications of stack
2. To understand the designing techniques and applications of subroutines.

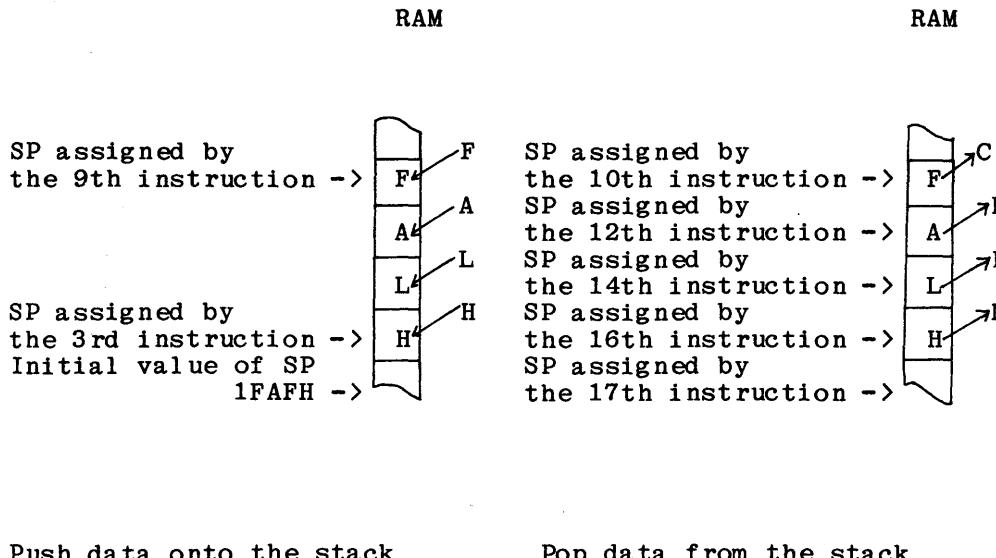
Time Required: 4 hours

I. Theoretical Background

1. Stack: In program design, a stack is recognized as a memory section which has only one port for input and output. Data are written in or retrieved from stack via this port. The first item of data placed in stack is said to be at the bottom of stack. The data most recently placed in stack is said to be at the top of stack. Thus, a stack is also called a last-in first-out memory. A stack can be constructed by hardware shift registers or general RAMs. In the Z80 microcomputer system, the programmer can assign a region of RAM as the stack. To define a stack at the top of RAM, the highest address of RAM is incremented by 1 and then loaded into the stack pointer (SP) in the CPU. The following program and diagrams illustrate the operation of stack.

Instruction Number	Instruction	Comment
(1)	LD SP,1FAFH	; Stack pointer is set to 1FAFH, i.e. the RAM section with address less than or equal to 1FAEH is assigned as stack.
(2)	DEC SP	; Decrement SP by 1. Stack pointer is at 1FAEH, i.e. at the bottom of stack.
(3)	LD (SP),H	; Load the contents of register H into memory (RAM) address 1FAEH.
(4)	DEC SP	; Decrement SP by 1 again.
(5)	LD (SP), L	; Place the contents of L at the top of stack (i.e. above H).
(6)	DEC SP	
(7)	LD (SP),A	; Place the contents of A at the top of stack (i.e. above L).
(8)	DEC SP	

- (9) LD (SP), F ; Place the contents of F at the top of stack (i.e. above A).
- .
- .
- .
- .
- (10) LD C, (SP) ; Pop one byte of data from the top of stack and move it to register C.
- (11) INC SP ; Increment SP by 1. SP is moved towards the top of the stack.
- (12) LD B,(SP) ; Pop data from the top of stack.
- (13) INC SP ; Increment SP by 1 again.
- (14) LD E,(SP) ; Pop data from the top of stack and move it to register E.
- (15) INC SP
- (16) LD D,(SP) ; Pop data from the top of stack and move it to register D. This data is the first one that is stored in stack.
- (17) INC SP ; SP is at the initial value.



Push data onto the stack

Pop data from the stack

From the above illustrations of stack operation, we can see that data can be stored in RAM by using SP as the pointer. SP is decremented by 1 whenever one-byte of data is stored in and the stack area becomes larger. The SP will be incremented by 1 whenever one-byte data is retrieved from the stack area and the stack area becomes smaller. The process of decrementing SP (pushing data onto stack) or incrementing SP (popping data out of stack) can be accomplished automatically by special hardware design. A stack can

also be used to store a 16-bit address (or data). In the Z80/8085 system, there are instructions to push a 16-bit register pair onto stack and pop a 16-bit data out of stack. During each operation, SP is decremented or incremented by 2. The following program is equivalent in function to that of the program given above.

```
LD SP, 1FAFH      ; Same as 1st instruction.  
PUSH HL          ; Same as no. (2)(3)(4)(5) instructions.  
PUSH AF          ; Same as no. (6)(7)(8)(9) instructions.  
POP BC           ; Same as no. (10)(11)(12)(13) instructions.  
POP DE           ; Same as no. (14)(15)(16)(17) instructions.
```

Instructions PUSH and POP can be used to temporarily store data in registers and also used to transfer register data. An example is given below.

```
PUSH BC  
POP IX          ; Move the 16-bit data in BC to IX  
PUSH HL  
AND A  
SBC HL,DE      ; Compare HL with DE to generate status flags. The value of HL is kept unchanged.
```

It is very important to keep the number of PUSH instructions equal to the number of POP instructions in the stack operation.

2. Subroutine:

Programs for arithmetic (addition, subtraction, multiplication or division), keyboard and display control, etc are often used as part of a large program in practical applications. If the programmer rewrites these small programs everytime he needs them, the whole program would be very tedious to write. To save memory space for the program and reduce errors, subroutines are often used in a large program. Instructions CALL and RET are used to manipulate the subroutines. The subroutines can be executed unconditionally or according to the conditions of flags. The instruction CALL in the main program is used to call the subroutine. Its function consists of two operations which are illustrated below.

→CALL 1A38H ; Call the subroutine stored in address 1A38H.

Equivalent to

```
{ PUSH PC      ; Push the current program counter onto stack.  
  JP 1A38H    ; Jump to address 1A38H and continue the program execution.
```

RET instruction doesn't need an operand (1 byte instruction), it is the same as 'POP PC' instruction.

```

RET          ; Return to original program and continue
            ; to execute.

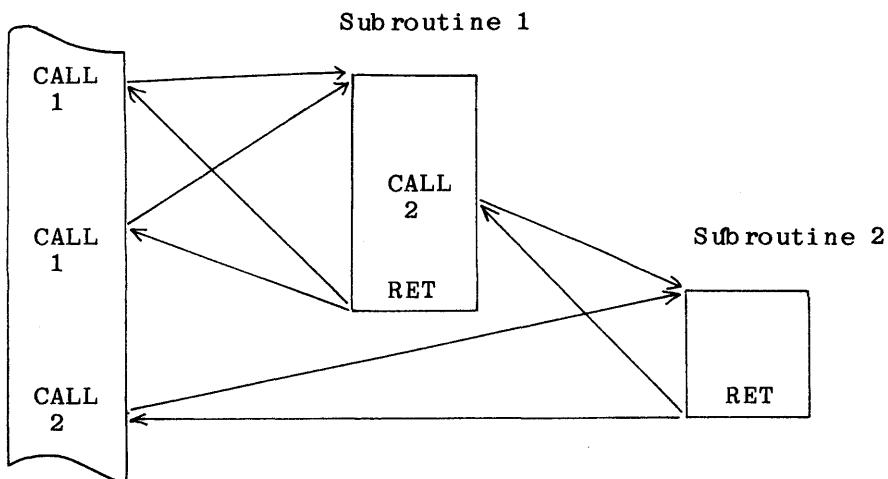
Equivalent to ; Retrieve 16-bit data in stack and load into
              ; PC, then execute program according PC
              ; contents.

POP PC

```

Calling a subroutine is an important step in a program. Subroutines in a program can be in a nested form that is a subroutine can be another subroutine. The relationship is shown below:

Main Program



Usually, subroutines are written by a specialist. The user only has to understand its calling procedure . If the subroutine is written by the user himself, the following items must be considered in designing a subroutine:

- (1) An easily-remembered name must be chosen for the subroutine.
- (2) How to get the data required in the subroutine before executing the subroutine.
- (3) How to express the result after executing the subroutine.
- (4) Which register will be changed after executing the subroutine.
- (5) How much memory will be occupied by the subroutine and how much time is needed for the CPU to execute the subroutine.

The following items must also be considered when a subroutine is called by the main program:

- (1) Registers that should not be changed by the execution of the subroutine must be pushed onto stack before calling the subroutine.

- (2) How the results obtained from the subroutine execution will be transmitted by the main routine (the calling routine).

The following listing is a sample subroutine named MADD. It can be used for multi-byte BCD addition.

LOC	OBJ CODE	MADD LISTING		PAGE 1
		STMT	SOURCE STATEMENT	ASM 3.0
		1	*** MULTIBYTE BCD ADDITION ROUTINE ***	
		2	ENTRY: HL POINTS TO LOW ORDER BYTE OF AUGEND	
		3	DE POINTS TO LOW ORDER BYTE OF ADDEND	
		4	B = BYTE NUMBER, 1 BYTE = 2 BCD DIGIT	
		5	EXIT : IX POINTS TO LOW ORDER BYTE OF RESULT	
		6	REG. CHANGE : AF,B,HL,DE,IX	
		7	MEMORY USED : 15 BYTES	
		8		
0000	AF	9	MADD XOR A ; CLEAR CARRY FLAG	
0001	1A	10	MADD1 LD A,(DE)	
0002	86	11	ADD A,(HL)	
0003	27	12	DAA	
0004	DD7700	13	LD (IX),A	
0007	13	14	INC DE	
0008	23	15	INC HL	
0009	DD23	16	INC IX	
000B	10F4	17	DJNZ MADD1	
000D	C9	18	RET	

0 ASSEMBLY ERRORS

Two 4-byte BCD data are stored in the memory with starting addresses at 1A00H and 1A40H, respectively. To add these BCD data together and store the result in RAM address 1A08H, subroutine MADD is called by the following procedure:

```

LD      B,  4          ; Set Byte Number = 4 .
LD      HL, 1A00H       ; HL points to the address of augend.
LD      DE, 1A40H       ; DE points to the address of addend.
LD      IX, 1A08H       ; IX points to the address of sum.
CALL   MADD

```

II. Example Experiment:

- (1) Using the instructions for stack operation, write a routine to move the data in HL, DE and BC to HL', BC' and DE', respectively. Load the program into MPF-I and execute it.

- (2) In the following program, a small loop is embedded in a large loop. The function of this program is to shift all the 8-bit data in bytes in the address 1A11H - 1A20H left four bits. Use register B as the loop counter for both small and large loops. Load the program into MPF-I and execute it. Discuss the reason why register B can be used as the counter for both loops.

1800		1	ORG 1800H
1800	0621	2	LD B,21H
1802	21001A	3	LD HL,1A00H
1805	C5	4	LOOP1 PUSH BC
1806	7E	5	LD A,(HL)
1807	0604	6	LD B,4
1809	87	7	LOOP2 ADD A,A
180A	10FD	8	DJNZ LOOP2
180C	77	9	LD (HL),A
180D	23	10	INC HL
180E	C1	11	POP RC
180F	10F4	12	DJNZ LOOP1
1811	76	13	HALT

- (3) By calling the subroutine given in part 1 of this experiment (multi-byte BCD addition routine), write a program to add two 8-byte data stored in memory 1A00H and 1A08H. The result must be stored in the 8-byte memory starting at 1A00H.
- (4) Revise the above program for BCD subtraction or multi-byte binary addition/subtraction. Test the program and record the method of revision used.
- (5) Write a subroutine to change the 16-bit data in HL to its 2's complement. Write a main program to change the data in IX and IY to their 2's complements. Load the program into MPF-I and test it.
- (6) By using the above routine for complementing the HL register pair, write a program to subtract DE from the data in IY and store the result in IY.

Experiment 6

Rotate Shift Instructions and multiplication Routines

Purposes:

1. To understand the use of Rotate and Shift instructions
2. To understand the designing techniques and uses of a binary multiplication subroutine.

Time Required: 4 - 8 hours

I. Theoretical Background:

1. The 9-bit data formed by the carry flag and 8-bit data in a register or memory can be shifted one bit left or right by ROTATE or SHIFT instructions. The ROTATE and SHIFT instructions are mainly used for multiplication and division. We multiply a number by rotating and shifting left the bits that constitute a number, while a division operation is done by rotating or shifting right the bits that constitute a number. There are many ways to rotate or shift the bits of a number. So, there are 13 different types of ROTATE and SHIFT instructions. Please refer to the MPF-I User's Manual, Appendix C. The mnemonic codes of these instructions are described below.
 - (1) If the leftmost character of an instruction is "R", it is a "ROTATE" instruction. Such instructions can be used to rotate the 9-bit data (formed by 8-bit data and carry flag) left or right one bit, e.g. RLCA, RL, RRA, etc.
If the leftmost character is "S", then it is a "SHIFT" instruction. All the 9-bits of the data are shifted left or right by one bit. The bit shifted out from one side will not be moved in from other side. Examples of such instructions are SAL and SRL.
 - (2) If the second character from the left is "R", it means "shift right" or "rotate right". Instructions RR, SRL, RRCA, etc. are examples.
If the second character in the left is "L", it means "shift left" or "rotate left". Instructions RL, SLA, RLCA, etc. are the examples.
 - (3) The meaning of the third character is more complicated, but it can be summarized as follows:
 - (a) In ROTATE instructions:
The third character "C" represents the circular rotation of 8-bit data, carry flag is not included. The third character (or the fourth character) "A" means that this instruction is operated with the accumulator.
Instructions RLA, RRA, RLCA and RRCA are examples.
The third character "D" indicates the shift operation on decimal or hexadecimal numbers, for example, RLD and RRD. These instructions are designed to rotate the memory pointed to by HL left or right one digit (4 bits)

The digit entering from the left or right direction comes from bit 0 - bit 3 of the accumulator. The digit moving out from the other side is sent to bit 0 - bit 3 of the accumulator.

(b) In SHIFT instructions:

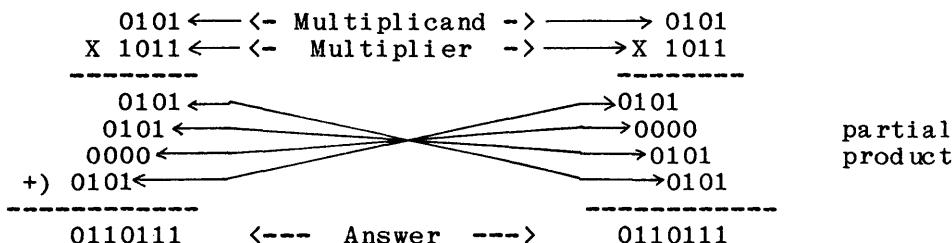
The third character "A" indicates "Arithmetic Shift". Binary data shifted left means multiplying it by 2 . Binary data shifted right means dividing it by 2 . Two of these instructions are SLA and SRA. Because bit 7 is assigned as "sign bit" and the sign of the data is not changed by these operations, the leftmost bit (bit 7) must be kept unchanged.

The third character "L" means "logical shift".

Instruction SRL is an example. In these operations, a "0" is always moved to bit 7 from the left direction.

2. Binary Multiplication:

The operation of unsigned binary multiplication can be accomplished by shifting the binary number left or by a program loop of addition. An example of binary multiplication by hand-calculation is illustrated below.



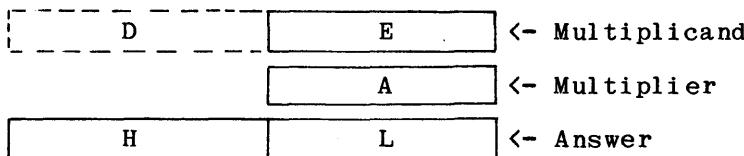
In the above calculation, one bit of the multiplier is checked. If that bit is 1, the multiplicand is copied as the partial product. If that bit is 0, 0000 is given instead. The position of the partial product is arranged such that the least significant bit of the multiplicand is aligned with the bit of the multiplier being checked. In this example, multiplicand and multiplier are both 4-bit data. Thus, it is necessary to repeat the operations of checking, shifting and addition four times. Similarly, the operations must be repeated 8 times for 8-bit data multiplication and 16 times for 16-bit data multiplication. In the left-hand side calculation given above, the bit-checking process starts from the least significant bit of the multiplier. In the right-hand side calculation, the bit-checking process starts from the most significant bit. But the results of the two calculations are identical. The program of binary multiplication for microcomputers can be designed by a method similar to the above calculation.

Example: Multiply the 8-bit data in register E by the 8-bit data in register A. The product is stored in the HL register pair.

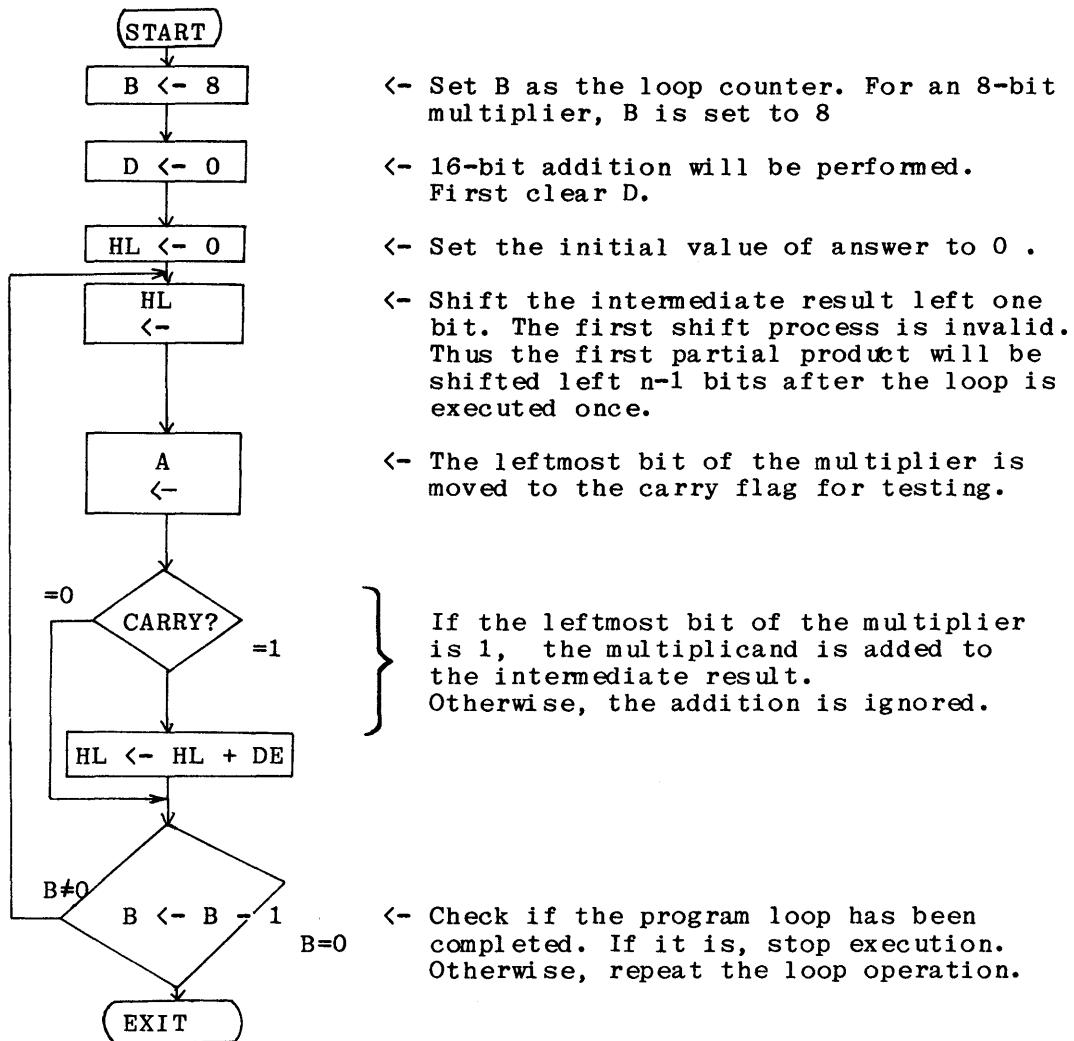
Answer: Specific registers have been assigned to store multiplicand, multiplier and product according to the characteristics of the Z80 instruction set. Using the calculation algorithm given in the right-hand side of the above example, the program is designed as follows.

1. In the above hand calculation, the bit-checking process starts from the least significant bit. A program loop can be employed in the example. The multiplier is 8-bits long, thus the loop number is equal to 8 . In every loop execution, the bit being checked (in register A) can be shifted into the carry flag by the RLCA instruction. Then, according to the condition of the carry flag, we can decide what will (or will not) be done next.
2. If the first bit checked (the leftmost bit) is 1, the partial result is actually obtained by shifting the multiplicand left $(n-1)$ bits, where n is the number of bits in the multiplier. The other partial results are obtained by shifting the partial products left $(n-2)$ bits, $(n-3)$ bits,....., etc. In this example, no other registers are required to store the partial results. Each partial result can be added directly to the HL register pair.
3. From the above description, we can see that the partial products must be shifted left $(n-1)$ bits, $(n-2)$ bits, $(n-3)$ bits,....,etc. Since the bit-checking is also moving left in the process, we can generate a new intermediate result by immediately adding each partial product to the previous intermediate result. This method is more efficient and is used in the following program flowchart.

4. Register Assignments:



5. Program Flowchart :



MP 8 LISTING

LOC	OBJCODE	STMT	SOURCE STATEMENT	ASM 3.0
		1	;***MULTiPLY***	
		2	;ENTRY:	
		3	;MULTIPLIER IN E	
		4	;MULTIPLICAND IN A	
		5	;EXIT:	
		6	;PRODUCT IN HL	
		7	;REG. CHANGE : B,D,HL	
		8	;MEMORY BYTE : 14	
		9	;EXICUTION TIME:<395 CLOCK / <197.5 μ S.	
		10	;	
		11	MP 8 :	
0000	0608	12	MULTI LD B,8 ; SET BYTE COUNTER = 8	
0002	1600	13	LD D,0	
0004	62	14	LD H,D	
0005	6A	15	LD L,D ;CLEAR D,HL REGISTER	
0006	29	16	LOOP ADD HL,HL ;SHIFT HL LEFT	
0007	07	17	RLCA ;ROTATE BIT 7 OF "A" INTO ;CARRY FLAG	
0008	3001	18	JR NC,NADD ;TEST CARRY FLAG	
000A	19	19	ADD HL,DE ;ADD DE TO HL	
000B	10F9	20	NADD DJNZ LOOP ; END?	
000D	C9	21	RET	

II. Example Experiments:

1. The following program can be used to shift the 32-bit data stored in the HL and DE register pairs, which are adjacent, right one bit (or divide the data by 2). Load the program into MPF-I and test it. Next, revise the program such that it can be used to shift the 32-bit data left one bit (or multiply it by 2).

```
ORG      1800H
SRA      H
RR       L
RR       D
RR       E
RST      38H
```

2. Write a program to shift the 32-bit data, stored in RAM addresses 1A00H - 1A03H, left five bits (or multiply it by 20H). Load the program into MPF-I and test it. The starting address of the program is assigned as 1810H.
3. Using the RLD instruction, write a program to shift the BCD data, stored in RAM addresses 1A00H - 1A03H, left four bits. The starting address is assigned as 1830H. Load the program into MPF-I and test it.
4. The following program can be used to multiply the 16 bit data stored in the DE register pair by the contents of register A. Load the program into MPF-I and test it. Compare this program with the program given in Theoretical Background. Discuss the advantages and disadvantages of this program.

```
MPY8    LD      BC,800H
        LD      H,C
        LD      L,C
M1      ADD    HL,HL
        RLA
        JR     NC,M2
        ADD    HL,DE
        ADC    A,C
M2      DJNE   M1
        RST    38H
```

5. Write a program to multiply the 32-bit data stored in RAM addresses 1A00H - 1A03H by the 32-bit data stored in RAM addresses 1A04H - 1A07H. The product must be stored in RAM addresses 1A08H - 1A0FH.

