

# CHAPTER 1

1-1

A	B	C	$A \cdot B \cdot C$	$(A \cdot B \cdot C)'$	$A'$	$B'$	$C'$	$A' + B' + C'$
0	0	0	0	1	1	1	1	1
0	0	1	0	1	1	1	0	1
0	1	0	0	1	1	0	1	1
0	1	1	0	1	1	0	0	1
1	0	0	0	1	0	1	1	1
1	0	1	0	1	0	1	0	1
1	1	0	0	1	0	0	1	1
1	1	1	1	0	0	0	0	0

1-2

A	B	C	$A \oplus B$	$A \oplus B \oplus C$
0	0	0	0	0
0	0	1	0	1
0	1	0	1	1
0	1	1	1	0
1	0	0	1	1
1	0	1	1	0
1	1	0	0	0
1	1	1	0	1

1-3

(a)  $A + AB = A(1 + B) = A$

(b)  $AB + AB' = A(B + B') = A$

(c)  $A'