Experiment 7

Binary Division Routine

Purposes:

1. To understand how to write a binary division subroutine for a microcomputer.
2. To familiarize the reader with the technique of software programming.

Time Required: 4 - 8 hours

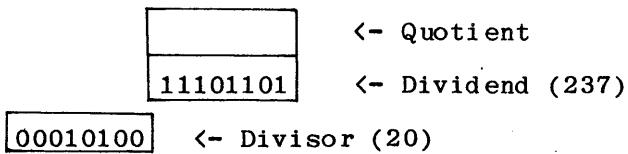
I. Theoretical Background:

1. Binary division by hand-calculation:

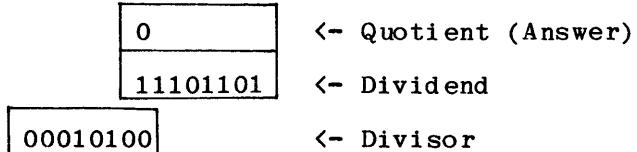
The following example will be used to illustrate the detailed procedure of binary division.

Divide 11101101 by 00010100

(1) Write the dividend on the right-hand side, divisor on the left-hand side, and put the quotient above the divisor.



(2) Shift the dividend and the quotient left one bit.



To compare the dividend and the divisor, place seven zeros after the divisor in the columns beneath the dividend. It can then be seen that the dividend is smaller than the divisor. Therefore put "0" in the position of quotient.

(3) Continue to test if the dividend is less than the divisor with each shift. If the dividend is still less than the divisor, then put a "0" in the quotient. Otherwise, put a "1" in the quotient and the divisor is subtracted from the dividend. In this example, the dividend and the quotient must be shifted left five bits before a "1" can be put in the quotient. Thus four "0"s and one "1" are put in the quotient in the following way.

00001	<- Quotient (when the dividend is larger than the divisor "1" is put in the quotient.)
11101101	<- Dividend
00010100	<- Divisor

- (4) Subtract the divisor from the dividend.
The difference becomes the dividend.

00001	<- Quotient (Answer)
01001101	<- Dividend after subtraction
00010100	<- Divisor

- (5) The dividend and the quotient are shifted left two bits,
then a "1" is put in the quotient.

0000101	<- Quotient (Answer)
01001101	<- Dividend
00010100	<- Divisor

- (6) Subtract the divisor from the dividend.
The difference becomes the dividend.

0000101	<- Quotient (Answer)
00100101	<- Dividend after subtraction
00010100	<- Divisor

- (7) Both dividend and quotient are shifted one bit again. Since the dividend is not less than the divisor, put "1" in the quotient.

00001011	<- Quotient (Answer)
00100101	<- Dividend
00010100	<- Divisor

- (8) Subtract the divisor from the dividend, the remainder is placed in the position of the dividend.

00001011	<- Quotient (11)
00010001	<- Remainder (17)
00010100	<- Divisor

- (9) If the remainder is not zero, the division process can be continued, but the result will contain fractions.

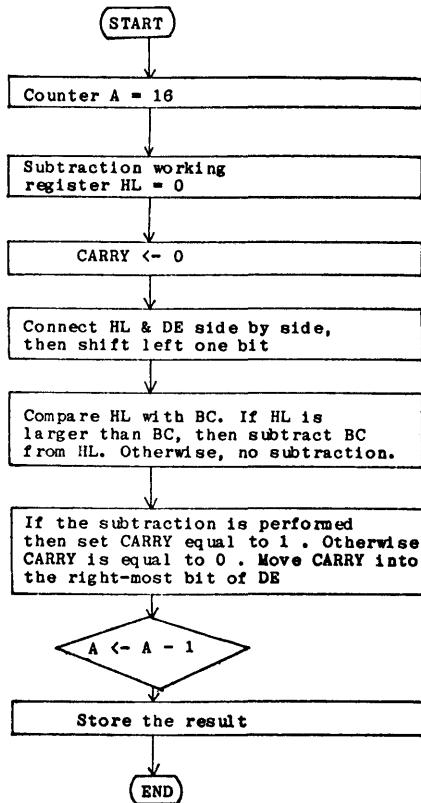
2. Division Program Design:

For the above algorithm, three memory locations are required to store the dividend, divisor and quotient.

Example : Write a program to divide the 16-bit data in the DE register pair by the 16-bit data in the BC register pair. The result (quotient) must be stored in the HL register pair and the remainder in the DE register pair.

Solution: The register assignment has been given in the problem description. The HL register pair can be used as the working register for 16-bit arithmetic subtraction. Shift the 16-bit data in DE left one bit to the HL register pair. Compare HL with BC. If HL is not less than BC, then subtract BC from HL and the carry flag is set to 1 automatically. Otherwise, no subtraction operation is performed and the carry flag will be 0 . Since the right-most bit of DE is now empty, the carry flag is then moved to this position.

The flowchart and the assembly language program are given below.



```

1 ; *** MPF-I EXAMPLE PROGRAM 008 ***
2 ;16 BIT DIVISION ROUTINE
3 ;ENTRY:DIVIDEND IN 'DE'
4 ;           :DIVISOR IN 'BC'
5 ;EXIT  :RESULT IN 'HL'
6 ;           :REMAINDER IN 'DE'
7 ;REG. CHANG :AF,DE,HL
8
0000 AF    9 DIV16 XOR A      ;CLEAR CARRY FLAG
0001 67    10 LD H,A
0002 6F    11 LD L,A      ;HL=0
0003 3E10  12 LD A,16     ;A = 16,LOOP COUNTER
13
0005 CB13  14 DVO   ;HL&DE 4 BYTE ROTATE LEFT 1 BIT
0006          15 RL E    ;SHIFT LEFT,STORE PARTIAL RESULT
0007          16           IN BIT 0
0008 CB12  17 RL D
0009 ED6A  18 ADC HL,HL   ;ROTATE HL LEFT
19
000B ED42  20 ; IF HL GREAT THAN BC, SUBTRACT FROM BC
000C 3001  21 SBC HL, BC   ;HL = HL - BC
000D          22 JR NC,DV1
000F 09    23 ADD HL,BC   ;IF NEGATIVE, RESTORE HL
24
0010 3F    25 DV1   CCF      ;PARTIAL RESULT 'IN CARRY FLAG
0011 3D    26 DEC A
0012 20F1  27 JR NZ,DVO
28
0014 EB    29 EX DE HL
0015 ED6A  30 ADC HL,HL   ;STORE LAST BIT OF RESULT
0017 C9    31 RET

```

- (1) Statement 10 and 11 of the program can be replaced by instruction LD HL,0 . But this instruction occupies 3 bytes memory and takes 10 clock cycles to execute. Instead, in this example, LD H,A and LD L,A are used (A is cleared to zero by statement 9). They occupy 2 bytes of memory and can be executed in 8 clock cycles.
- (2) Addition and subtraction instructions can be used for "shift left" or "rotation" operations. In this example, instructions ADC HL,HL is identical with rotating the 16-bit data in HL pair left one bit (The bit moved to the carry flag comes from the leftmost bit of register D). The functions of the following instructions are described on the right-hand side.

ADD A,A ; Shift register A left one bit;
or multiply A by 2.

ADC A,A ; Rotate A left one bit

```

ADD      HL, HL ; Shift HL left one bit; or double it.

ADC      HL, HL ; Rotate HL left one bit.

ADD      IX, IX ; Shift IX left one bit; or double it.

ADD      IY, IY ; Shift IY left one bit; or double it.

```

II. Illustrations of Experiments :

1. Load the above program into MPF-I and then store it on audio tape.
2. Replace the last instruction (RET) in the above division subroutine by RST 38H and execute it. Record the obtained results in the following table.

Dividend	Divisor	Answer	Remainder	Check
8686H	0020H			
FFFFH	0003H			
5A48H	0142H			
OH	0142H			
1234H	OH			

3. Modify the above program such that the division process can be continued until a 16-bit fractional quotient is obtained.
4. Using the above program as a subroutine, write a main program to divide the data in RAM addresses 1A00H - 1A01H by the data in RAM addresses 1A04H - 1A05H. The result (quotient) must be stored in addresses 1A00H - 1A01H.
5. Write a program to divide the 4-byte data stored in addresses 1A00H - 1A03H by the 4-byte data stored in the memory address pointed to by the HL register pair. The result (quotient) must be in addresses 1A00H - 1A03H. The remainder must be stored in addresses 1A04H - 1A07H.

Experiment 8

Binary-to-BCD Conversion Program

Purposes:

1. To understand the programming techniques of binary-to-BCD conversion and its applications.
2. To understand the relation between subroutines and the main program.
3. To familiarize the reader with the technique of program writing.

Time Required: 4 hours

I. Theoretical Background:

1. Methods of binary-to-BCD conversion:

There are several methods for binary-to-BCD conversion. The method given below will be very neat because it uses the DAA instruction. Two memory sections are assigned to store binary and BCD data, respectively. The memory addresses for BCD data are initially cleared to zero. The following process of shifting and checking data is repeated until all binary data bits are shifted left completely: shift the binary data left one bit, and its leftmost bit is automatically transferred to CARRY. The BCD data is then doubled and its rightmost bit-position is filled with the CARRY of binary data.

The flowchart will be:

(1) Preparation:

Store the binary data in RAM with a starting address of 1A00H. Assign register D as the byte counter for the binary data, and register E as byte counter for the BCD data. (Since the bit number of the BCD data may be larger than that of the binary data, the value of E is usually not less than that of D).

(2) Clear the RAM section (starting address at 1A08H) for the BCD data.

(3) Shift the binary data (stored in RAM with starting address at 1A00H) left one bit. The leftmost bit is automatically transferred to CARRY Flag.

(4) Add CARRY to the BCD data (starting address at 1A08H) and then double the BCD data.

(5) Check if all the bits of binary data have been shifted out of the original memory section. If not, repeat step (3). If yes, it is end of the program.

The actual assembly language program is listed below.

EX001 LISTING
LOC OBJ CODE STMT SOURCE STATEMENT

PAGE 1
ASM 3.0

```
1 ;*** MPF-I EXAMPLE PROGRAM 001***  
2 ;MULTIBYTE BINARY TO BCD CONVERSION  
3 ;ENTRY: BINARY DATA STORED IN ADDR. 1AO0H  
4 ;EXIT :BCD DATA STORED IN ADDR. 1A08H  
5 ;REGISTER USE  
6 ; D CONTAINS BYTE NUMBER OF BINARY DATA  
7 ; E CONTAINS BYTE NUMBER OF BCD DATA  
8 ; A BCD DATA WORKING REGISTER  
9 ; B LOOP COUNTER  
10 ; C BINARY BIT NUMBER  
11  
1800 12 ORG 1800H  
13 BINBCD:  
1800 AF 14 ;CLEAR BCD DATA BUFFER  
1801 43 15 CLEAR XOR A ;A=0  
1802 21081A 16 LD B,E ; B=BCD BYTE NUMBER  
1805 77 18 CLR LD (HL),A ;CLEAR MEMORY  
1806 23 19 INC HL ;NEXT ADDRESS  
1807 10FC 20 DJNZ CLR  
21  
22 ;CALCULATE BIT NUMBER  
1809 7A 23 LD A,D ;A=BYTE NUMBER  
180A 87 24 ADD A,A  
180B 87 25 ADD A,A  
180C 87 26 ADD A,A ;A=A*8  
180D 4F 27 LD C,A ;C=BIT NUMBER  
28  
29 LOOP:  
30 ;SHIFT BINARY DATA LEFT  
180E 2E00 31 LD L,0 ;HL=1A00=BINARY STARTING ADDRESS  
1810 42 32 LD B,D  
1811 CB16 33 SHLB RL (HL)  
1813 23 34 INC HL  
1814 18FB 35 DJNZ SHLB  
36  
37 ;ADD CARRY & DOUBLE BCD DATA  
1816 2E08 38 LD L,8 ;HL=1A08=BCD STARTING ADDRESS  
1818 43 39 LD B,E  
1819 7E 40 BCDADJ LD A,(HL)  
181A 8F 41 ADC A,A  
181B 27 42 DAA  
181C 77 43 LD (HL),A  
181D 23 44 INC HL  
181E 10F9 45 DJNZ BCDADJ  
46  
1820 0D 47 DEC C  
1821 20EB 48 JR NZ,LOOP  
1823 FF 49 RST 38H
```

0 ASSEMBLY ERRORS

2. Assembly Language Programming Technique.

- (a) Multiply (or divide) a piece of binary data by a fixed number:

Of course, the standard multiplication (or division) subroutine can be used to multiply (or divide) a binary number by a constant. However, a simple multiplication (or division) can be easily accomplished by shifting, additions or subtraction operations. For instance, in the above program, if the byte number of the binary data is known, then the bit number of the data can be easily obtained by multiplying the byte number by 8. In statements 22 - 27, instruction ADD A,A is used three times for multiplying the data in register D by 8 and then storing the result in register C. If the multiplier is not an exponential of 2, then addition or subtraction instructions must also be used.

Example: Multiply the data in D register by 6 and then store the result in register A. The program can be designed as follows.

```
LD      A,D      ; A = D
ADD    A,A      ; A = 2 * D
ADD    A,D      ; A = 3 * D
ADD    A,A      ; A = 6 * D
```

- (b) Addressing method for memory on the same page:

A memory address can be pointed to indirectly by a register pair (16 bits). To change a memory address pointed to by a required pair within the same page (each page contains 256 bytes), only a change in the low-order byte of the register pair is required. For instance, in the program listed above, the binary and BCD data are stored on the same page of memory (page 1AH). Since statement 1A assigns the contents of register H as 1AH, only a change in the contents of register L is required to change the pointed address in statements 31 and 38.

II. Example Experiments:

1. Load the binary-to-BCD conversion program listed in part I into MPF-I and then store it on audio tape for future applications.
2. Test the above program:

First, store the byte numbers of binary and BCD data in registers D and E, respectively. Next, load the binary data into RAM, with a starting address at 1A00H. Record the obtained result and check if is correct.

Binary	Hexadecimal	BCD	registers D & E
1000000000	0200H		D = 2, E = 2
	FFFFH		D = 2, E = 3
	18000H		D = 3, E = 4
	5A48347FH		D = 4, E = 6
	2^{32}		D = 8, E = OAH
	2^{63}		D = 8, E = OAH
	$2^{64} - 1$		D = 8, E = OAH

3. Change the above program to a subroutine format (Replace the last instruction RST 38H by RET). Using this subroutine, write a program to convert the contents of the DE register pair into a BCD number and then store the converted BCD data in the HL register pair. The contents of the DE register pair will not be changed after the program execution. Test the program and write down the complete program in the blanks below.
4. Write a program to multiply the binary data in register E (<20H) by 7 and store the result in register A.

Experiment 9

BCD-to-Binary Conversion Program

Purposes:

1. To understand the methods of BCD-to-Binary conversion.
2. To familiarize the reader with programming technique.

Time Required: 4 - 8 hours

I. Theoretical Background:

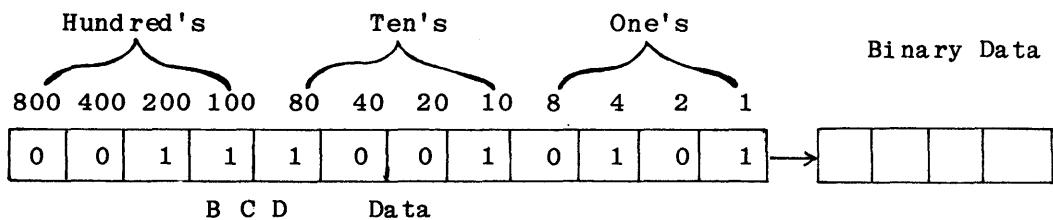
1. Methods of BCD-to-Binary conversion:

There are also several method for BCD-to-Binary conversion. In this experiment, the simple yet efficient method of shifting and checking is used. The RAMs used for storing the binary and BCD data are adjacent (in a row with the low-order digit on the right side). The BCD data is stored on the left-hand side and the converted binary data is stored on the right-hand side. The conversion procedure is given as follows.

- (1) Assign the bit number of the binary number as N for N program loops.
- (2) Shift the connected data right one bit.
- (3) Check the left-most bit of each digit (4 bits). If the checked bit is 1, then subtract 3 from the corresponding digit.
- (4) Repeat step (2) & (3) N times. The conversion process is then completed.

2. Principle of the checking process :

The real purpose of steps (2) & (3) of the above method is to divide the BCD number by 2 and put the remainder in the memory. The principle is illustrated in the following figure.



- (1) Each BCD digit contains 4 bits. Shifting the 4 bits of a digit right one bit will divide this digit by 2. For instance, the leftmost digit of the ten's four bits represents 80 if it is "1". If this bit is shifted right, then it represents 40, that is, half of its original value.
- (2) If a "1" is shifted from high a order digit to a lower order digit, the value is reduced to 5 (or 50, 500, ---, etc). However, the resulting BCD code will interprete this bit as 8 (or 80, 800, ---, etc). Thus 3 (or 30, 300, ---, etc) must be subtracted from the resulting BCD number.
- (3) The conversion method can be illustrated by the following hand-calculation.

$$\begin{array}{r}
 205 \leftarrow \text{Decimal} \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 102 \quad \text{Remainder} \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 51 \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 25 \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 12 \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 6 \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 3 \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 1 \\
 \hline
 \begin{array}{r}
 \overline{\quad} \quad 2 \\
 \hline
 0 \rightarrow 1 \quad 1 \quad 0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 1
 \end{array}
 \end{array}
 \end{array}
 \end{array}
 \end{array}
 \end{array}$$

2	<u>205</u>	---	1	BIT 0
2	<u>102</u>	---	0	BIT 1
2	<u>51</u>	---	1	BIT 2
2	<u>25</u>	---	1	BIT 3
2	<u>12</u>	---	0	BIT 4
2	<u>6</u>	---	0	BIT 5
2	<u>3</u>	---	1	BIT 6
	<u>1</u>			BIT 7
	1100	1101		
	C	D		

3. BCD-to-Binary conversion program:

Once the conversion method is decided, it is very easy to design the program. The following program can be used to convert 5-byte (or 10-digit) BCD data stored in RAM into 4-byte binary data. Since the largest value of 4-byte binary data is 4,294,967,295, the BCD number to be converted can not exceed this value. In RAM, the memory of addresses 1A00H - 1A03H are reserved for storing the binary data (lowest-order byte in 1A00H). The memory of addresses 1A04H - 1A08H are assigned to store the BCD data. Sample programs for BCD-to-Binary conversion and Binary-to BCD conversion are listed below for reference.

EX007 LISTING
 LOC OBJ CODE STMT SOURCE STATEMENT

```

1 ;*** MPF-I EXAMPLE PROGRAM 007 ***
2
3 ; 10 DIGIT BCD TO BINARY CONVERSION
4 ; ENTRY: BCD DATA IN RAM 1A04H TO 1A08H
5 ; : MAX. BCD DATA IS (4294967295)
6 ; EXIT : BINARY DATA IN RAM 1A00H TO 1A03H
7 ; REG. CHG : AF, HL, BC
1800 1800H
1800 OE20
1800 1800H ;PRESET CONV. LOOP = 32
18 DBLP:
11 ; DECIMAL DIVID BY 2
1802 0605 12 LD B,5 ;BCD BYTE COUNT = 5
1804 AF 13 XOR A ;CLEAR CARRY FLAG
1805 21081A 14 LD HL,1A08H ;HL POINT TO LEFT BYTEL
1808 7E 15 COR0 LD A,(HL) ;TRANSFER DATA TO A REG.
1809 1F 16 RRA ;ROTATE RIGHT
180A F5 1A PUSH AF ;SAVE CARRY FLAG
180B CB7F 18 ;* BCD DIVID CORRECTION
180D 2802 19 BIT 7,A ;TEST BIT 7
180F D630 20 JR Z,COR1 ;NO CORRECT IF BIT 7 = 0
1811 CB5F 21 SUB 30H ;SUBTRACT FROM 30H IF BIT 7 = 1
1813 2802 22 COR1 BIT 3,A ;TEST BIT 3
1815 D603 23 JR Z,COR2
1816 25
181A 77 24 SUB 3
1818 2B 25
1819 F1 26 COR2 LD (HL),A ;STORE TO MEMORY
181A 10EC 27 DEC HL ;NEXT BYTE
181C 0604 28 POP AF ;RESTORE CARRY FLAG
181E CB1E 29 DJNZ COR0 ;DONE LOOP
1820 2B 30
1821 10FB 31 ;ROTATE BINARY RIGHT
1823 0D 32 LD B,4 ;BINARY BYTE = 4
1824 20DC 33 SHR4 RR (HL)
1825 34 DEC HL
1826 C9 35 DJNZ SHR4
1827 36
1828 37 DEC C
1829 38 JR NZ,DBLP
1830 C9 39 RET

```

EX007 LISTING

LOC	OBJ	CODE	STMT	SOURCE STATEMENT
		40	*E	
		41	;4	BYTE BINARY TO BCD CONVERSION
		42	;	ENTRY: BINARY DATA STORE IN ADDR. 1A00H TO 1A03H
		43	;	EXIT :BCD DATA STORE IN ADDR. 1A04H TO 1A08H
		44	;	REG. CHANG : AF,BC,HL
		45		
		46	BINBCD:	
		47	;	CLEAR BCD DATA BUFFER
1827	21041A	48		LD HL 1A04H
182A	0605	49		LD B,5
182C	3600	50	CLEAR	LD (HL),0
182E	23	51		INC HL
182F	10FB	52		DJNZ CLEAR
		53		
1831	OE20	54		LD C,32
		55	LOOP	
		56	;	SHIFT BINARY DATA LEFT
1833	68	57		LD L,B ; HL=1A00=BINARY STARTING ADDRESS
1834	0604	58		LD B,4
1836	AF	59		XOR A
1837	CB16	60	SHLB	RL (HL)
1839	23	61	INC	HL
183A	10FB	62		DJNZ SHLB
		63		
		64	;	ADD CARRY & DOUBLE BCD DATA
183C	0605	65		LD B,5
183E	7E	66	BCDADJ	LD A,(HL)
183F	8F	67		ADC A,A
1840	27	68		DAA
1841	77	69		LD (HL),A
1842	23	70		INC HL
1843	10F9	71		DJNZ BCDADJ
		72		
1845	OD	73		DEC C
1846	20EB	74		JR NZ, LOOP
1848	C9	75		RET

0 ASSEMBLY ERRORS

II. Example Experiments:

1. Load the two subroutines for BCD-to-Binary and Binary-to-BCD conversion into MPF-I and then store them on audio tape for future application.
2. Replace the last instruction RET of the above subroutines by RST 38H so that control of the microcomputer MPF-I will be returned to monitor after program execution. Load an arbitrary 5-byte BCD number in RAM address 1A04H - 1A08H. Convert this BCD data into binary data by using the above program. Check if the result is correct.
3. By a method similar to that described in part I (Theoretical Background), write a program to convert the 4-digit BCD data into binary data : The processing must be held within CPU registers and the result will be stored in the DE register pair.

Assigned Decimal Number	Converted Binary Number	Re-converted Decimal Number
1		
2		
3		
4		
5		

4. Using the binary multiplication routine and the routines for conversion between binary and BCD data, write a program for decimal multiplication. The decimal multiplier and multiplicand must be stored in the HL and DE register pairs, respectively. The result must be stored in RAM addresses 1A04H - 1A08H. The data in HL and DE must be unchanged after program execution.

Experiment 10

Square-Root Program

Purposes:

1. To understand how the microcomputer calculates the square root of a binary number.
2. To practice microcomputer programming.

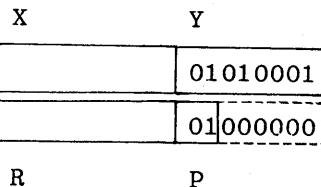
Time Required: 4 - 8 hours

I. Theoretical Background:

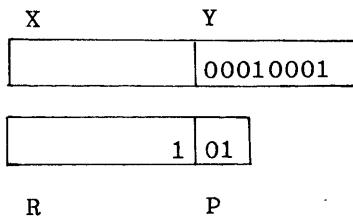
1. Calculating square roots of binary numbers by hand:

There are several methods for calculating the square root of a binary number. The following method for hand-calculation can be easily converted into a microcomputer program. This method is illustrated by calculating the square root of 01010001 (or 81):

- (1) Each of the following blocks represents the position for storing data. The original binary number is stored in Y block, the number 01 is permanently stored in P block. X and R blocks are prestored with 0.



- (2) Subtract the number formed by the R & P blocks from the number formed by the X and Y blocks. If the result is non-negative, then put 1 at the rightmost position in the R block and shift the original data in the R block left one bit. If the result is negative, then restore the original data in the X & Y blocks and shift the data in R left one bit. In this example, the result of subtraction is positive. Thus, the following result is obtained.



(3) Shift the data in the X & Y blocks left two bits.

X	Y
	00 01000100
	1 01

R P

(4) Since the number in the X and Y blocks after the shift process is still less than that in the R and P blocks, thus the data in the R block must be shifted left one bit and a "0" is put in the rightmost position. The data in the X and Y blocks remains unchanged.

(5) Shift the data in the X and Y blocks left two bits.

X	Y
0001	00010000
10	01

R P

(6) The new data in the X and Y blocks is still less than the R and P block. Thus, shift the data in the R block left one bit again. An "0" is put in the rightmost position of the R block. The data in the X and Y blocks is also shifted left two bits.

X	Y
000100	01
100	01

R P

-
- (7) The number in the X and Y blocks is not less than that in the R and P blocks. Subtract the number in the R and P blocks from the number in the X and Y blocks. Shift the data in R left one bit and put a "1" in the left-most bit-position.

X	Y
000000	00
1001	01

R P

- (8) Shift data in the X and Y blocks left two bits. Since the the orginal data in the Y blocks has been shifted out completely, the final result is given in the R block.

X	Y
00000000	
1001	01

R P

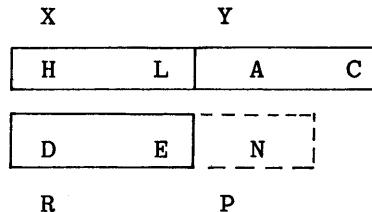
- (9) If the original data in the Y block is not the square root of some integral binary number, then the above method may be continued to find the fractional part of the square root.

2. Square root routine

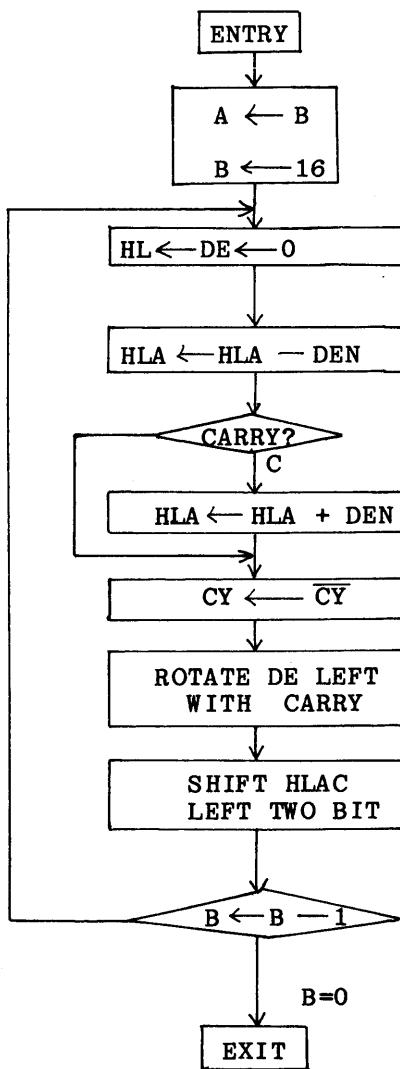
The square root routine can be designed by the method described above. A subroutine for calculating the square root of a 16-bit piece of data is illustrated below.

Example: Find the square root of a 16-bit piece of data stored in the BC register pair. The calculation must be continued till the fractional part of the solution contains 8 bits. The integral part of the solution will be stored in register D, while the fractional part will be stored in register E.

Solution: The CPU registers are assigned as follows:



The original data is stored in registers A and C (Y block). The HL register pair is used as the working area of subtraction operation. The answer will be stored in the DE register pair (R block). The data in the P block is a fixed number, its left-most two bits are 01, i.e. the data in the P block may be written as 01000000B (40H). The program and its flowchart are given below.



```

1 ; *** MPF-I EXAMPLE PROGRAM 009 ***
2 ; 16 BIT SQUARE ROOT ROUTINE
3 ; ENTRY: BINARY DATA IN 'BC'
4 ; EXIT : RESULT IN 'D'(INTEGER)
5 ; 'E' (FRACTION)
6 ;REG. CHANG.AF,BC,DE,HL
0000 78    7 SQRT16 LD A,B      ;A&C = ENTRY DATA
0001 0610   8 LD B,16       ;LOOP COUNTER
0003 210000  9 LD HL,0      ;HL:WORKING AREA
0006 54    10 LD D,H
0007 5C    11 LD E,H      ;DE=0,RESULT PRESET TO 0
0008 D640   12 SQ0 SUB 40H   ;A=A-40H,40H IS A FIXED DATA
000A ED52   13 SBC HL,DE   ;HL=HL-DE
000C 3004   14 JR NC,SQ1   ;IS HL > DE ?
000E C640   15 ADD A,40H
0010 ED5A   16 ADC HL,DE   ;IF NOT, RESTORE A&HL
0012 3F    17 SQ1 CCF      ;PARTIAL RESULT IN CARRY FLAG
0013 CB13   18 RL E        ;STORE PARTIAL RESULT
0015 CB12   19 RL D        ; & SHIFT 'DE' (RESULT) LEFT
                           20 ;'HL.A C' 4 BYTE SHIFT LEFT TWICE
0017 CB21   21 SLA C
0019 17    22 RLA
001A ED6A   23 ADC HL,HL
001C CB21   24 SLA C
001E 17    25 RLA
001F ED6A   26 ADC HL,HL
                           27
0021 10E5   28 DJNZ SQ0   ;DONE LOOP
0023 C9    29 RET

```

0 ASSEMBLY ERRORS

II. Example Experiments:

1. Load the above program onto MPF-I and then store it in audio tape for future applications.
2. Replace the last instruction (RET) by RST 38H. Prestore a 16-bit data in the BC register pair and then execute the square root program. Write down the result obtained.

Data Prestored in BC	Result of Program Execution	Check
0051H		
0000H		
FFFFH		
4000H		

-
3. Revise the above program such that it can be used for calculating the square root of a 32-bit piece of data. Store the original data in the BC and IX registers. The answer will be stored in the De register pair. Only the integral part of the square root is required.
 4. Using the square root routine and binary multiplication routine, write a program for finding the absolute value of the vector formed by two mutual perpendicular vectors. The length of each vector component can be represented by an 8-bit binary number. These two numbers are stored in the H and L registers, respectively. The result of the program execution will be stored in register D.

$$(D) = \sqrt{(H)^2 + (L)^2} .$$

Experiment 11

Introduction to MPF-1 Display

Purposes:

1. To understand how to use subroutines of the monitor program.
2. To understand how a character is displayed by a seven segment display.
3. To understand the application of conversion tables of characters.
4. To understand the structure and characteristics of a matrix-form keyboard.

Time Required: 8 hours

I. Theoretical Background:

1. Structure of seven-segment display

The seven-segment display is one of the least expensive displays for alphanumeric characters. The display is very suitable for applications in microcomputer systems. Illumination of each individual segment can be accomplished by using LEDs, fluorescent devices or small incandescent lamps. The hardware connection is shown in Fig. 11-1. Each digit consists of seven independently controlled segments which are designated as a, b, c, d, e, f, and g. All the cathodes (or anodes) of the same segment in all digits are connected together by a common wire. The control lines for the seven segments are designated as Sa, Sb, ..., Sg, respectively. A common line (e.g. D0, D1, D2, ...) connected to each segment of a digit is used for digit selection. A segment is illuminated only when both the control signal and the digit-selection signal are applied simultaneously. The structure of this kind of display is simple but it requires a fast scanning circuit to display each digit.

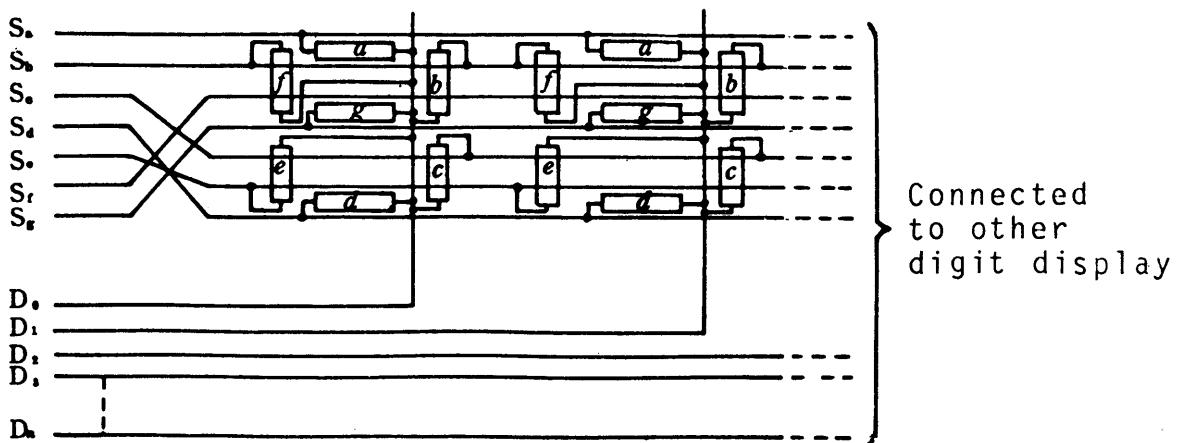


Fig. 11-1 7 Segment Display Connecting Circuit

2. Scanning method of the seven-segment display

The principle of scanning the seven-segment display is as follows: output a digit-selection signal and activate the segment-control line of the corresponding word format. For instance, if the digit-selection line chosen is D_0 and only the segment-control line S_a , S_b , and S_c are activated, then a digit "7" will be displayed at the position indicated by the D_0 line. The scanning method is : Apply a signal voltage to the digit-selection lines D_0 , D_1 , ..., D_n in sequence. When a digit-selection line is activated, voltage signals are applied to the segment-control lines S_a , S_b , ..., S_g of the corresponding word format. After digits have been scanned once, the scanning is repeated from the beginning. Each digit must be scanned at least 40 times per second. Due to persistence of vision of human eyes, all digits in the display appear to be lit simultaneously. The scanning speed can not be too fast, since the residual light of the neighboring digit may cause confusion.

3. Scanning period and keybounce:

The keypad is usually depressed by hand. In general, the microcomputer's reaction is much faster than a human's response. To key in data or a command from the keyboard, the microcomputer must scan the keyboard repeatedly until a key is found depressed. A key bounces for a short time when being depressed or released. Fig. 11-2 is a time response diagram of typical key-depressing or key-releasing operation. Thus, a key-depression might be identified as two or more key-depressions if the key-board scanning rate is too fast. To avoid this problem the period of scanning must be longer than the bouncing time (usually bouncing time is no longer than 10m sec). The period of scanning is between 10m sec and 50m sec. In the figure below an upward arrow indicates when the key is examined. At T_{n+2} , microcomputer program found that the key was depressed and identified the keycode. At T_{n+3} , the key was also found depressed. Since the key was found depressed in a previous scan, the microcomputer program would determine that this was not a new key-depression (i.e. the key had not been released during this time interval). Only if the key is found depressed at T_{n+4} or T_{n+5} is a key-depression found at T_{n+6} really a new key-depression. A program for getting data from a keyboard designed by this rule will be error-free, no matter how long the duration of key-depression is and whatever is found at T_{n+1} and T_{n+4} (0 or 1).

The hardware connection is shown in Fig 11-3

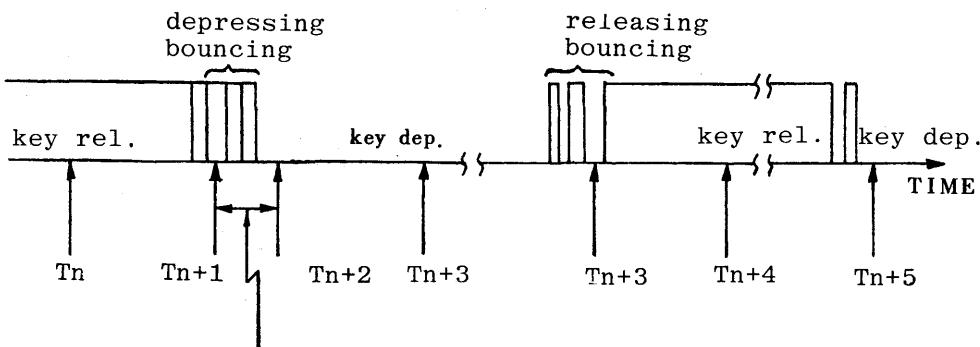


Fig 11-2 The Time Response of Keyboard Scanning

4-1 Construction of MPF-I display:

The display of the MPF-I is composed of 6 LEDs. 14 output lines are used to control the display. The addresses of the 14 output ports are given in Fig 11-3. The 8 output lines with addresses PB0 - PB7 are used to control the seven segments and a decimal point in the display. The 6 output lines with addresses PC0 - PC5 are connected to the 74LS492 to select the digit to be displayed. All the segments are controlled by logic "1" signals. If a segment is at logic "1", then it is lit. If a segment is at logic "0", then it is extinguished. Before MPF-I executes the user's program, the output ports PB0 - PB7, PC0 - PC5 are set at logic "0". If the output port PC0 is set at logic "1", then digit 1 is selected. If the output ports PB0 - PB7 are at logic "1", then only digit 1 of the display is illuminated.

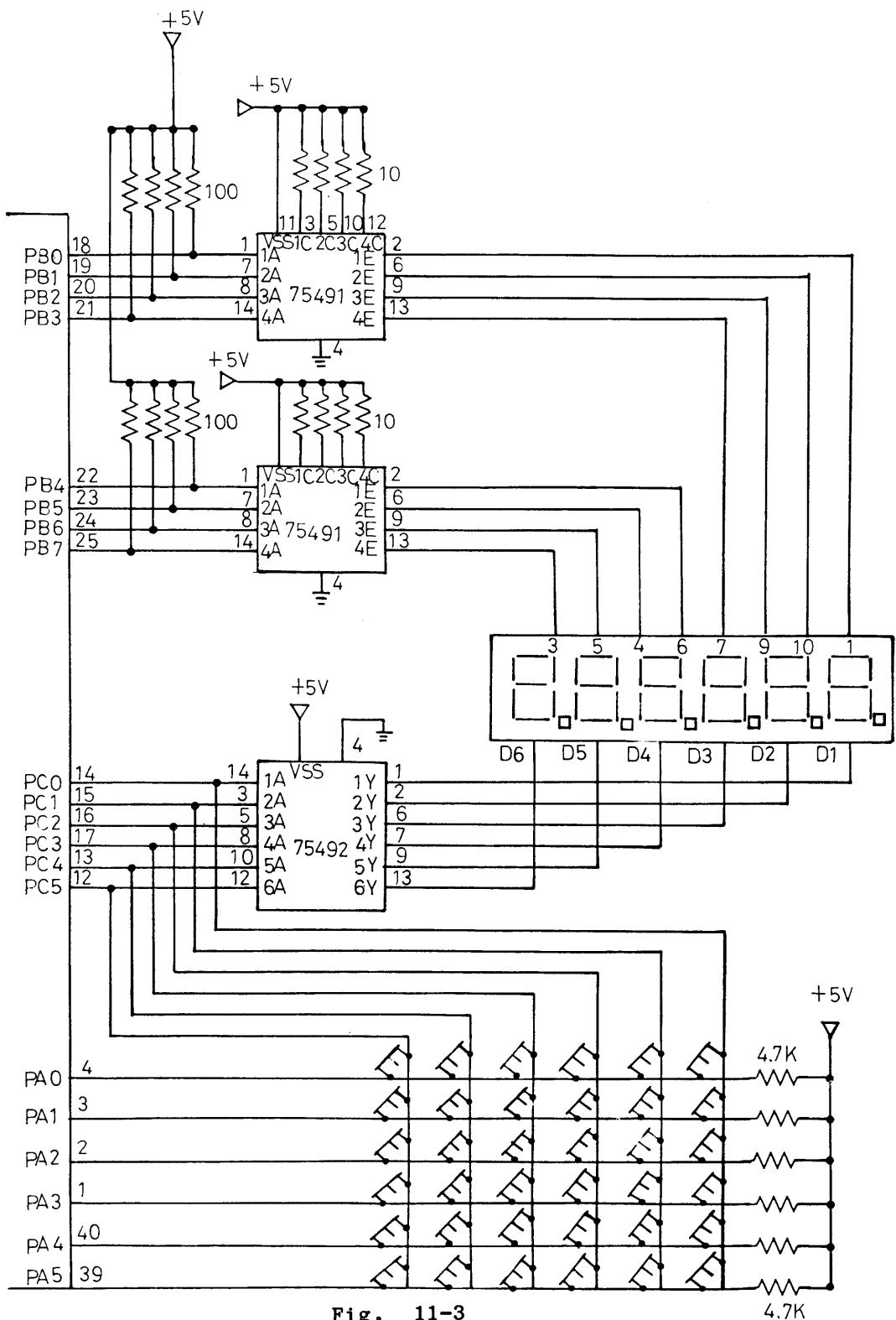


Fig. 11-3

4-2 The structure of matrix-from keyboard:

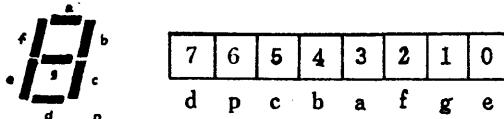
A matrix-form keyboard is an important yet inexpensive input device for the microcomputer. The structure of the keyboard is a number of wires in a matrix form. At each node of the matrix a keypad is positioned. The 6 vertical lines and 6 horizontal lines (6x6) in Fig. 11-3 provide 36 contact points for keyboards. When a key is depressed, it makes a contact between one row and one column of the matrix. The 6 horizontal lines are connected to the microcomputer input port. The input port addresses are PA0 - PA5. When no key is depressed, the 6 input addresses are connected to +5V power supply via 6 resistors. Thus, logic "1" will be read in by the microcomputer input ports. The 6 column lines are connected to the output ports PC0 - PC5 which are also connected to the display circuit.

4-3 Keyboard scanning program

The microcomputer may select the rightmost column line from the output line PC0. The voltage of the 6 row lines are then examined in sequence. At the beginning of keyboard scanning, a counter is set to zero, port "C" will output "11000001", the value of PC5 - PC6 are "000001". PC6 and PC7 must always be high during keyboard scanning because the output line of PC6 is connected to BREAK and PC7 is connected to the speaker. The voltage of the 6 row lines are then examined in sequence. If a key is depressed (a zero voltage at the corresponding row), it can be identified from the port address. If no key in the first column is depressed then the microcomputer port C will output "11000010" to select the second column for examination. In general the keyboard scanning proceeds in sequence, from upper side to lower side, from right side to left side of the key matrix, to examine if any key is depressed. Each key in the keyboard is encoded. Once a key being examined is found to be not pressed, the counter's value is increased until a key is found depressed. Then the counter's value is the position code of that key.

4-4 Conversion table

A subroutine SCAN in MPF-I monitor program with starting address 05F can be used to control simultaneously 6 byte of data stored in RAM. The addresses of the display buffer are 1FB6 - 1FBB. Fig. 11-4 is a conversion table.



DISPLAY FORMAT:

CODE	BD	30	9B	BA	36	AE	AF	38	BF	BE	3F	A7	8D	B3
DATA	0	1	2	3	4	5	6	7	8	9	A	B	C	D
DISP	0	1	2	3	4	5	6	7	8	9	R	b	C	d
CODE	BF	0F	AD	37	89	41	97	85	2B	23	A3	1F	3E	03
DATA	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
DISP	E	F	G	H	I	J	U	L	ñ	n	o	P	q	r
CODE	A6	87	B5	B7	A9	07	B6	8A	83	A2	32	02	C0	00
DATA	S	T	U	V	W	X	Y	Z	()	+	-	,	.
DISP	S	E	U	B	U	F	Y	Z	c	o	+	-	,	.

Fig. 11-4 Conversion Table

1. Position-Code (CALL SCANI) :

1E SBR	18 CBR	12 '0'	0C '1'	06 '2'	00 '3'
1F '-'	19 PC	13 '4'	0D '5'	07 '6'	01 '7'
20 DATA	1A REG	14 '8'	0E '9'	08 'A'	02 'B'
21 '+'	1B ADDR	15 'C'	0F 'D'	09 'E'	03 'F'
22 INS	1C DEL	16 CO	10 STEP	0A	04
23 MOVE	1D RELA	17 TPWR	11 TPRD	0B	05

2. Internal-Code (CALL SCAN) :

15 SBR	1A CBR	00 '0'	01 '1'	02 '2'	03 '3'
11 '-'	18 PC	04 '4'	05 '5'	06 '6'	07 '7'
14 DATA	1B REG	08 '8'	09 '9'	0A 'A'	0B 'B'
10 '+'	19 ADDR	0C 'C'	0D 'D'	0E 'E'	0F 'F'
16 INS	17 DEL	12 CO	13 STEP	22	20
1C MOVE	1D RELA	1E TPWR	1F TPRD	23	21

Fig. 11-5

Fig. 11-5 are table of Position-code and internal-code. If a scanned key is depressed, then we can pick up a Position-code (by CALL SCAN1). Adding this data to the starting address of the KEYTAB (The address of KEYTAB in monitor program is 077B) then key position code is converted to key internal code. For example when "F KEY" is depressed we pick up a position code 03, then by the conversion gives the internal code with OF.

4-5 Keyboard and display program

The microcomputer usually executes some part of the user's program before it scans the keyboard to fetch new data or command. Since the keyboard scanning need not be very fast, the microcomputer has can assign time-slot to scan the display. In MPF-I, a combined program is written for both keyboard and display scanning. The interval between two consecutive scans is 10 msec, ie. 100 times per second.

5. Useful Subroutines of the Monitor Program

5.1 Summary

ADDRESS	MNEMONIC	FUNCTION
0624	SCAN1	Scan Keyboard and the display one cycle.
05FE	SCAN	Scan keyboard and the display until a new key-in.
0689	HEX7	Convert a hexadecimal digit into the 7-segment dispaly format.
0678	HEX7SG	Convert two hexadecimal digits into 7-segment display format.
0665	ADDRDP	Convert two bytes data stoed in DE to 7-segment display format. The output is stored in the address field of display buffer 1FB8 - 1FBB.
0671	DATADP	Convert the data stoed in A to 7-segment display format. The output is stored in the data field of display buffer 1FB6 - 1FB7.

5.2 SCAN1

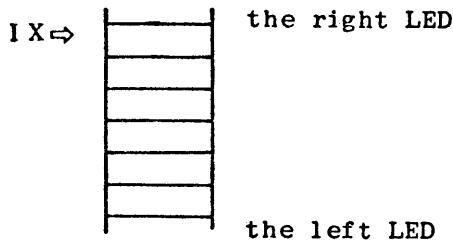
[Address]: 0624

Function]: Scan the keyboard and the display 1 cycle from right to left.
Execution time is about 10ms (9.97ms exactly).

[Input]: IX points to the display buffer which contains six bytes.

[Output]: (1) If no key-in, then carry flag = 1.
(2) If key-in, carry flag = 0 and the position-code of the key is stored in register A.

[Supplement]: (1) 6 bytes are required for 6 LED's.
(2) IX points to the rightmost LED, IX+5 points to the left most LED.



(3) See Fig. 11-4 for the relation between each bit and the seven segments.

[Register]: Destroy the contents of AF, B, HL, AF', BC', DE'.

5.3 SCAN

[Address]: 05FE

[Function]: Similar to SCAN1 except:

- (1) SCAN1 scans one cycle, but SCAN will scan till a new key-in.
- (2) SCAN1 returns the position while SCAN returns the internal code of the key pressed.

[Input]: IX points to the display buffer.

[Output]: Register A contains the internal code of the key pressed.

[Register]: Destroy AF, B, HL, AF', BC', DE'.

5.4 HEX7

[Address]: 0689

[Function]: Decode a hexadecimal number to its 7-segment display format.

[Input]: The least significant 4 bits of A register contain the hexadecimal number. (0-F).

[Output]: The result is also stored in A register.

[Register]: Destroy AF only.

5.5 HEX7SG

[Address]: 0678

[Function]: Convert two hexadicimal number into 7-segment display format.

[Input]: The first number is stored in the right 4 bits of A. The second number is stored in the left 4 bits of A.

[Output]: The first display pattern is stored in (HL), the second is in (HL+1), HL is increased by 2.

[Register]: Destroy AF, HL.

II. Program Examples

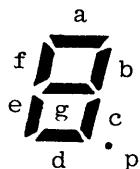
EXAMPLE 1: Display HELPUS , HALT when Step is pressed.

```

1      DISPLAY 'HEL US' UNTIL KEY-STEP PUSHED:
1800    2      ORG      1800H
1800 DD212018 3      LD       IX,HELP
1804 CDFE05   4      DISP     CALL     SCAN
1807 FE13     5      CP       13H      ;KEY-STEP
1809 20F9     6      JR       NZ,DISP
180B 76       7      HALT
1820
1820 AE       9      ORG      1820H
1821 B5       10     HELP    DEFB     OAEH      ; 'S'
1822 1F       11     DEFB     OB5H      ; 'U'
1823 85       12     DEFB     01FH      ; 'P'
1824 8F       13     DEFB     085H      ; 'L'
1825 37       14     DEFB     08FH      ; 'E'
1825
1825          15     DEFB     037H      ; 'H'
1825
1825          16     ;
1825          17     SCAN    EQU      05FEH
1825          18     END

```

Details of the display buffer are given below:



Position	Display Format	Segment of Illumination	d p c b a f g e	Data	Addr
Right ↑ ↓ Left	5	a,c,d,f,g,	1 0 1 0 1 1 1 0	AE	1820
	U	b,c,d,e,f,	1 0 1 1 0 1 0 1	B5	1821
	P	a,b,e,f,g,	0 0 0 1 1 1 1 1	1F	1822
	L	d,e,f,	1 0 0 0 0 1 0 1	85	1823
	E	a,d,e,f,g,	1 0 0 0 1 1 1 1	8F	1824
	H	b,c,e,f,g,	0 0 1 1 0 1 1 1	37	1825

EXAMPLE 2: Flash 'HELP US'

Use routine SCAN1 to display 'HELPUS' and blank alternately.
Each pattern is display 500ms by looping SCAN1 50 times.

```
1      ;FLASH  'HELP US'
1800   2          ORG    1800H
1800 212618  3          LD     HL, BLANK
1803 E5    4          PUSH   HL
1804 DD212018 5          LD     IX, HELP
1808 DDE3   6    LOOP   EX     (SP), IX
180A 0632   7          LD     B, 50
180C CD2406 8    HELPSEG CAL    SCAN1
180F 10FB   9          DJNZ   HELPSEG
1811 18F5   10         JR    LOOP
1820           11         ;
1820 AE    12         ORG    1820H
1821 B5    13    HELP   DEFB   OAEH   ; 'S'
1822 1F    14         DEFB   OB5H   ; 'U'
1823 85    15         DEFB   01FH   ; 'P'
1824 8F    16         DEFB   085H   ; 'L'
1825 37    17         DEFB   08FH   ; 'E'
1826 00    18         DEFB   037H   ; 'H'
1827 00    19    BLANK  DEFB   0
1828 00    20         DEFB   0
1829 00    21         DEFB   0
182A 00    22         DEFB   0
182B 00    23         DEFB   0
182C 00    24         DEFB   0
182D 00    25         ;
182E 00    26         SCAN1  EQU    0624H
182F 00    27         END
```

The content of 180B determines the flash frequency. You may change it to any value.

EXAMPLE 3: Display the key code of the key pressed.

```
1 ;DISPLAY INTERNAL CODE
1800          2      ORG    1800H
1800 DD210019 3      LD     IX,OUTBF
1804 CDFE05   4      LOOP   CALL   SCAN
1807 210019   5      LD     HL,OUTBF
180A CD7806   6      CALL   HEX7SG
180D 18F5    7      JR    LOOP
1900          8      ;
1900 00       9      ORG    1900H
1900 00       10     OUTBF  DEFB   0
1901 00       11     DEFB   0
1902 00       12     DEFB   0
1903 00       13     DEFB   0
1904 00       14     DEFB   0
1905 00       15     DEFB   0
1900          16     ;
1900 00       17     SCAN   EQU    05FEH
1900 00       18     HEX7SG QU     0678H
1900          19     END
```

When a key is pressed, the internal code of it is displayed on the data filed. The user may compare it with Fig. 2-11-5.

If you want to display the position code of the keys, you may change the program as follow:

```
1 ;DISPLAY POSITION CODE
1800          2      ORG    1800H
1800 DD210019 3      LD     IX,OUTBF
1800 CD2406   4      LOOP   CALL   SCAN1
1807 38FB    5      JR    C,LOOP
1809 210019   6      LD     HL,OUTBF
180C CD7806   7      CALL   HEX7SG
180F 18F3    8      JR    LOOP
1900          9
```

EXAMPLE 4: Convert 3 continuous bytes into 7-segment display format.
Store the results in 1903 - 1908 then display them.

	1	;DISPLAY 3 BYTES IN RAM TO 6 HEXA-DIGITS	
1800	2	ORG	1800H
1800	110019	LD	DE, BYTEO
1803	210319	LD	HL, OUTBF
1806	0603	LD	B, 3
1808	1A	LOOP	LD A,(DE)
1809	CD7806	CALL	HEX7SG
180C	13	INC	DE
180D	10F9	DJNZ	LOOP
	10	;CONVERSION COMPLETE, BREAK FOR CHECK	
180F	DD210319	LD	IX, OUTBF
1813	CDFE05	CALL	SCAN
1816	76	HALT	
	14	;	
1900	15	ORG	1900H
1900	10	BYTEO	DEFB 10H
1901	32		DEFB 32H
1902	54		DEFB 54H
1903	19	OUTBF	DEFS 6
	20	;	
	21	HEX7SG	EQU 0678H
	22	SCAN	EQU 05FEH
	23	END	

The three bytes binary data are stored in 1900 - 1902. The user can set break point at 180F to check if the conversion is correct before displaying the result.

III. Illustrations of Experiments

(1)

- (a) Load program 1 into MPF-I and store it on audio tape for future application.
- (b) Test this program and record the display response.
- (c) Change the content of 1808 to 1A, then display will HALT with STEP-KEY replaced by CBR-KEY, why?
- (d) Change the contents of 1820 - 1822 with 3F, BD, 85 respectively what will the display show?
- (e) Write a program to display "SYS-SP", HALT when PC-KEY is depressed.

(2)

- (a) Load program 2 into MPF-I and store it on audio tape for future application.
- (b) Test this program and record the display response.
- (c) Change the content of 180B to 01, what will the display show?
- (d) Change the content of 180B to 05 and to see what display will show?
- (e) Write a program to change the flash frequency. The word format "HELP US" is required to be lit at a rate of 2 secc per cycle.

(3)

- (a) Change the contents of 1900 - 1905 to FF, what will the display show?
- (b) What is the meaning of position code and internal code in monitor program?

(4)

- (a) Change the contents of 1900 - 1902 so that the display will show "333446".

Experiment 12

Fire-Loop Game

Purpose:

1. To understand how to use a subroutine contained in the monitor program.
2. To familiarize the reader with programming techniques.

Time Required: 4 hours

I. Theoretical Background:

1. Monitor Program:

After the microcomputer is powered on, it will execute programs from the designated address. Besides some initialization task (e.g. setting 8255 or selecting I/O mode), a special software program called monitor is used to monitor the presence of data or commands from peripheral devices (e.g. a keyboard, an external switch, a button, a sensor, etc.) If no signal is monitored, then the scanning process continues (using the looping method to search) until a signal input is detected. The input signal is then analyzed and the microcomputer jumps to the service routine to perform the job assigned by the input signal. After this service routine has been executed, the microcomputer returns to scan the peripheral devices.

Since MPF-I is a general-purpose microcomputer, it has a monitor. The main function of this monitor is to respond to key closures on the keyboard and displaying necessary data. Tracing the monitor program will improve your programming skill.

2. Fig. 12-1 is the flowchart of the Fire Loop.

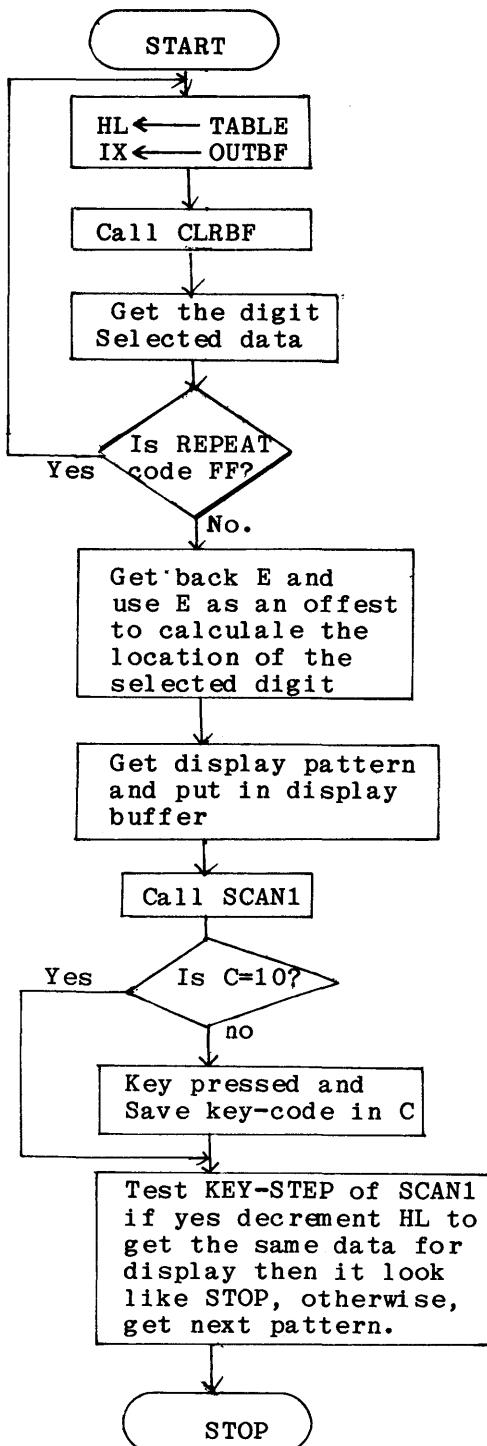


Fig. 12-1 The Flowchart of Fire Loop

LOC OBJ CODE M STMT SOURCE STATEMENT

```

1   ;
2   ; Segment Illuminates one by one until key-step is pushed
3   ; Any other key will resume looping again.
4   ;
1800      5      ORG    1800H
1800  214018  6      INI    LD     HL, TABLE
1803  DD210019 7      LD     IX, OUTBF
1807  CD3018   8      LOOP   CALL   CLRBF  ;Clear display buffer
180A  5E       9      LD     E, (HL) ;Get the DIGIT-select data
180B  1C       10     INC    E       ;Test REPEAT code: FF
180C  28F2     11     JR     Z,INI   ;If yes, go to INI
180E  1D       12     DEC    E       ;Otherwise, get back E
180F  1600     13     LD     D, 0    ;Use E as an offset to
1811  DD19     14     ADD    IX,DE   ;Calculate the location of
1813  23       15           ;the selected digit.
1814  7E       16     INC    HL
1815  DD7700   17     LD     A, (HL) ;Get display PATTERN
1818  DD210019 18     LD     (IX),A  ;Put in display buffer
181C  0603     19     LD     IX, OUTBF
181C          20     LD     B, SPEED
21   ;
22   ; The following 4 instruction display the pattern
23   ; for B times (can be adjusted in the above SPEED)
24   ;
181E  CD2406   25     LIGHT  CALL   SCAN1
1821  3801     26     JR     C, NSCAN
1823  4F       27     LD     C,A    ;Key pressed, save key-code in C
1824  10F8     30     NSCAN  DJNZ   LIGHT
1826  79       31     ;           ;Note that, reg C will not be
1827  FE10     32     LD     A,C    ;Changed until next key input
1829  2802     33     CP     10H    ;Test KEY-STEP of SCAN1
1829          34     JR     Z,STOP ;If yes, decrement HL to get
1829          35           ;the same data for display
1829          36           ;Then it locks like STOP.
182B  23       37     INC    HL    ;Otherwise, get next pattern
182C  23       38     INC    HL
182D  2B       39     STOP   DEC    HL
182E  18D7     40     STOP   JR     LOOP
182E          41     ;           ;
182E          42     ;           ;
1830  0606     43     CLRBF:
1832  DD360000 44     LD     B, 6
1832          45     CLR    LD     (IX), 0
1836  DD23     46     INC    IX
1838  10F8     47     DJNZ   CLR
183A  11FAFF   48     LD     DE, -6  ;Get original IX
183D  DD19     49     ADD    IX, DE
183F  C9       50     RET

```

```

51  ;
52  ; The 1st byte indicates which DIGIT is to be selected
53  ; The 2nd byte indicates what PATTERN to be displayed
54  ;
1840 05      55 TABLE   DEFB    5
1841 08      56        DEFB    SEG_A
1842 04      57        DEFB    4
1843 08      58        DEFB    SEG_A

```

LOC	OBJ	CODE	M	STMT	SOURCE	STATEMENT
1844	03	59		DEFB	3	
1845	08	60		DEFB	SEG_A	
1846	02	61		DEFB	2	
1847	08	62		DEFB	SEG_A	
1848	01	63		DEFB	1	
1849	08	64		DEFB	SEG_A	
184A	00	65		DEFB	0	
184B	08	66		DEFB	SEG_A	
184C	00	67		DEFB	0	
184D	10	68		DEFB	SEG_B	
184E	00	69		DEFB	0	
184F	20	70		DEFB	SEG_C	
1850	00	71		DEFB	0	
1851	80	72		DEFB	SEG_D	
1852	01	73		DEFB	1	
1853	80	74		DEFB	SEG_D	
1854	02	75		DEFB	2	
1855	80	76		DEFB	SEG_D	
1856	03	77		DEFB	3	
1857	80	78		DEFB	SEG_D	
1858	04	79		DEFB	4	
1859	80	80		DEFB	SEG_D	
185A	05	81		DEFB	5	
185B	80	82		DEFB	SEG_D	
185C	05	83		DEFB	5	
185D	01	84		DEFB	SEG_E	
185E	05	85		DEFB	5	
185F	04	86		DEFB	SEG_F	
1860	FF	87		DEFB	OFFH	
		88	;			
1900		89		ORG	1900H	
1900		90	OUTBF	DEFS	6	
		91	;			
		92	SPEED	EQU	3	
		93	SEG_A	EQU	08H	
		94	SEG_B	EQU	10H	
		95	SEG_C	EQU	20H	

```
96 SEG_D EQU 80H
97 SEG_E EQU 01H
98 SEG_F EQU 04H
99 SCAN1 EQU 0624H
100 END
```

3. Further Experiments

- (a) Load the above program into MPF-I and then store it on audio tape for future applications.
Test this program and record the display response.
- (b) Write a program to make the Fire-Loop illuminate counterclockwise.
- (c) Change the contents of 1828. Then KEY-STEP will not respond as before. Why?
- (d) Change the contents of 181D and the display will change. Why?
- (e) Write a program that will cause the segments to move in a pattern of your choice.
- (f) Write a delay program to display "HELP US" for 20 secs, then the display will play the "Fire Loop Game".

Experiment 13

Stop-Watch

Purpose:

1. To illustrate how to use monitor subroutines.
2. To practise programming skills.

Time Required: 2 hours

I. Theoretical Background:

1. The object specification of this experiment is to design a 1/100 second-based stop watch. Actually, this is only roughly accurate. The accuracy varies with the system clock and the number of instructions used in the keyboard/display scan subroutine.
2. The demonstration program calls two monitor subroutines SCAN1 and HEX7SG which are located at 0624H and 0678H respectively.

The flowchart is given below.

3. The counting procedure is halted by depressing a key. This is done by checking the result of SCAN1 routine.
4. Flow Chart of STOP WATCH

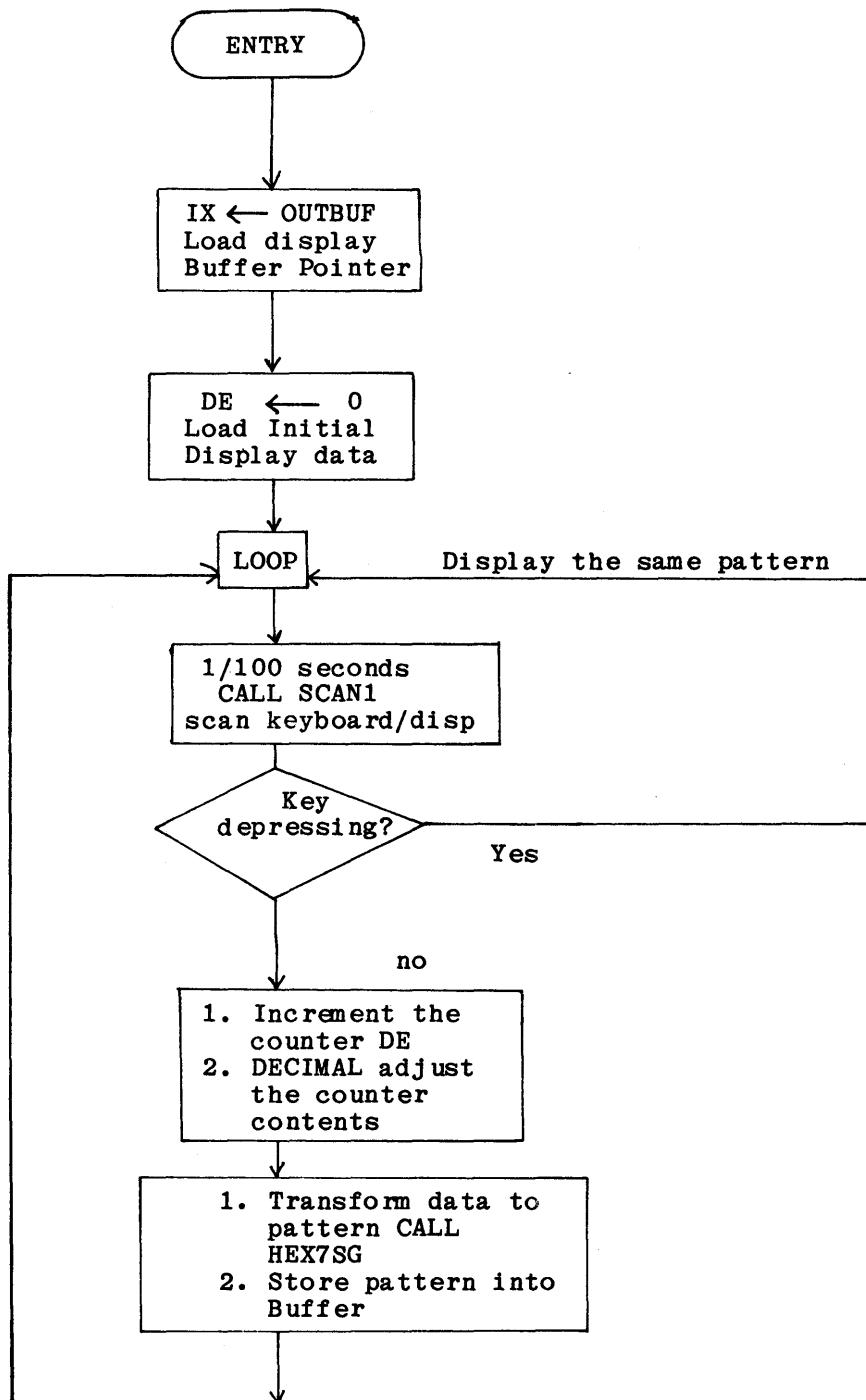


Fig 13-1 Flowchart of stop watch

5. Stop Watch program

LOC	OBJ	CODE M	STMT	SOURCE STATEMENT
1800		1	ORG	1800H
1800	DD210019	2	LD	IX,OUTBF ;initial display pointer
1804	110000	3	LD	DE,0 ;initial SEC & 1/100 SEC in DE
1807	CD2406	4LOOP	CALL	SCAN1 ;display for 0.01 second
180A	30FB	5	JR	NC,LOOP ;if any key pressed, then NC
		6		;so looping the same pattern
180C	7B	7	LD	A,E ;otherwise increment 1/100
				SEC by 1
180D	C601	8	ADD	A,1
180F	27	9	DAA	
1810	5F	10	LD	E,A
1811	7A	11	LD	A,D ;if carry, increment SEC again
1812	CE00	12	ADC	A,0
1814	27	13	DAA	
1815	57	14	LD	D,A
1816	7B	15	LD	A,E ;convert 1/100 SEC to display
				format
1817	210019	16	LD	HL,OUTBF ;and put them into display
				buffer
181A	CD7806	17	CALL	HEX7SG
181D	3602	18	LD	(HL),2 ;put into display of '-'
181F	23	19	INC	HL
1820	7A	20	LD	A,D ;convert SEC to display format
1821	CD7806	21	CALL	HEX7SG ;and put them into display
				buffer
1824	3600	22	LD	(HL),0 ;put BLANK into MSD
1826	18DF	23	JR	LOOP
		24		
1900		25	ORG	1900H
1900		26	DEFS	6
	OUTBF		EQU	0678H
	27 HEX7SG		EQU	0624H
	28 SCAN1		END	
	29			

II. Illustration of the Experiments

- (1) Load the program and GO!
- (2) Depress any key other than RS and MONI, record the results.
- (3) Note that the program will loop continuously. The user can interrupt the execution only by RS or MONI.
- (4) Users are encouraged to modify the program:
 - a. Build a 1/10 second based stop watch.
 - b. Display all zeros at the beginning, start the stop watch by depressing an arbitrary key or the user defined key.
 - c. Build a stop key.
- (5) Check the timing on the display with your watch for one minute. Perhaps, there is an error. Try to find the reasons for the error and note them.

Experiment 14

Clock 1 (How to design a clock)

Purposes:

1. To practise calculating the clock cycle of a program.
2. To construct a software driven digital clock.

Time Required: 4 hours.

I. Theoretical Background:

1. This is an example of how to use the software delay to build a digital clock.
2. All the timing is based on the system clock, which is 1.79 MHZ. So that 1 cycle is about 0.56 micro-seconds.
3. The total number of cycles in ONE LOOP has been carefully calculated.
4. The cycle count calculation is given as follow:

SCAN1 : 17812

LOOP1 : $(17 + 17812 + 13) * 100 - 5 = 1784195$

TMUPDT : 258

BFUPDT : 914

LOOP2 : $(4 + 13) * 256 - 5 = 4347$

The total number of counts is 1789755

and

$0.56 \text{ usec} \times 1789755 \div 1 \text{ sec}$

5. Flowchart of clock

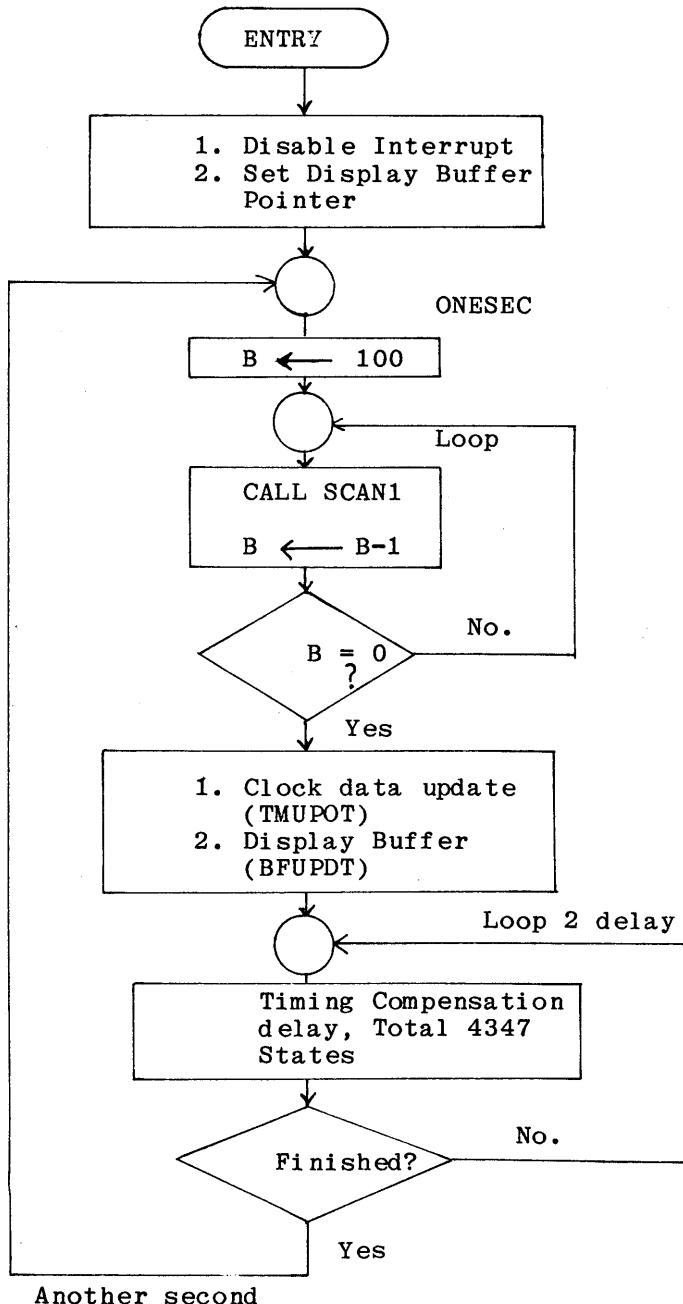
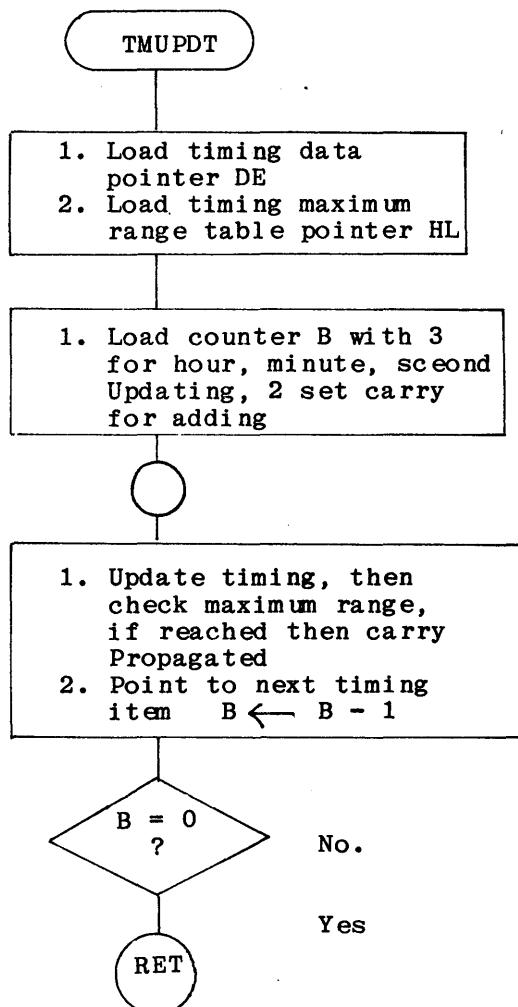


Fig 14-1 Flowchart of clock

Time Update Flowchart



Display buffer Update Flowchart

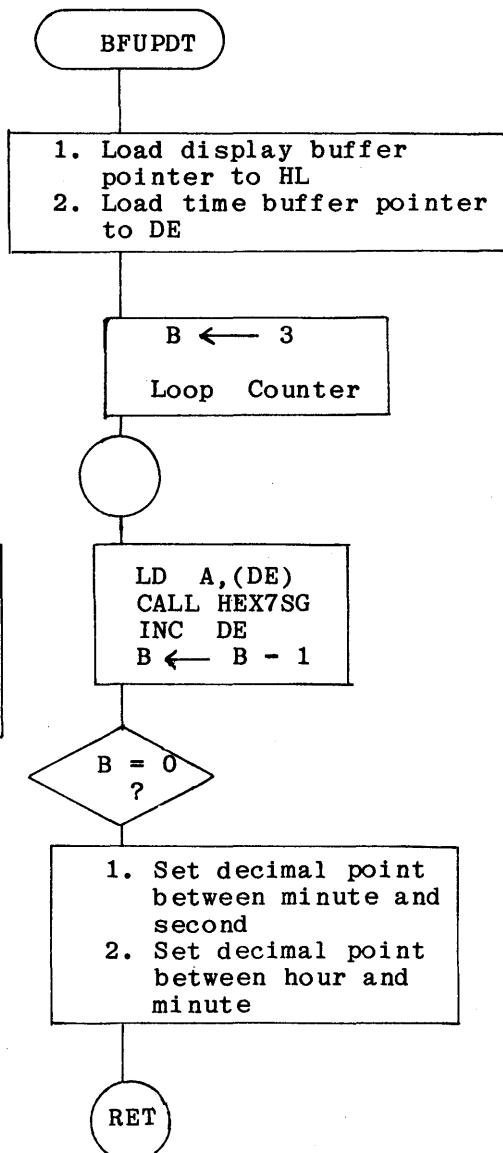


Fig 14-2 Flowchart of Update

6. Program of software designed clock

LOC OBJ CODE M STMT SOURCE STATEMENT

```

1800      1      ORG    1800H
1800  F3      2      DI     ;Disable interrupt, which affects
                           timing
1801 DD21031A  3      LD     IX,OUTBF
                           4 ;
                           5 ;ONESEC loop takes 1 second to execute, it
                           consists of 3
                           6 ;subroutines & 1 additional delay process
                           7 ;
                           8 ;ONESEC:
1805 0664      9      LD     B,100      ;7
1807 CD2406    10     LOOP1  CALL   SCAN1
180A 10FB      11     DJNZ   LOOP1   ;(17+17812+13)*100-5=1784195
180C CD1718    12     CALL   TMUPDT  ;17+258=275
180F CD2F18    13     CALL   BFUPDT  ;17+914=931
1812 00'       14     LOOP2  NOP
1813 10FD      15     DJNZ   LOOP2   ;(4+13)*256-5=4347
1815 18EE      16     JR     ONESEC  ;12
                           17 ;
                           18 ;Time-buffer is updated here.
                           19 ;Note that this routine takes the same time in any
                           20 ;condition, 275 cycles.
                           21 ;
                           22 TMUPDT:
1817 214718    23     LD     HL,MAXTAB
181A 11001A    24     LD     DE,SEC
181D 0603      25     LD     B, 3
181F 37        26     SCF
                           ;Set carry flag: force add 1
1820 1A        27     TMINC LD     A,(DE)
1821 CE00      28     ADC   A,0
1823 27        29     DAA
1824 12        30     LD     (DE),A
1825 96        31     SUB   (HL)   ;Compare wth data in MAX TAB
                           ;if the result is less than
                           ;that.
                           32
                           33   ;the following loop will be
                           ;null.
                           34   ;delay, because of no carry
                           ;propagation
                           35
                           36   JR     C,COMPL
1828 12        37   LD     (DE),A
1829 3F        38 COMPL CCF
                           ;complement carry flag
182A 23        39   INC   HL
182B 13        40   INC   DE
182C 10F2      41   DJNZ   TMINC
182E C9        42   RET

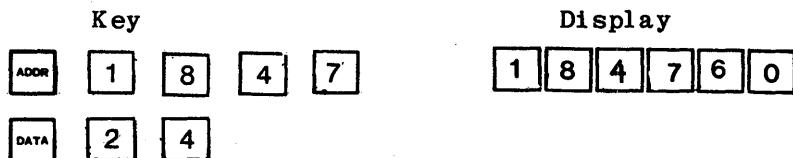
```

LOC OBJ CODE M STMT SOURCE STATEMENT

```
44 ;Display_buffer is updated here.  
45 ;It takes 914 cycles.  
46 ;  
47 BFUPDT:  
182F 21031A 48 LD HL,OUTBF  
1832 11001A 49 LD DE,SEC  
1835 0603 50 LD B,3  
1837 1A 51 PUTBF LD A,(DE)  
1838 CD6D06 52 CALL HEX7SG  
183B 13 53 INC DE  
183C 10F9 54 DJNZ PUTBF  
183E 2B 55 DEC HL  
183F 2B 56 DEC HL  
1840 CBF6 57 SET 6,(HL) ;Set decimal point of HOUR  
1842 2B 58 DEC HL  
1843 2B 59 DEC HL  
1844 CBF6 60 DEC HL ;Set decimal point of MTNUITE  
1846 C9 61 RET ;B=0 when return  
62 ;  
63 MAXTAB:  
1847 60 64 DEFB 60H  
1848 60 65 DEFB 60H  
1849 12 66 DEFB 12H  
67 ;  
1A00 69 ORG 1A00H  
70 TMBF:  
1A00 71 SEC DEFS 1  
1A01 72 MIN DEFS 1  
1A02 73 HOUR DEFS 1  
74 ;  
1A03 75 OUTBF DEFS 6  
76 ;  
77 SCAN1 EQU 624H  
78 HEX7SG EQU 66DH  
79 END
```

II. Illustrations of the Experiments

1. Load the program
2. Load the time data into TMBF (1A00 - 1A02)
3. Observe the results.
4. What will happen if proceed as follows?



5. This program can be modified to be a second counter with arbitrary base. Design a 20 seconds, 20 minutes and 1 hour counter.
6. Trace the program, and draw your own flowchart. Are there any differences between your flow chart and the demonstrated flowchart above?

Explain why differences occurred.

Experiment 15

Clock 2 (with CTC interrupt mode 2)

Experiment Purpose:

1. To practise using Interrupt Mode 2 through the CTC.
2. To practise programming.

Time Required: 8 hours

I. Theoretical Background:

I-1. Introduction to the Z80 CPU interrupt:

1. Z80 CPU Interrupt Request Lines :

The Z80 CPU can suspend the current program execution by external interrupt request. The CPU then starts executing the interrupt service routine. Once the service routine is completed, the CPU returns to the main program from which it was interrupted.

The Z80 CPU has two interrupt inputs : a non-maskable interrupt and a software maskable interrupt. The non-maskable interrupt (NMI) line can not be disabled by the programmer and will be activated whenever an external device inputs an interrupt request to it. The maskable interrupt (INT) line can be disabled by resetting an internal Interrupt Enable Flip Flop (IFF). The enable flip flop can be set or disabled by the programmer using Enable Interrupt (EI) and Disable Interrupt (DI) instructions.

2. NMI Request :

The NMI signal is sampled by the CPU at the rising edge of the last clock at the end of any instruction. The NMI request line will be at logic "0" if there is a non-maskable interrupt request. The CPU automatically saves the program counter (PC) in the stack area and jumps to location 0066H (a fixed memory address assigned by the Z80 CPU). THE CPU will not respond to any further NMI request. The CPU then executes the service routine until a RETN instruction appears and then it fetches the PC of main program from the stack to continue the execution of main program. At this time, the CPU can accept another NMI request.

In MPF-I, memory addresses 0000H through 07FFH are for the monitor program. Once a non-maskable interrupt is accepted, the CPU automatically jumps to location 0066H . The non-maskable interrupt request line has a higher priority than any other interrupt. It is very useful in event of a power failure, which obviously takes precedence over all other activities. For instance, if the voltage level of the power supply battery of the micro computer

drops to a certain level, then a voltage comparator circuit will activate a non-maskable interrupt request signal. The CPU then suspends its current program execution and starts battery-recharging. The recharging process is controlled by a software program. The starting address of this control sequence must be at 0066H.

3. INT Interrupt Request :

The interrupt request at the INT line can be masked. For instance, after the battery-recharging process has been started, the CPU can return to its main program execution. When the battery is charged to certain level, another voltage comparator circuit will generate an INT interrupt request signal. If the CPU is not executing a very important program, then it may acknowledge the interrupt request and jump to a service routine designed to stop the recharging process. Usually, stopping the recharging process is not an emergency task, thus the CPU may continue to execute an important program and ignore this kind of interrupt request. For instance, when the CPU is reading data from a tape, and interrupt will cause the data in the tape to be missed. Thus, if a DI instruction is included at the beginning of the "Read Tape" routine, then the INT interrupt request will be masked. An EI (Enable Interrupt) is usually included at the end of the "Read Tape" routine in order to enable the INT interrupt request line.

The Z80 CPU can be programmed to respond to the maskable interrupt in three possible modes by the IM (Interrupt Mode) instruction. With IMO mode, whenever the CPU receives an instruction (usually, it is a "RESTART" operation) in the data bus from a peripheral device, then the CPU will jump to one of the 8 fixed of memory addresses (0000-0038H) and execute the program. When the IM1 mode has been selected by programmer, the CPU will respond to an interrupt by executing a restart instruction to location 0038H. In MPF-I mode 0 can not be used because the addresses specified for the restart instructions are already reserved for the monitor program.

The last mode is the IM2 mode which is the most powerful interrupt response mode. With this mode, the programmer maintains a table of 16-bit starting addresses for interrupt service routines. The low-order 8-bits of the pointer must be supplied by the interrupting device. The high-order 8 bits of the pointer is formed from the contents of the internal I register (Interrupt Vector Register). When an interrupt is accepted, the 16-bit pointer must be formed to obtain the starting address of the desired interrupt service routine from the table.

If the Z80 input/output interface devices (PIO, CTC, SIO) are used in the microcomputer system, then the IM2 mode will give rise to the most useful interrupt request response.

II. Example Experiments:

1. Testing the NMI interrupt response :

- (1) An interrupt request may be generated by touching a copper wire connected to the NMI input line of the CPU to the ground. After touching the NMI input line of the CPU, then the CPU will execute the program with starting address at 0066H.

2. Testing the INT interrupt response :

After a reset, the Z80 CPU will be automatically in the IMO interrupt response mode and will disable the interrupt enable flip flop. Thus, before the CPU responds to the interrupt request, the following program must be executed.

```
E05E IM      2      ; Select interrupt mode 2.  
3E18 LD      A, 18H ; Assign 18H as the high-order byte of  
E047 LD      I,A    ; the interrupt vector address.  
F0    EI      ; Enable the interrupt request line INT.
```

In case the Z80 peripheral devices are not used in the system, the interrupt request signal is sent directly to the CPU. When the CPU acknowledges an interrupt request, the 8-bit data must be read in as the low-order byte of the vector address. If there is no electronic circuit for supplying this 8-bit vector address, then the data bus will be pulled up to "high" voltage state (logic "1") and read as FFH. That is, the CPU will form 18FFH as the 16-bit vector address. This 16-bit vector address is used as a pointer to obtain the starting address of the desired interrupt service routine from the table.

Suppose the starting address of the interrupt service routine is arranged at 1920H, then the number 1920H must be stored in memory addresses 18FFH and 1900H. Load the following program into MPF-I for later testing.

FF

LOC OBJ CODE M STMT SOURCE STATEMENT

1800	1	ORG	1800H
1800 3E18	2	LD	A,18H
1802 ED47	3	LD	I,A ; Define high-order vector address.
1804 212019	4	LD	HL,1920H
1807 22FF18	5	LD	(18FFH),HL ;Store interrupt vector.
180A ED5E	6	IM	2
180C FB	7	EI	
180D F7	8	RST	30H ; Return to monitor program.
1920	9	ORG	1920H ; Interrupt service routine.
1920 211234	10	LD	HL,3412H
1923 224019	11	LD	(1940H),HL ;Store 3412H to RAM (1940H).
1926 FB	12	EI	; Enable another interrupt.
1927 ED4D	13	RETI	; Return from interrupt.

- (1) Execute the above program by depressing the control key on the keyboard. After the program is executed, the monitor will resume control of the microcomputer. The interrupt request line INT is also enabled. Then, key in some arbitrary numbers into RAM addresses 1940H and 1941H, and depress the INTR key in the keyboard. That is, an interrupt request signal is input to the CPU INT line. Depress the AD key in teh keyboard to reset the display buffer in the monitor program. Check if the interrupt service routine with starting address 1920H is executed so that the designated numbers have been stored in RAM addresses 1940H - 1941H. Repeat the testing several times (change the contents of RAM before each test).

Results of test:

- (2) Instruction RETI is used as the end of an interrupt service It is a routine to signal the I/O device that the interrupt routine has been completed. It facilitates the nesting of routine allowing higher priority devices to suspend service of lower priority service routines. The standard Z80 I/O devices are not used in this experiment, thus, RETI is not a necessary instruction. Replace instruction RETI in the above program by RST 30H and then repeat the test in (1). Record the result shown in the display after the interrupt request signal is input to the CPU. Discuss the results of the test.
- (3) instruction EI (Enable Interrupt) must be included in every interrupt service routine, otherwise the INT line will be disabled after the CPU acknowledges an INT interrupt request. Instruction EI must be used to enable the maskable interrupt. The function of the EI instruction can not be replaced by that of the RETI instruction.

Replace instruction Repeat the test for interrupt request and to show that only the first interrupt is acknowledged and all other interrupts are ignored.

Results of test:

- (4) Write a program that will cause the PAO line of the Z80 PIO to output "1" after the CPU receives an INT interrupt request and clear this line to "0" after 3 seconds has elapsed.

(I-2) Introduction to the Z80-CTC :

1.0 INTRODUCTION

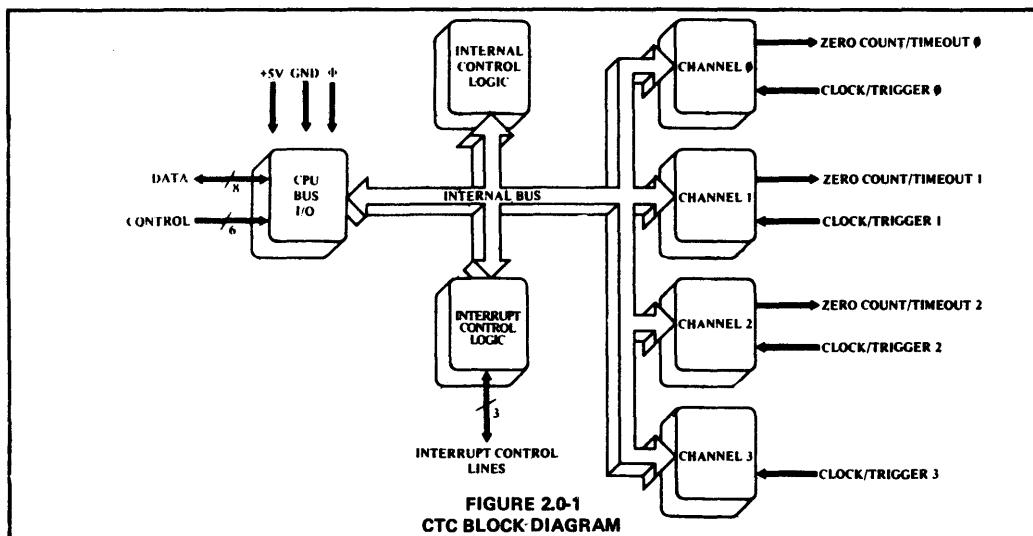
The Z80-Counter Timer Circuit (CTC) is a programmable component with four independent channels that provide counting and timing functions for microcomputer systems based on the Z80-CPU. The CPU can configure the CTC channels to operate under various modes and conditions as required to interface with a wide range of devices. In most applications, little or no external logic is required. The Z80-CTC utilizes N-channel silicon gate depletion load technology and is packaged in a 28-pin DIP. The Z80-CTC requires only a single 5 volt supply and a one-phase 5 volt clock. Major features of the Z80-CTC include :

- * All inputs and outputs are fully TTL compatible.
- * Each channel may be selected to operate in either Counter Mode or Timer Mode.
- * Used in either mode, a CPU-readable Down Counter indicates number of counts-to-go until zero.
- * A Time Constant Register can automatically reload the Down Counter at Count Zero in both Counter and Timer Modes.
- * A selectable positive or negative trigger initiates time operation in Timer Mode. The same input is monitored for event counts in Counter Mode.
- * Three channels have Zero Count/Timeout outputs capable of driving Darlington transistors.
- * Interrupts may be programmed to occur on the zero count condition in any channel.
- * Daisy chain priority interrupt logic included to provide for automatic interrupt vectoring without external logic.

2.0 CTC ARCHITECTURE

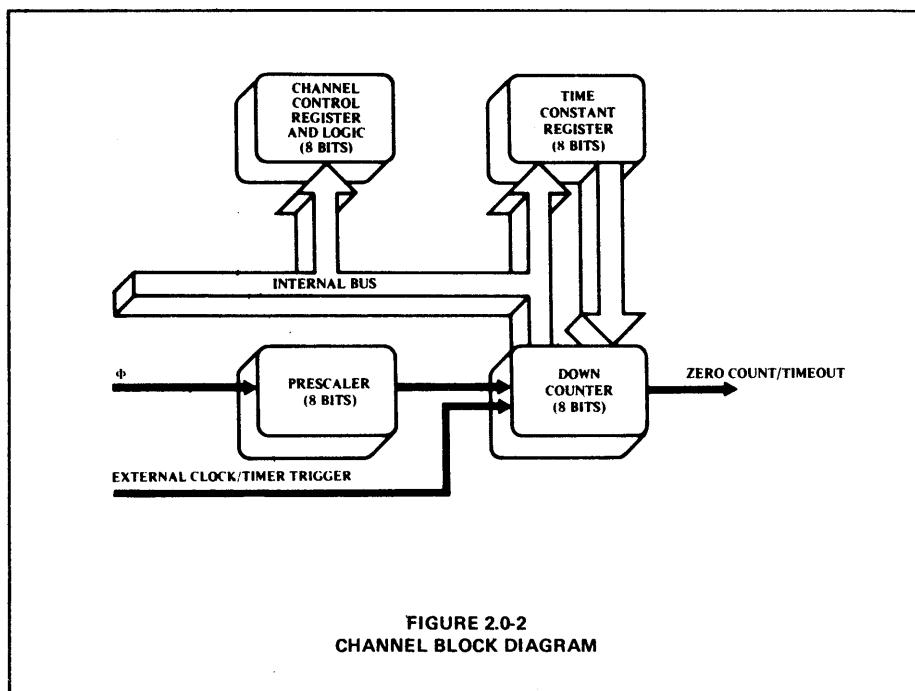
2.1 OVERVIEW

A block diagram of the Z80-CTC is shown in figure 2.0-1. The internal structure of the Z80-CTC consists of a Z80-CPU bus interface, Internal Control Logic and four sets of Counter/Timer Channels. Timer channels are identified by sequential numbers from 0 to 3. The CTC has the capability of generating a unique interrupt vector for each separate channel (for automatic vectored to an interrupt service routine). The 4 channels can be connected into four contiguous slots in the standard Z80 priority chain with channel number 0 having the highest priority. The CPU bus interface logic allows the CTC device to interface directly to the CPU with no other external logic. However, port address decoders and/or line buffers may be required for large systems.



2.2 STRUCTURE OF CHANNEL LOGIC

The structure of one of the four sets of Counter/Timer Channel Logic is shown in figure 2.0-2. This logic is composed of 2 registers, 2 counters, and control logic. The registers are an 8-bit Time Constant Register and an 8-bit Channel Control Register. The counters are an 8-bit CPU-readable Down Counter and an 8-bit prescaler.

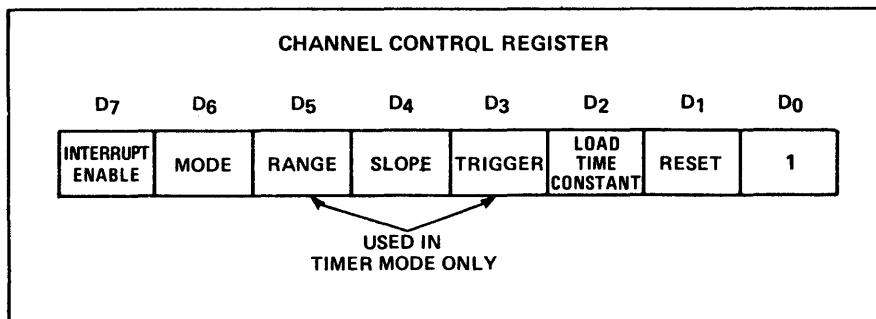


2.2.1 THE CHANNEL CONTROL REGISTER AND LOGIC

The Channel Control Register (8-bits) and Logic is written to by the CPU to select the modes and parameters of the channel. Within the entire CTC device there are four such registers, corresponding to the four Counter/Timer Channels. Which of the four is being written into depends on the encoding of two channel select input pins : CS1 and CS0 (usually attached to A0 and A1 of the CPU address bus. This is illustrated in the truth table below.

	CSI	CS0
Ch0	0	0
Ch1	0	1
Ch2	1	0
Ch3	1	1

In the control word written to program each Channel Control Register, bit 0 is always set and the other 7 bits are programmed to select alternative channel's operating modes and parameters, as shown in the diagram below, (For a more complete discussion see section 4.0 "CTC Operating Modes" and section 5.0 "CTC Programming").



2.2.2 THE PRESCALER

Used in the Timer Mode only, the Prescaler is an 8-bit device which can be programmed by the CPU via the Channel Control Register to divide its input, the System Clock (Φ), by 16 or 256. The output of the Pre-scaler is then fed as an input to clock the Down Counter, which initially, and every time it clocks down to zero, is reloaded automatically with the contents of the Time Constant Register. In effect this again divides the System Clock by an additional factor of the time constant. Every time the Down Counter counts down to zero, its output, Zero Count/Timeout (ZC/TO), is pulsed high.

2.2.3 THE TIME CONSTANT REGISTER

The Time Constant Register is an 8-bit register, used in both Counter Mode and Timer Mode, programmed by the CPU just after the Channel Control Word. It has an integer time constant value of 1 through 256. This register loads the programmed value into the Down Counter when the CTC is first initialized and reloads the same value into the Down Counter automatically whenever it counts down thereafter to zero. If a new time constant is loaded into the Time Constant Register while a channel is counting or timing, the present down count will be completed before the new time constant is loaded into the Down Counter. (For details of how a time constant is written into a CTC channel, see section 5.0: "CTC Programming.")

2.2.4 THE DOWN COUNTER

The Down Counter is an 8-bit register, used in both Counter Mode and Timer Mode loaded initially, and later when it counts down to zero, by the Time Constant Register. The Down Counter is decremented by each external clock edge in the Counter Mode or in the Time Mode, by the clock output of the Prescaler. At any time, by performing a simple I/O Read at the port address assigned to the selected CTC channel, the CPU can access the contents of this register and obtain the number of counts-to-zero. Any CTC channel may be programmed to generate an interrupt request sequence each time the zero count is reached.

In channels 0, 1 and 2, when the zero count condition is reached, a pulse appears on the corresponding ZC/T0 pin. Due to package pin limitations, however, channel 3 does not have this pin and so may be used only in applications where this output pulse is not required.

2.3 INTERRUPT CONTROL LOGIC

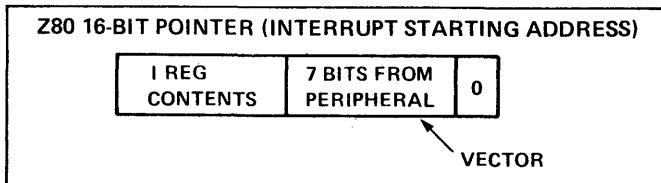
The Interrupt Control Logic insures that the CTC acts in accordance with Z80 system interrupt protocol for nested priority interrupting and return from interrupt. The priority of any system device is determined by physical location in a daisy chain configuration. Two signal lines (IEI and IEO) are provided in CTC devices to form this system daisy chain. The device closest to the CPU has the highest priority: within the CTC interrupt priority is predetermined by channel number with channel 0 having highest priority down to channel 3 which has the lowest priority. The purpose of a CTC-generated interrupt, as with any other peripheral device is to force the CPU to execute an interrupt service routine. According to Z80 system interrupt protocol, lower priority devices or channels may not interrupt higher priority devices or channels that have already interrupted and have not had their interrupt service routines completed. However, high priority devices or channels may interrupt the servicing of lower priority devices or channels.

A CTC channel may be programmed to request an interrupt every time its Down Counter reaches a count of zero. (To utilize this feature requires that the CPU be programmed for interrupt mode 2.) Sometime after the interrupt request, the CPU will send out an interrupt acknowledge, and the CTC's Interrupt Control Logic will determine the highest-priority channel which is requesting an interrupt within the CTC device. Thus if the CTC's IEI input is active, indicating that it has priority within the system daisy chain, it will place an 8-bit Interrupt Vector on the system data bus. The high-order 5 bits of this vector will have been written to the CTC earlier as part of the CTC initial programming process the next two bits will be provided by the CTC's Interrupt Control Logic as a binary code corresponding to the highest-priority channel requesting an interrupt; finally the low-order bit of the vector will always be zero according to a convention described below.

INTERRUPT VECTOR								
D7	D6	D5	D4	D3	D2	D1	D0	
V7	V6	V5	V4	V3	X	X	0	
					0	0	CHANNEL 0	
					0	1	CHANNEL 1	
					1	0	CHANNEL 2	
					1	1	CHANNEL 3	

This interrupt vector is used to form a pointer to a location in memory where the address of an interrupt service routine is stored in a table. The vector represents the least significant 8 bits, while the CPU reads the contents of the I register to provide the most significant 8-bits of the 16-bit pointer. The address in memory

pointed to will contain the low-order byte, and the next highest address will contain the high-order byte of an address which in turn contains the first opcode of the interrupt service routine. Thus in mode 2, a single 8-bit vector stored in an interrupting CTC can result in an indirect call to any memory location.



There is a Z80 system convention that all addresses in the interrupt service routine table should have their low-order byte in the next highest location in memory, and their high-order byte in the next highest location in memory. Which will always be odd so that the least significant bit of any interrupt vector will always be even. Hence the least significant bit of any interrupt vector will always be zero.

The RETI instruction is used at the end of any interrupt service routine to initialize the daisy chain enable line IEO for proper control of nested priority interrupt handling. The CTC monitors the system data and decodes this instruction when it occurs. Thus the CTC channel control logic will know when the CPU completed servicing an interrupt, without any further communication with the CPU being necessary.

3.0 CTC PIN DESCRIPTION

A diagram of the Z80-CTC pin configuration is shown in figure 3.0.1. This section describes the function of each pin.

D7-D0

Z80-CPU Data Bus (bi-directional, tri-state)

This bus is used to transfer all data and command words between the Z80-CPU and the Z80-CTC. There are 8 bits on this bus, of which D0 is the least significant.

CS1-CS0

Channel Select (input, active high)

These pins form a 2-bit binary address code for selecting one of the four independent CTC channels for an I/O Write or Read.
(See truth table below.)

	CS1	CS0
Ch 0	0	0
Ch 1	0	1
Ch 2	1	0
Ch 3	1	1

CE

Chip Enable (input, active low)

A low level on this pin enables the CTC to accept control words, Interrupt Vectors, or a time constant, date words from the Z80 Data Bus during an I/O Write cycle, or to transmit the contents of the Down Counter to the CPU during an I/O Read cycle. In most applications this signal is decoded from the 8 least significant bits of the address bus for any of the four I/O port addresses that are mapped to the four Counter/Timer Channels.

Clock (Φ)

System Clock (input)

This single-phase clock is used by the CTC to synchronize certain signals internally.

M1

Machine Cycle One Signal from CPU (input, active low)

When M1 is active and the RD signal is active, the CPU is fetching an instruction from memory. When M1 is active and the IORQ signal is active, the CPU is acknowledging an interrupt or alerting the CTC to place an interrupt Vector on the Z80 Data Bus if it has daisy chain priority and one of its channels has requested an interrupt.

IORQ

Input/Output Request from CPU (input, active low)

The IORQ signal is used in conjunction with the CE and RD signals to transfer data and Channel Control Words between the Z80-CPU and the CTC. During a CTC Write Cycle, IORQ and CE must be true and RD FALSE. The CTC does not receive a specific write signal. Instead it generates its own internally from the inverse of a valid RD signal. In a CTC Read Cycle, IORQ, CE, and RD must be active to place the contents of the Down Counter on the Z80 Data Bus. If IORQ and M1 are both true, the CPU is acknowledging an interrupt request. and the highest-priority interrupting channel will place its Interrupt Vector on the Z80 Data Bus.

3.0 CTC PIN DESCRIPTION (CONT'T)

RD

Read Cycle Status from the CPU (input, active low).

The RD signal is used in conjunction with the IORQ and CE signals to transfer data and Channel Control Words between the Z80-CPU and the CTC. During a CTC Write Cycle, IORQ and CE must be true and RD false. The CTC does not receive a specific write signal, instead generating its own internally from the inverse of a valid RD signal. In a CTC Read Cycle, IORQ, CE and RD must be active to place the contents of the Down Counter on the Z80 Data Bus.

IEI

Interrupt Enable In (input, active high)

This signal is used to help form a system-wide interrupt daisy chain which establishes priorities when more than one peripheral device in the system has interrupting capability. A high level on

this pin indicates that no other interrupting devices of higher priority in the daisy chain are being serviced by the Z80-CPU.

IEO

Interrupt Enable Out (output, active high)

The IEO signal, in conjunction with IEI, is used to form a system-wide interrupt priority daisy chain. IEO is high only if IEI is high and the CPU is not servicing an interrupt from any CTC channel. Thus this signal blocks lower priority devices from interrupting while a higher priority interrupting device is being serviced by the CPU.

INT

Interrupt Request (output, open drain, active low)

This signal goes true when any CTC channel which has been programmed to enable interrupts has a zerocount condition in its Down Counter.

RESET

Reset (input, active low)

This signal stops all channels from counting and resets channel interrupt enable bits in all control registers thereby disabling CTC-generated interrupts. The ZC/TO and INT outputs go to their inactive states. IEO reflect IEI, and the CTC's data bus output drivers go-to the high impedance state.

CLK/TRG3-CLK/TRGO

External Clock/Timer Trigger (input, user-selectable active high or low)

There are four CLK/TRG pins, corresponding to the four independent CTC channels. In the Counter Mode every active edge on this pin decrements the Down Counter. In the Timer Mode, an active edge on this pin initiates the timing function. The user may select the active edge to be either rising or falling.

ZC/TO2-AC/TO0

Zero Count/Timeout (output, active high)

There are three ZC/TO pins, corresponding to CTC channels 2 through 0. (Due to package pin limitations channel 3 has no ZC/TO pin.) In either Counter Mode or Timer Mode, when the Down Counter decrements to zero an active high going pulse appears at this pin.

3.0 CTC PIN DESCRIPTION

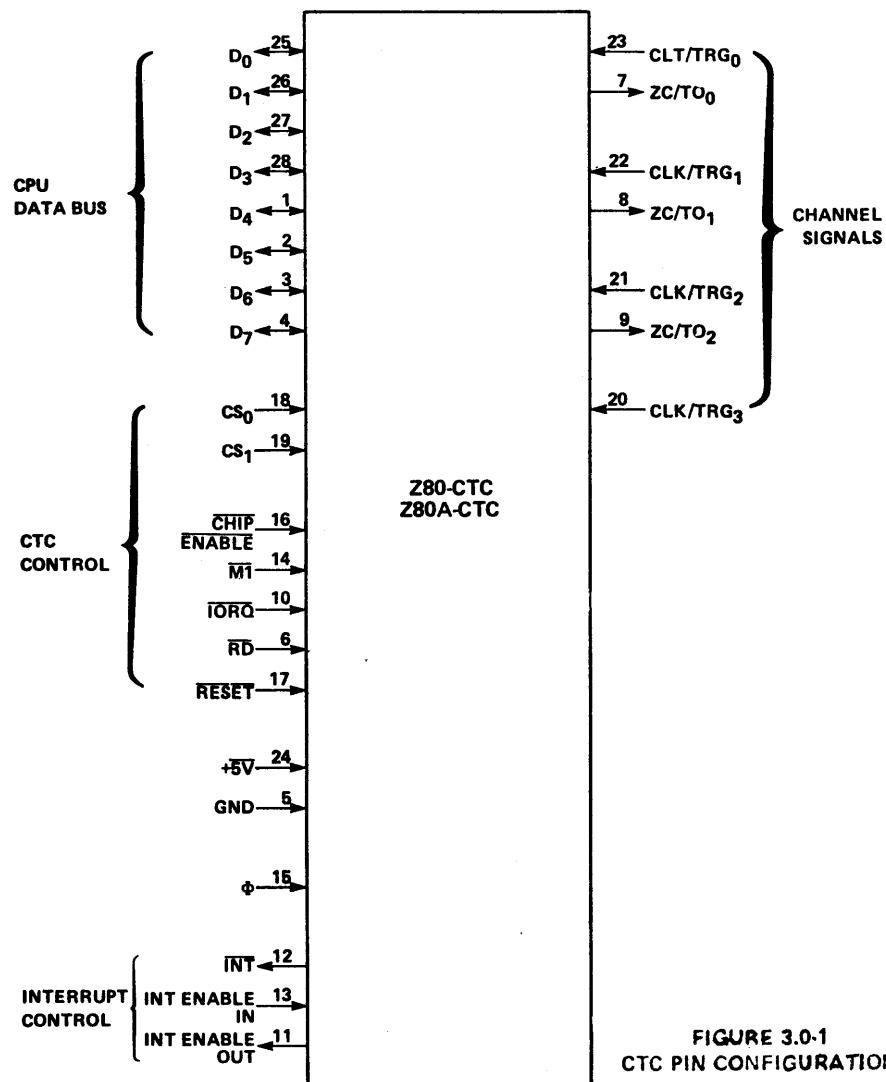


FIGURE 3.0-1
CTC PIN CONFIGURATION

4.0 CTC OPERATING MODES

At power-on, the Z80-CTC state is undefined. Asserting RESET puts the CTC in a known state. Before any channel can begin counting or timing, a Channel Control Word and a time constant data word must be written on the appropriate registers of that channel.

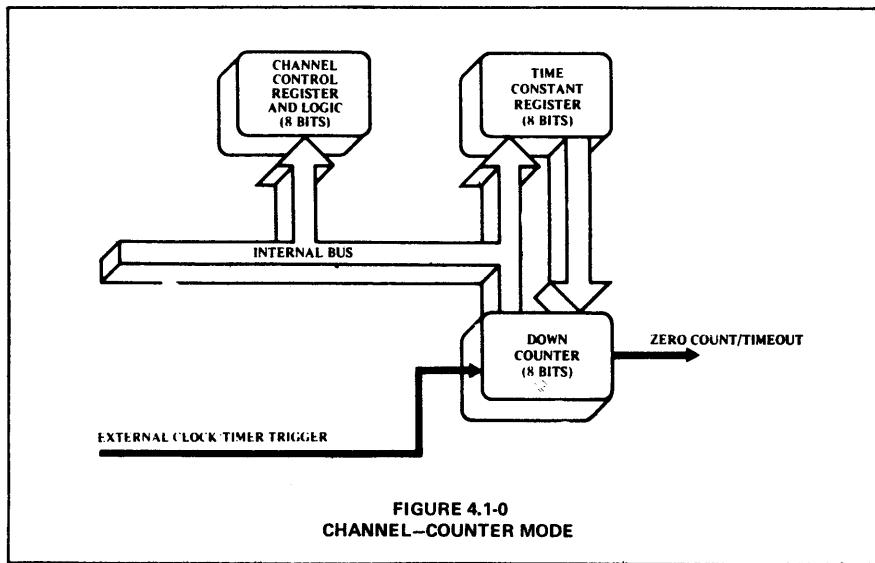
Further, if any channel has been programmed to enable int interrupts, an Interrupt Vector word must be written to the CTC's Interrupt Control Logic (For further details, refer to section 5.0 "CTC Programming"). When the CPU has written all of these words to the CTC all active channels will be programmed for immediate operation in either the Counter Mode or the Time Mode.

4.1 CTC COUNTER MODE

In this mode the CTC counts edges of the CLK/TRG input. The Counter Mode is programmed for a channel when its Channel Control Word is written with bit 6 set. The Channel's External Clock CLK/TRG) input is monitored for a series of triggering edges; after each edge, in synchronization with the next rising edge of the System Clock, the Down Counter (which was initialized with the time constant data word at the start of any sequence of down-counting) is decremented. Although there is no set-up time requirement between the triggering edge of the External Clock and the rising edge of the Clock, the Down Counter will not be decremented until the following pulse. (See the parameter t_s (CK) in section 8.3: "A.C. Characteristics"). A channel's External Clock input is pre-programmed by bit 4 of the Channel Control Word to trigger the decrementing sequence with either a high or a low going edge.

In any of Channels 0, 1, or 2, when the Down Counter is successively decremented from the original time constant until it finally reaches zero, the Zero Count (ZC/TO) output pin for that channel will be pulsed active (high). However, due to package pin limitations channel 3 does not have this pin and so may only be used in applications where this output pulse is not required. Further, if the channel has been so pre-programmed by bit 7 of the Channel Control Word, an interrupt request sequence will be generated.

As the above sequence is proceeding, the zero count condition also results in the automatic reload of the Down Counter with the original time constant data word in the Time constant Register. There is no interruption in the sequence of continued down-counting. If the Time Constant Register is written on with a new time constant data word while the Down Counter is decrementing, the present count will be completed before the new time constant will be loaded into the Down Counter.



4.2 CTC TIMER MODE

In this mode the CTC generates timing intervals that are an integer value of the system clock period. The Time Mode is programmed for a channel when its Channel Control Word is written with bit 6 reset. The channel then may be used to measure intervals of time based on the System Clock Period. The System Clock is fed through two successive counters, the Prescaler and the Down Counter. Depending on the pre-programmed bit 5 in the Channel Control Word the Prescaler divides the System Clock by a factor of either 16 or 256. The output of the Prescaler is then used as a clock to decrement the Down Counter, which may be pre-programmed with any time constant integer between 1 and 256. As in the Counter Mode, the time constant is automatically reloaded into the Down Counter at each zero-count condition, and counting continues. Also at zero-count, the channel's Time Out (ZC/TO) output (which is the output of the Down Counter) is pulsed, resulting in a uniform pulse train of the precise period given by the product:

$$t_C * P * TC$$

where t is the System Clock period, P is the Prescaler factor of 16 or 256 and TC is the pre-programmed time constant.

Bit 3 of the Channel Control Word is pre-programmed to select whether timing will be automatically initiated, or whether it will be initiated with a triggering edge at the channel's Timer Trigger (CLK/TRC) input. If bit 3 is reset the timer automatically begins operation at the start of the CBU cycle following the I/O Write

machine cycle that loads the time constant data word into the channel. If bit 3 is set the timer begins operation on the second succeeding rising edge after the Time Trigger edge following the loading of the time constant data word. If no time constant data word is to follow then the timer begins operation on the second succeeding rising edge of after the Time Trigger edge following the control word write cycle. Bit 4 of the Channel Control Word is pre-programmed to select whether the Timer Trigger will be sensitive to a rising or falling edge. Although there is no set-up requirement between the active edge of the Timer Trigger and the next rising edge. If the Timer Trigger edge occurs closer than a specified minimum set-up time to the rising edge, the Down Counter will not begin decrementing until the following rising edge.

If bit 7 in the Channel Control Word is set, the zero-count condition in the Down Counter, besides causing a pulse at the channel's Time Out pin, will be used to initiate an interrupt request sequence.

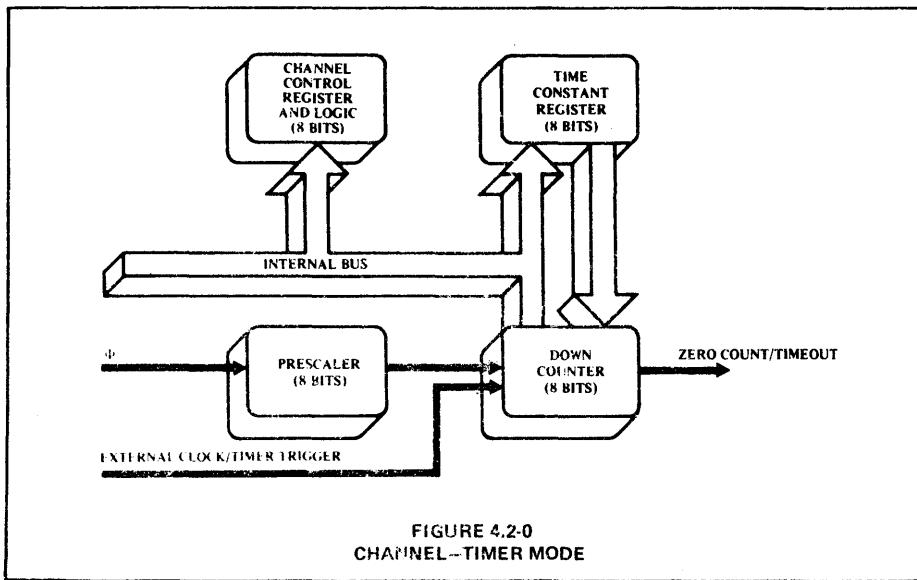


FIGURE 4.2-0
CHANNEL-TIMER MODE

5.0 CTC PROGRAMMING

Before a Z80-CTC channel can begin counting or timing operations, a Channel Control Word and a Time Constant data word must be written on it by the CPU. These words will be stored in the Channel Control Register and the Time Constant Register of that channel. In addition, if any of the four channels have been programmed with bit 7 of their Channel Control Words to enable interrupts, an Interrupt Vector must be written an the appropriate register in the CTC. Due to automatic features in the Interrupt Control Logic, one pre-programmed Interrupt Vector suffices for all four channels.

5.1 LOADING THE CHANNEL CONTROL REGISTER

To load a Channel Control Word, the CPU performs a normal I/O write sequence to the port address corresponding to the desired CTC channel. Two CTC input pins, namely CS0 and CS1, are used to form a 2-bit binary address to select one of four channels within the device (For a truth table, see section 2.2.1: "The Channel Control Register and Logic"). In many system architectures, these two input pins are connected to Address Bus lines A0 and A1 respectively, so that the four channels on a CTC device will occupy contiguous I/O port addresses. A word written on a CTC channel will be interpreted as a Channel Word and loaded into the Channel Control Register, its bit 0 is a logic 1. The other seven bits of this word select operating modes and conditions as indicated in the diagram below. Following the diagram the meaning of each bit will be discussed in detail.

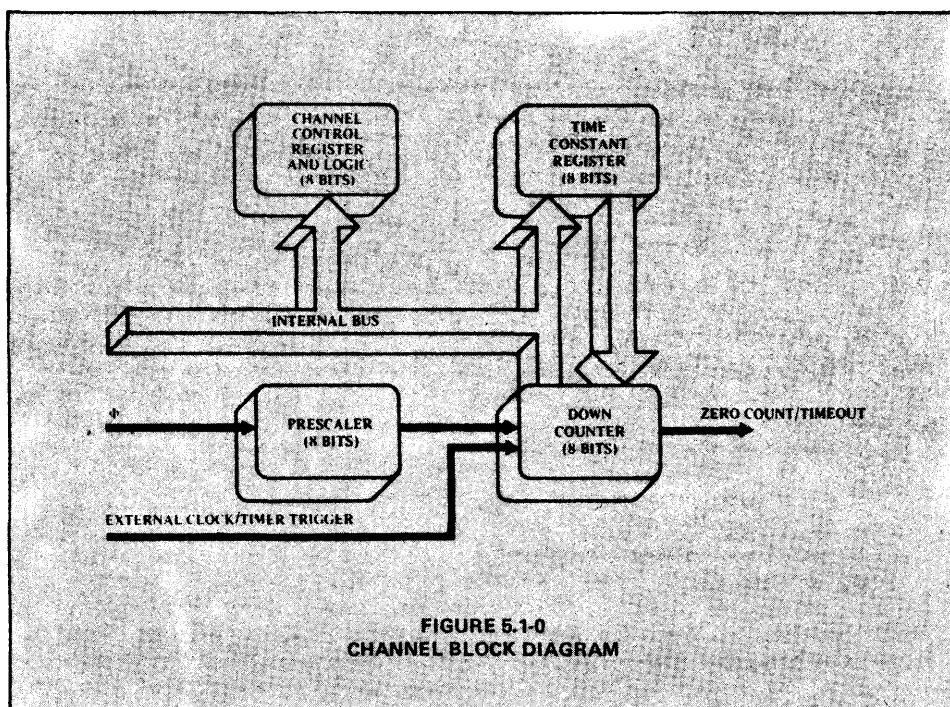
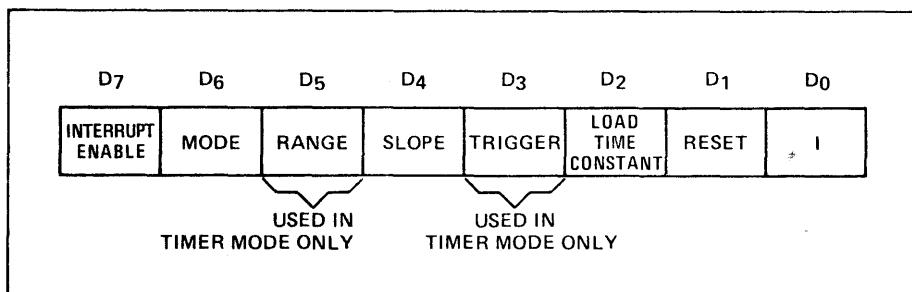


FIGURE 5.1-0
CHANNEL BLOCK DIAGRAM

5.1 LOADING THE CHANNEL CONTROL REGISTER (CONT'D)



Bit 7=1

The channel is enabled to generate an interrupt request sequence every time the Down Counter reaches a zero-count condition. To set this bit to 1 in any of the four Channel Control Registers necessitates that an Interrupt Vector also be written on the CTC before operation begins. Channel interrupts may be programmed in either Counter Mode or Timer Mode. If an updated Channel Control Word is written on a channel already in operation, with bit 7 set, the interrupt enable selection will not be retroactive to a preceding zero-count condition.

Bit 7=0

Channel interrupt disabled

Bit 6=1

Counter Mode selected. The Down Counter is decremented by each triggering edge of the External Clock (CLK/TRG) input. The Prescaler is not used.

Bit 6=0

Timer Mode selected. The Prescaler is clocked by the System Clock(Φ), and the output of the Prescaler in turn clocks the Down Counter. The output of the Down Counter (the channel's ZC/TO output) is a uniform pulse train of period given by the product:

$$t_c * P * TC$$

where t is the period of the System Clock, P is the Prescaler factor of 16 or 256, and TC is the time constant data word.

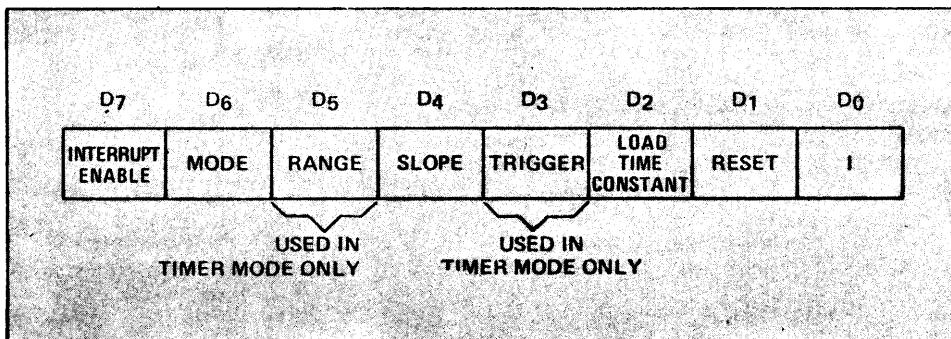
Bit 5=1

(Defined for Timer Mode only) Prescaler factor is 256.

Bit 5=0

(Defined for Timer Mode only) Prescaler factor is 16.

5.1 LOADING THE CHANNEL CONTROL REGISTER (CONT'D)



Bit 4=1

TIMER MODE -- positive edge trigger starts timer operation.
COUNTER MODE -- positive edge decrements the down counter.

Bit 4=0

TIMER MODE -- negative edge trigger starts timer operation.
COUNTER MODE -- negative edge decrements the down counter.

Bit 3=1

Timer Mode Only -- External trigger is valid for starting timer operation after rising edge T of the machine cycle following the one that loads the time constant. The Prescaler is decremented 2 clock cycles later if the setup time is met, otherwise 3 clock cycles later.

Bit 3=0

Timer Mode Only -- Timer begins operation on the rising edge T of the machine cycle following the one that loads the time constant.

Bit 2=1

The time constant data word for the Time Constant Register will be the next word written on this channel. If an updated Channel Control Word and time constant data word are written on a channel while it is already in operation, the Down Counter will continue decrementing to zero before the new time constant is loaded into it.

Bit 2=0

No time constant data word for the Time Constant Register should be expected to follow. To program bit 2 to this state implies that this Channel Control Word is intended to update the status of a channel already in operation, since a channel will not operate without a correctly programmed data word in the Time Constant Register, and a set bit 2 in this Channel Control Word provides the only way of writing to the Time Constant Register.

Bit 1=1

Reset channel. Channel stops counting or timing. This is not a stored condition. Upon writing into this bit a reset pulse discontinues current channel operation, however, none of the bits in the channel control register are changed. In both bit 2=1 and bit 1=1 the channel will resume operation upon loading a time constant.

Bit 1=0

Channel continues current operation.

5.2 LOADING THE TIME CONSTANT REGISTER

A channel may not begin operation in either Timer Mode or Counter Mode unless a time constant data word is written into the Time Constant Register by the CPU. This data word will be expected on the next I/O write to this channel following the I/O Write of the Channel Control Word, provided that bit 2 of the Channel Control Word is set. The time constant data word may be any integer value in the range 1-256. If all eight bits in his word are zero, it is interpreted as 256. If a time constant data word is loaded into a channel already in operation the Down Counter will continue decrementing to zero before the new time constant is loaded from the Time Constant Register in to the Down Counter.

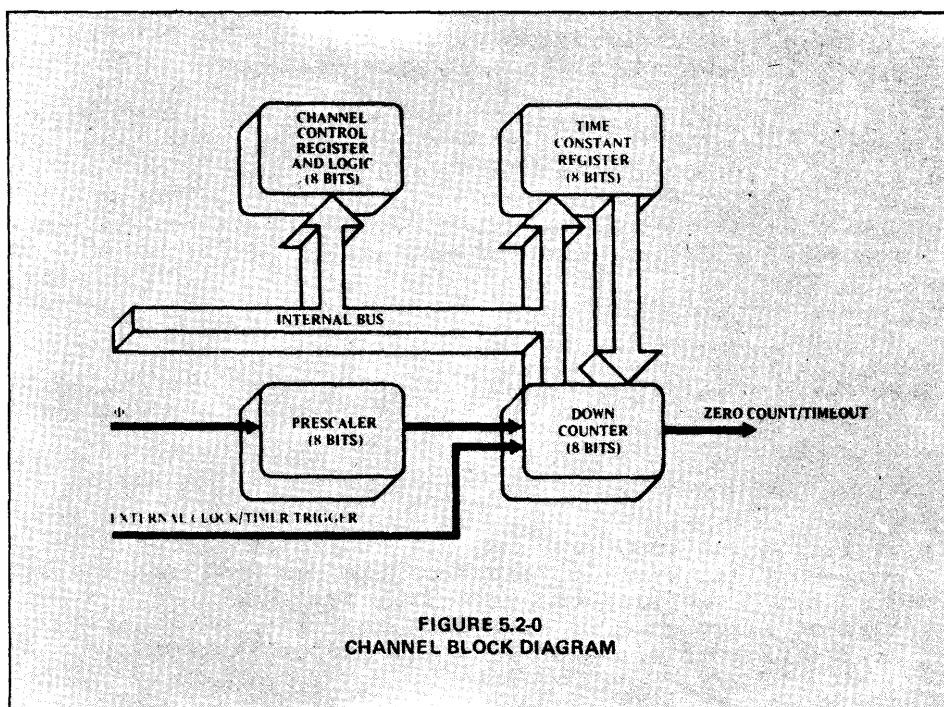
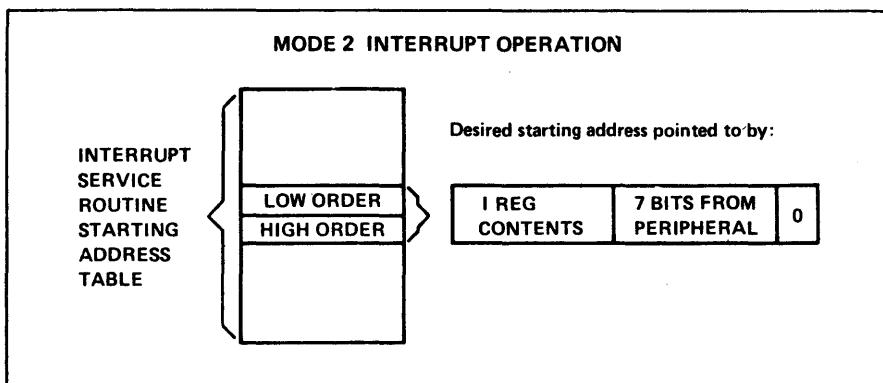


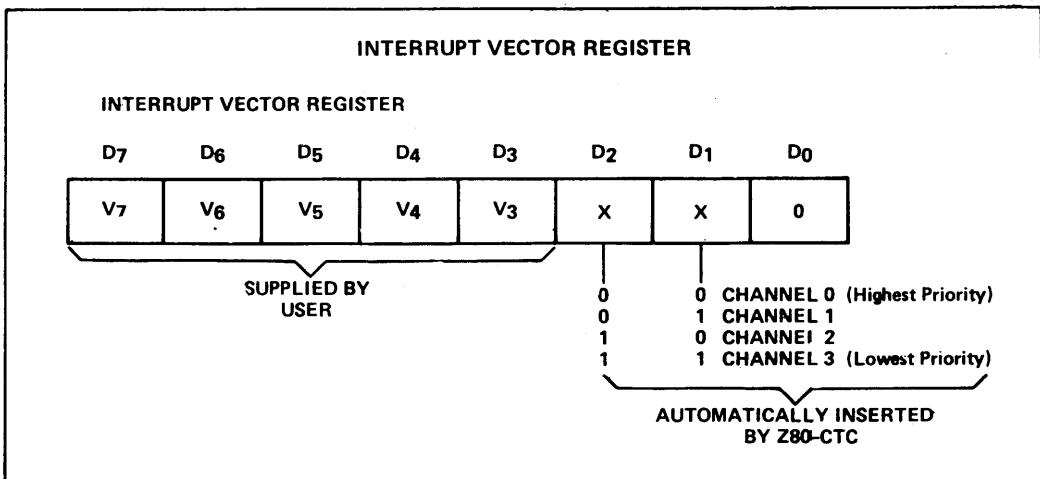
FIGURE 5.2-0
CHANNEL BLOCK DIAGRAM

5.3 LOADING THE INTERRUPT VECTOR REGISTER

The Z80-CTC has been designed to operate with the Z80-CPU programmed for mode 2 interrupt response. Under the requirements of this mode, when a CTC channel requests an interrupt and is acknowledged, a 16-bit pointer must be formed to obtain a corresponding interrupt service routine starting address from a table in memory. The upper 8 bits of this pointer are provided by the CPU's I register and the lower 8 bits of the pointer are provided by the CTC in the form of an Interrupt Vector unique to the particular channel that requested the interrupt.



The high order 5 bits of this Interrupt Vector must be written to the CTC in advance as part of the initial programming sequence. To do so, the CPU must write to the I/O port address corresponding to the CTC channel 0, just as it would if a Channel Control Word were being written to that channel, except that bit 0 of the word being written must contain a 0 (As explained above in section 5.1, if bit 0 of a word written to a channel were set to 1, the word would be interpreted as a Channel Control Word, so a 0 in bit 0 signals the CTC to load the incoming word into the Interrupt Vector Register). Bits 1 and 2, however, are not used when loading this vector. At the time when the interrupting channel must place the Interrupt Vector on the Z80 Data Bus, the Interrupt Control Logic of the CTC automatically supplies a binary code in bit 1 and 2 identifying which of the four CTC channels is to be serviced.



6.0 To see the program as follows you will have the whole idea about CTC programming.

START	LD	A, 18H
	LD	I, A
	LD	A, 10110101B
	OUT	(CTC0), A
	LD	A, 020H
	OUT	(CTC0), A
	LD	A, 0A8H
	OUT	(CTC0), A
	IM	2
	EI	

In MPF-I the four port addresses of the CTC are 40, 41, 42, 43 respectively. Since the contents of the Channel Control Register is "10110101B", So CH0 is programmed to be in the timer mode. Since bit 5 in the Channel Control word is set the Prescaler divides the System Clock by a factor of 256. Since the content of Time Constant Register is 020H, CTC channel 0 will request a interrupt every time its Down Counter reaches a count of zero. In other words, CTC will generate an interrupt when the count of the System Clock reaches 8192 (i.e. 256 x 32). Since RESET forces the program counter to zero and initializes the CPU. The CPU initialization includes:

1. Disabling the interrupt enable flip-flop
2. Setting Register I=00H

II. The flowchart of the clock are given below.

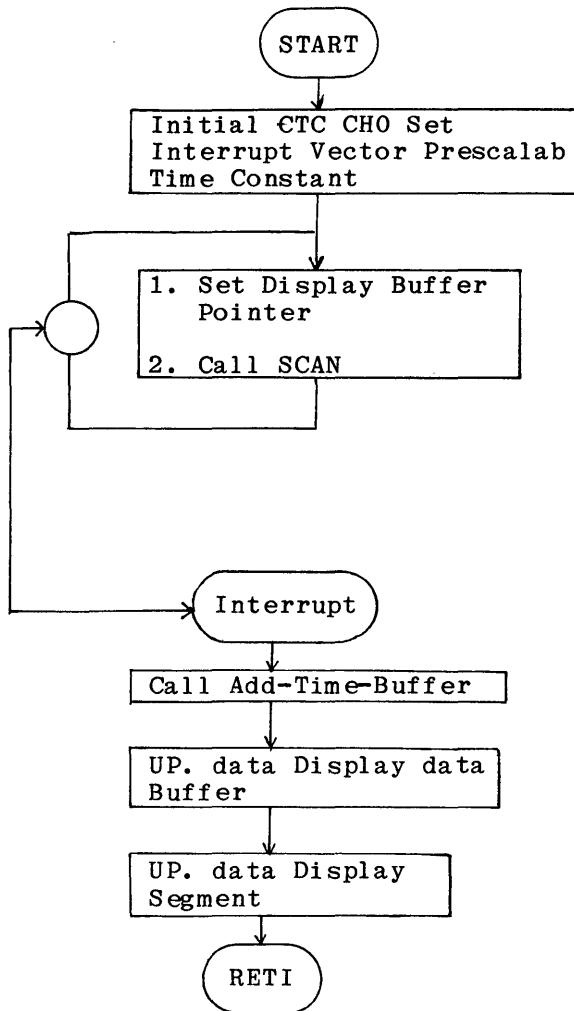


Fig 15-3 The flowchart of clock

LOC OBJ CODE M STMT SOURCE STATEMENT

```

      1 ;
1800      2     ORG    1800H
      3 ;
      4 CTC0   EQU    40H
      5 SCAN   EQU    05FEH
      6 START: LD     A,18H ;Loading the interrupt register
1800 3E18    7     LD     I,A
1802 ED47    8     LD     A,10110101B ;Loading the channel
1804 3EB5    9     LD     control
      10    OUT    (CTCO),A
1806 D340    11    LD     A,020H ;Loading the constant register
1808 3E20    12    OUT   (CTCO),A
180A D340    13    LD     A,0A8H ;Loading the interrupt vector
180C 3EA8    14    OUT   (CTCO),A
register
180E D340    15    IM     2      ;Set interrupt mode 2
1810 ED5E    16    EI
1812 FB      17 MAIN: LD     IX,DISP_BUFFER
1813 DD21041A 18     CALL  SCAN
1817 CDFE05  19     JR    MAIN
181A 18F7    20
21 ; ****
22 ADD_TIME_BUFFER:
181C 11001A  23    LD     DE,TIME_BUFFER
181F 1A       24    LD     A,(DE)
1820 3C       25    INC   A
1821 12       26    LD     (DE),A
1822 FEDA    27    CP     ODAH ;Increment SEC only if the
1824 0604    28    LD     B,4 ;number of interrupt reaches
1826 C0       29    RET   NZ    ;218 (ie ODAH).
1827 AF       30    XOR   A
1828 05       31    DEC   B
1829 12       32    LD     (DE),A
182A 13       33    INC   DE
182B 215318  34    LD     HL,MAX_TIME_TABLE
35 ATB1: LD     A,(DE)
182E 1A       36    ADD   A,1
182F C601    37    DAA
1831 27       38    LD     (DE),A
1832 12       39    SUB   (HL) ;Compare with data in
1833 96       40    RET   MAX_TIME_TABLE
1834 D8       41    RET   C
1835 12       42    LD     (DE),A
1836 23       43    INC   HL ;If the result is less than, t
1837 13       44    INC   DE
1838 10F4    45    DJNZ  ATB1 ;following loop will be null.
183A C9       46    RET
47 SET_DISP_BUFFER:
183B 21041A  48    LD     HL,DISP_BUFFER ;Convert data in
display buffer
183E 11011A  49    LD     DE,SECOND ;to display format.
1841 0603    50    LD     B,3

```

		51	SDB1	
1843	1A	52	LD	A,(DE) ;
1844	CD7806	53	CALL	HEX7SG
1847	13	54	INC	DE
1848	10F9	55	DJNZ	SDB1
184A	2B	56	DEC	HL
184B	2B	57	DEC	HL
184C	CBF6	58	SET	6,(HL) ;Set decimal point for hour

LOC OBJ CODE M STMT SOURCE STATEMENT

184E	2B	59	DEC	HL
184F	2B	60	DEC	HL
1850	CBF6	61	SET	6,(HL)
1852	C9	62	RET	
		63	*****	
1853	60	64	MAX_TIME_TABLE:	
		65	DEFB	60H ;The maximal value of the time constant
1854	60	66	DEFB	60H ;e.g. the maximum of second is 60,
1855	12	67	DEFB	12H ;the maximum of hour is 12. (The use may change
18A8		68	ORG	18A8H ;12 to 24 as he wished)
18A8	AA18	69	DEFW	INTERRUPT
		70	INTERRUPT: ;Entry point of interrupt service	
18AA	F5	71	PUSH	AF ;routine.
18AB	C5	72	PUSH	BC
18AC	D5	73	PUSH	DE
18AD	E5	74	PUSH	HL
18AE	CD1C18	75	CALL	ADD_TIME_BUFFER
18B1	78	76	LD	A,B
18B2	FE04	77	CP	4
18B4	C43B18	78	CALL	NZ,SET_DISP_BUFFER
18B7	E1	79	POP	HL
18B8	D1	80	POP	DE
18B9	C1	81	POP	BC
18BA	F1	82	POP	AF
18BB	FB	83	EI	
18BC	ED4D	84	RETI	
		85	HEX7SG	EQU 678H
1A00		86	ORG	1A00H
		87	TIME_BUFFER:	
1A00	00	88	DEFB	0
		89	SECOND	
1A01		90	DEFS	1 ;Locations for presetting values.
		91	MINUTE	
1A02		92	DEFS	1
		93	HOUR	
1A03		94	DEFS	1
		95	DISP_BUFFER:	
1A04		96	DEFS	6

III. Illustration of Experiments 3-15

1. The timer mode is used in this experiment. This program carefully calculates the total number of counts of System Clock. The frequency of the System Clock is 1.7898 MHZ. In this experiment we use 1785856 (256 x 32 x 218) count for each SECOND, so the count error per second is $1789772 - 1785856 = 3916$. The SECOND error is $(1 \div 1789772) \times 3916 = 2.2$ msec. Hence there is 1 second error for every 455 seconds.
2. This program uses the Z80 CPU interrupt mode 2. The contents of the Interrupt Register are 018H and the content of the Interrupt vector Register are 0A8H, then the contents of the Interrupt Service Routine's starting address is stored in addresses 18A8 - 18A9. We can see that the Interrupt Service Routine's starting address in this experiment is 18AAH.
3. The statements 6-15 set the CTC with control words. Now in this experiment we use the CTC Timer Mode and the prescaler is set to 256. The contents of the Time Constant Register are 20H. The interrupt service routine's starting address is 18AAH. Statements 21-32 check whether the count of interrupts reaches 218 or not. Statements 33-45 compares data with MAX-TIME-TABLE. Statements 46-61 convert data in the display buffer to a 7-segment display format. Statements 64-67 set the decimal points for both hour and minute.
4. Load the program into MPF-I and record it on audio tape for future use.
5. Convert the contents of 1823 to 6D. What will the display show ?
6. If we want to use CH2 of the CTC what shall do ?
7. If we change the contents of the MAX-TIME-TABLE, what will the display show?
8. Typically, there are 1789772 T-cycles in one second. This program approximates one second with 1785856 T-cycles, it is pretty rough. So if a user needs more precise timing, Software compensation is needed.

Experiment 16

Telephone Tone

Purposes:

1. To simulate a telephone ring.
2. To familiarize the reader with the application of 'tone' subroutine.

Time required: 4 hours.

I. Theoretical Background:

1. The telephone ring can be simulated as a repeating 1 second tone with 2 seconds silence.
2. This tone is a frequency shift keying signal modulated by two 20HZ square waves (half-period of 25 m sec).
The low & high states of this 20HZ signal correspond to 320HZ and 480HZ, so that it takes 8 & 12 cycles respectively.
3. In the following program, register C controls the frequency of the sound and register pair HL controls the length of the sound.
 - a. Low frequency: C = 211, HL = 8, so the period is
$$(44 + 13 \times 211) \times 2 \times 0.56 = 3121 \text{ micro-sec.}$$

frequency : $f = 1/3121 = 320\text{Hz}$
length of the sound: $3121 \text{ micro-sec} \times 8 = 25\text{m sec.}$
 - b. High frequency: C = 140, HL = 12, so the period is
$$(44 + 13 \times 140) \times 2 \times 0.56 = 2087 \text{ micro-sec}$$

frequency: $1/2087 = 480\text{Hz.}$
length of the sound: $2087 \text{ micro-sec} \times 2 = 25\text{m sec.}$

4. Output Circuit of tone

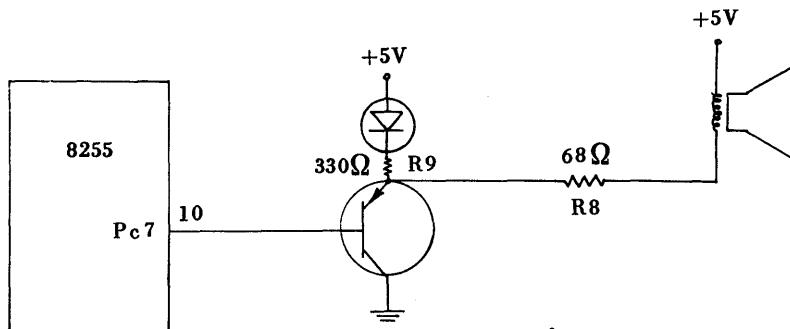


Fig 2-16-1 Output Circuit of tone

The output of the tone is sent via PC7 of 8255, 2N9015, R8, to the speaker. When the voltage of PC7 is low, the transistor will conduct; the voltage of PC7 is high, the transistor will nonconduct. By means of the transistor conducts and nonconducts, the speaker will make sound.

5. Flowchart of Telephone Tone

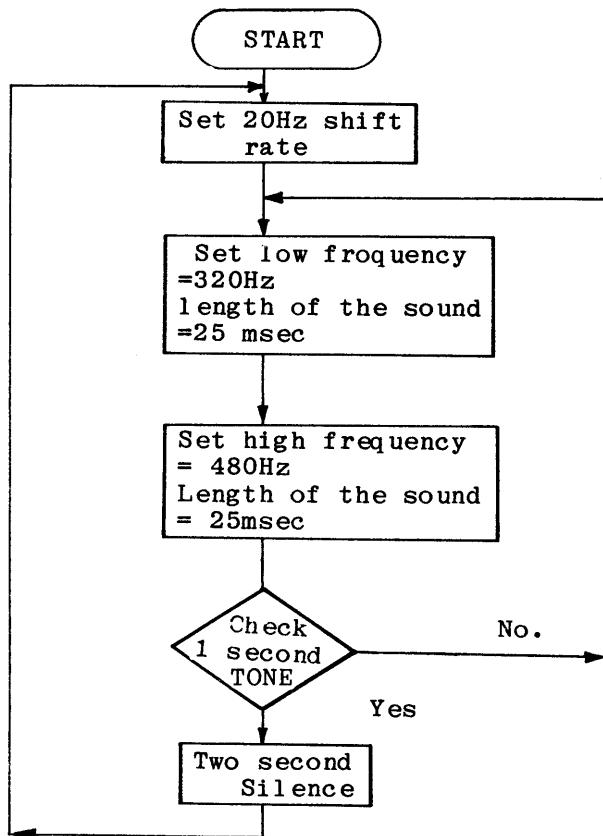


Fig 16-2 Flowchart of a telephone tone simulation

6. Telephone Tone Program

LOC OBJ CODE M STMT SOURCE STATEMENT

1800		1		
1800	3E14	2	ORG	1800H
		3	RINGBK	LD A,20 ;20HZ FREQ SHIFT RATE
		4		;SO THAT 1 SEC HAS 20 LOOPS
1802	08	5	RING	EX AF,AF' ;SAVE TO A'
1803	OED3	6	LD	C,211
1805	210800	7	LD	HL,8
1808	CDE405	8	CALL	TONE ;320HZ, 25 MSEC
180B	0E8C	9	LD	C,140
180D	210C00	10	LD	HL,12
1810	CDE405	11	CALL	TONE ;480HZ, 25 MSEC
1813	08	12	EX	AF,AF' ;RETRIEVE FROM A'
1814	3D	13	DEC	A ;DECREMENT 1 COUNT
1815	20EB	14	JR	NZ,RING
		15	;	
1817	0150C3	16	LD	BC,50000
181A	CD1F18	17	CALL	DELAY ;SILENT, 2 SEC
181D	18E1	18	JR	RINGBK
		19	;DELAY	SUBROUTINE: (BC) * 40 MICRO-SEC
		20	;BASED	ON THE 1. 79 MHZ SYSTEM CLOCK
181F	E3	21	DELAY	EX (SP),HL ;19 STATES
1820	E3	22	EX	(SP),HL ;19
1821	EDA1	23	CPI	;16
1823	E0	24	RET	PO ;5
1824	18F9	25	JR	DELAY ;12
		26	;	
		27	;	
		28	TONE	EQU 05E4H
		29		END

II. Example and Practice Experiments

1. Load the above program into MPF-I and then store it on audio tape.
2. Execute the program and listen to it. Does it like the telephone ring? If it doesn't try to modify the frequency of tone to closer simulate the sound.
3. Try to simulate the telephone busy tone

Hint: The busy tone can be simulated as follows: a repeating 0.5 seccond 400HZ tone with 0.5 seconds of silence.

Experiment 17

Microcomputer Organ

Purposes:

1. To enable the part of the Microprofessor to simulate an electronic organ.
2. To familiarize the reader with the application of the keyboard -scanning routine.

Time Required: 4 hours

I. Theoretical Background:

1. This experiment converts the MPF-I into a simple electronic organ.
2. When a key is pressed, the speaker will generate a tone corresponding this key. This tone will not terminate until the key is released.
3. Acceptable keyboard: key 0 - key F.

If other keys are entered, the response is unpredictable.

4. Key Mapping To Tones

C G	D A	SZ•H' B	PNC' C
8 IX	9 ZY	A SP	B 1-1F
C C	D D	E E	F F
4 AF'	5 BC'	6 DE'	7 HL'
F F	G G	A A	B B
0 AF	1 BC	2 DE	3 HL
B B	C C	D D	E E

Fig 17-1 Key Mapping To Tone

5. An octave ranges from a C to a B. The octave is divided into 5 full-tones and 2 half-tones, which equals to 12 half-tones, as follows:

C #C D #D E F #F G #G A #A B

The next octave is just twice the frequency of the current one, There is a logarithmic relationship between each half-tone. The frequency of each half-tone can be calculated by multiplying the last one by $2^{**}(1/12)$, which is approximately 1.059.

For example, if the frequency of E is 503HZ, then the frequency of F is equal to

$$503\text{Hz} \times 1.059 = 532\text{Hz}.$$

6. Flow chart of microcomputer organ program

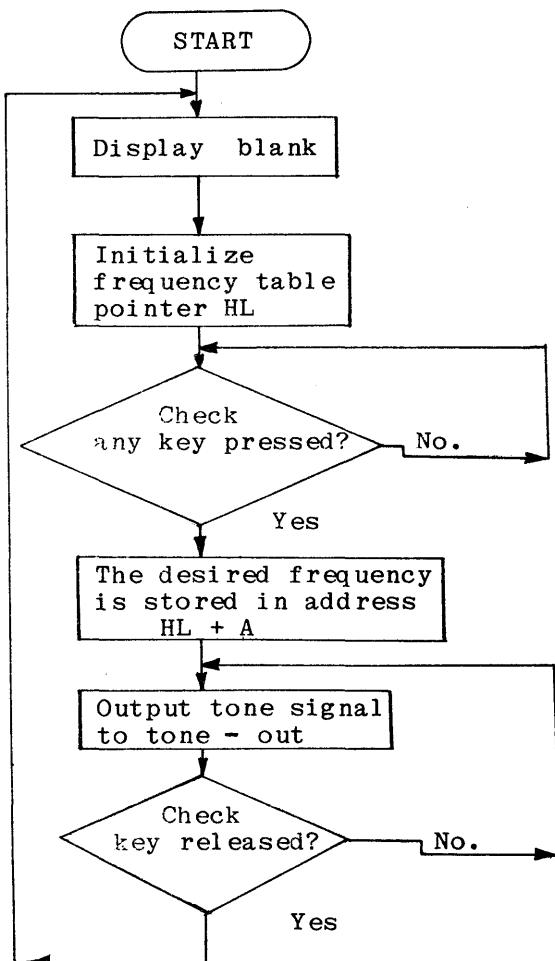


Fig 17-2 Flowchart of organ

LOC	OBJ	CODE M	STMT	SOURCE STATEMENT
1800		1	ORG	1800H
		2	START:	
1800	DD21A507	3	LD	IX, BLANK
1804	CDFE05	4	CALL	SCAN ;Display blank, return when any
		5		;Key is pressed. A register.
		6		;Contains the key-code.
1807	212318	7	LD	HL, FREQTAB ;Base address of frequency table.
		8		
		9		;After routine SCAN, A contains the code of the key pressed.
		10		;Use this code as table offset. The desired f
		11		;frequency is stored in address HL+A.
		12		
180A	85	13	ADD	A, L ;Add A to HL.
180B	6F	14	LD	L, A
180C	3EC0	15	LD	A, 11000000B
		16		
		17		HALF_PERIOD:
180E	D302	18	OUT	(DIGIT), A ;Output tone signal to TONE-OUT.
		19		;Activate all 6 columns of
		20		;the Keyboard matrix.
1810	46	21	LD	B, (HL) ;Get the frequency from FREQTAB.
		22		;HL has been calculated in
		23		;previous instructions.
1811	00	24	DELAY:	NOP
1812	00	25		NOP
1813	00	26		NOP
1814	10FB	27	DJNZ	DELAY ;Loop B times.
1816	EE80	28	XOR	80H ;Complement bit 7 of A.
		29		;This bit will be output to TONE.
1818	4F	30	LD	C, A ;Store A in C
1819	DB00	31	IN	A, (KIN) ;Check if this key is released.
		32		;All 6 columns have been activated.
		33		;If any key is pressed, the
		34		;corresponding matrix row
		35		;input must be at low.
181B	F6C0	36	OR	11000000B ;Mask out bit 6 (tape input)
				;and bit 7 (User's K) of register A.
181D	3C	38	INC	A ;If A is 11111111, increase
		39		;A by one will make A zero
		40		;Zero flag is changed here.
181E	79	41	LD	A, C ;Restore A from register C.
181F	28DF	42	JR	Z, START ;If all keys are released, re-start.
		43		;Otherwise, continue this frequency.
1821	18EB	44	JR	HALF_PERIOD
		45		
		46		FREQTAB:

1823	B2	47	DEFB	0B2H	;Key 0
1824	A8	48	DEFB	0A8H	;Key 1
1825	96	49	DEFB	096H	;Key 2
1826	85	50	DEFB	085H	;Key 3
1827	7E	51	DEFB	07EH	;Key 4
1828	70	52	DEFB	070H	;Key 5
1829	64	53	DEFB	064H	;Key 6
182A	59	54	DEFB	059H	;Key 7
182B	54	55	DEFB	054H	;Key 8
182C	4A	56	DEFB	04AH	;Key 9
182D	42	57	DEFB	042H	;Key A
182E	3E	58	DEFB	03EH	;key B

LOC OBJ CODE M STMT SOURCE STATEMENT

182F	37	59	DEFB	037H	;Key C
1830	31	60	DEFB	031H	;Key D
1831	2C	61	DEFB	02CH	;Key E
1832	29	62	DEFB	029H	;Key F
		63			
		64	BLANK	EQU	07A5H
		65	SCAN	EQU	05FEH
		66	DIGIT	EQU	2
		67	KIN	EQU	0
		68		END	

II. Example and Practice Experiments

1. Load the above program into MPF-I and then store it on audio tape.
2. Execute the program. When a key is pressed, the speaker will generate a tone corresponding to this key. Acceptable keys are key 0 to key F.
- Are these tones accurate?
3. Try to play a song using organ.
4. Extend this program so that more keys of the key board can be used as input keys of the organ.

Experiment 18

Music Box

Purposes:

1. To construct a music box.
2. To familiarize the reader with programming techniques.

Time Required: 4 hours.

I. Theoretical Background:

1. This experiment generates a song using programming techniques.
2. There are two tables (frequency-table & song-table) in this program, which is described below:
 - a. Frequency-table

Every element of this table has 2 bytes, the 1st byte is the frequency parameter and the 2nd byte is the number of half-periods in a unit-time duration.

One octave ranges from C to B. It is divided into 5 full-tones and 2 half-tones, which equals 12 half-tones, as follows:

C #C D #D E F #F G #G A #A B

The next octave is just twice the frequency of the current one, and there is a logarithmic relationship between each half-tone. So that the frequency of each half-tone can be calculated by multiplying the last tone by $2^{1/12}$, which is approximately 1.059.

b. Song-Table:

Each element of this table has 2 bytes:

The 1st byte contains the code of the NOTE or REST or command of REPEAT or STOP. These codes are:

bit 7	----	STOP
bit 6	----	REPEAT
bit 5	----	REST
bit 4-0	----	NOTE CODE

The 2nd byte contains the counts of the unit-time, i.e. the NOTE length.

3. A flowchart of music box simulation is given below:

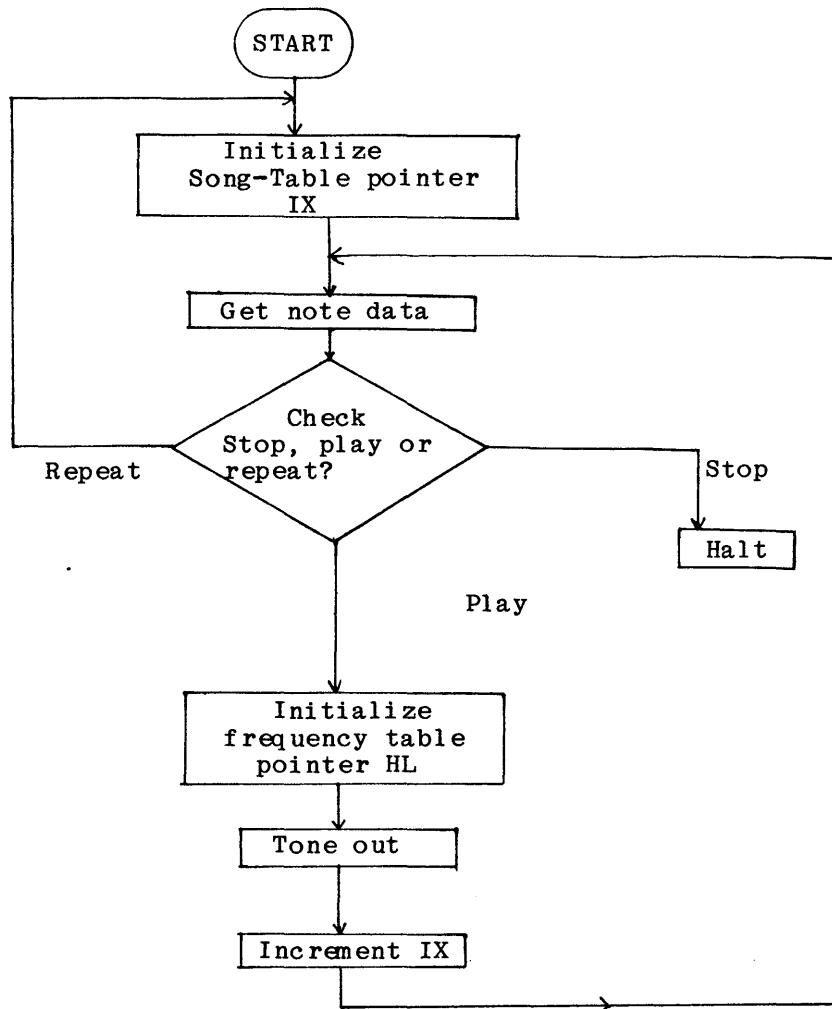


Fig 18-1 Flowchart of music box simulation

LOC OBJ CODE M STMT SOURCE STATEMENT

```

1
2           ORG    1800H
3   ;
4   START   LD     IX, SONG ;Initial SONG-TABLE pointer
5   FETCH   LD     A,(IX) ;Get note data
6   ADD     ADD    A,A   ;Each note data have 2 bytes
7   JR      C,STOP ;STOP?
8   JP      M,START ;REPEAT?
9   LD      C,0    ;Reset TONE-BIT (BIT-7 of C)
10  BIT     6,A   ;REST?
11  JR      NZ,PLAY
12  SET     7,C   ;Set ONTE-BIT
13  PLAY   AND    3FH   ;Mask out note data
14  LD      HL,FRQTAB
15  ADD     A,L
16  LD      L,A   ;Locate pointer in FRQTAB
17  LD      E,(HL);Counts of loop per HALF-PERIOD
                  delay
18  INC    HL
19  LD      D,(HL);Counts of HALF-PERIODS per UNIT-
                  TIME
20  INC    IX
21  LD      H,(IX);Counts of UNIT-TIME for this note
22  LD      A,OFFH
23   ;
24   ;The following loop runs for one NOTE or REST:
25   ;
26   TONE:
27  LD      L,D
28  UNIT   OUT   (02H),A ;Bit 7 is NOTE-OUT
29  LD      B,E
30  DELAY  NOP
31  NOP
32  NOP
33  DJNZ   DELAY
34  XOR    C      ;If C=80H then TONE-OUT.
35   ;If C=00H then REST.
36  DEC    L
37  JR     NZ,UNIT
38  DEC    H
39  JR     NZ,TONE
40   ;
41   ;The current note has ended, increment pointer next.
42   ;
43  INC    IX
44  JR     FETCH
45   ;
46  STOP   HALT
47   ;
48

```

```

49  FRQTAB:
50
51  ;
52 ;1st byte: counts of delay loop per HALF-PERIOD.
53 ;2nd byte: counts of HALF-PERIOD per UNIT-TIME.
54 ;
55 ;OCTAVE 3.

183B  E118      56      DEFW     18E1H    ;CODE 00 , G
183D  D41A      57      DEFW     1AD4H    ;CODE 01 , #G
183F  C81B      58      DEFW     1BC8H    ;CODE 02 , A

```

LOC	OBJ	CODE	M	PO		PAGE ASM 5.8
				STMT	SOURCE STATEMENT	
1841	BD1D	59		DEFW	1DBDH	;CODE 03 , #A
1843	B21E	60		DEFW	1EB2H	;CODE 04 , B
		61	;OCTAVE 4			
1845	A820	62		DEFW	20A8H	;CODE 05 , C
1847	9F22	63		DEFW	229FH	;CODE 06 , #C
1849	9624	64		DEFW	2496H	;CODE 07 , D
184B	8D26	65		DEFW	268DH	;CODE 08 , #D
184D	8529	66		DEFW	2985H	;CODE 09 , E
184F	7E2B	67		DEFW	2B7EL	;CODE OA , F
1851	772E	68		DEFW	2E77H	;CODE OB , #F
1853	7031	69		DEFW	3170H	;CODE OC , G
1855	6A33	70		DEFW	336AH	;CODE OD , #G
1857	6437	71		DEFW	3764H	;CODE OE , A
1859	5E3A	72		DEFW	3A5EH	;CODE OF , #A
185B	593D	73		DEFW	3D59H	;CODE 10 , B
		74	;OCTAVE 5			
185D	5441	75		DEFW	4154H	;CODE 11 , C
185F	4F45	76		DEFW	454FH	;CODE 12 , #C
1861	4A49	77		DEFW	494AH	;CODE 13 , D
1863	464D	78		DEFW	4D46H	;CODE 14 , #D
1865	4252	79		DEFW	5242H	;CODE 15 , E
1867	3E57	80		DEFW	573EH	;CODE 16 , F
1869	3B5C	81		DEFW	5C3BH	;CODE 17 , #F
186B	3762	82		DEFW	6237H	;CODE 18 , G
186D	3467	83		DEFW	6734H	;CODE 19 , #G
186F	316E	84		DEFW	6E31H	;CODE 20 , A
1871	2E74	85		DEFW	742EH	;CODE 21 , #A
1873	2C7B	86		DEFW	7B2CH	;CODE 1C , B
		87	;OCTAVE 6			
1875	2982	88		DEFW	8229H	;CODE 1D , C
1877	278A	89		DEFW	8A27H	;CODE 1E , #C
1879	2592	90		DEFW	9225H	;CODE 1F , D

```

91    ;
92    ;
93    ;1st byte, bit 7,6,5 & 4-0 STOP, REPEAT, REST & NOTE
94    ;      Code of STOP:   80H
95    ;      Code of REPEAT: 40H
96    ;      Code of REST:  20H
97    ;2nd byte, NOTE LENGTH: counts of UNTI-TIME (N*0.077 sec)
98    ;
99    ;JINGLE BELL: (Truncated)
1880   100 SONG    ORG    1880H
1880   09    101     DEFB    9
1881   04    102     DEFB    4
1882   09    103     DEFB    9
1883   04    104     DEFB    4
1884   09    105     DEFB    9
1885   06    106     DEFB    6
1886   20    107     DEFB    20H      ;REST
1887   02    108     DEFB    2
1888   09    109     DEFB    9
1889   04    110     DEFB    4
188A   09    111     DEFB    9
188B   04    112     DEFB    4
188C   09    113     DEFB    9
188D   06    114     DEFB    6
188E   20    115     DEFB    20H      ;REST
188F   02    116     DEFB    2

```

LOC	OBJ	CODE	M	STMT	PO	
					SOURCE	STATEMENT
1890	09		117		DEFB	9
1891	04		118		DEFB	4
1892	0C		119		DEFB	0CH
1893	04		120		DEFB	4
1894	05		121		DEFB	5
1895	04		122		DEFB	4
1896	07		123		DEFB	7
1897	04		124		DEFB	4
1898	09		125		DEFB	9
1899	08		126		DEFB	8
189A	20		127		DEFB	20H ;REST
189B	08		128		DEFB	8
189C	80		129		DEFB	80H ;STOP

```
130  ;
131 ;The following data are codes of the song 'GREEN SLEEVES'.
132 ;The user can put them at the SONG-table, i.e. from 1880H.
133 ;It will play until 'RS' key is pressed.
134 ;
135 ;
136 ;1880  07 08 0A 10 0C 08 0E 10  10 04 0E 04  0C 10 09 08
137 ;1890  05 10 07 04 09 04 0A 10  07 08 07 10  06 04 07 04
138 ;18A0  09 10 06 08 02 10 07 08  0A 10 0C 08  0E 10 10 04
139 ;18B0  0E 04 0C 10 09 08 05 10  07 04 09 04  0A 08 09 08
140 ;
141 ;18C0  07 08 06 08 04 08 06 08  07 10 20 08  11 10 11 08
142 ;18D0  11 10 10 04 0E 04 0C 10  09 08 05 10  07 04 09 04
143 ;18E0  0A 10 07 08 07 10 06 04  07 04 09 10  06 08 02 10
144 ;18F0  20 08 11 10 11 08 11 10  10 04 0E 04  0C 10 09 08
145 ;
146 ;1900  05 10 07 04 09 04 0A 08  09 08 07 08  06 08 04 08
147 ;1910  06 08 07 18 20 10 40
148 ;
149 ;
150 ;The ending address is 1916H.
151 ;
152
153
154
```

II. Example and practice Experiments:

1. Load the above program into MPF-I and then store it on audio tape.
2. Execute the program beginning at line 100 and listen to it. Does it sound like the song "JINGLE BELLS"?
3. On the last page of the above program line 30 there are codes for the song "GREEN SLEEVES". Put them on the SONG-table. The program will play until "RS" key is pressed.
4. Try to translate your favorite song into code and load it into MPF-I.



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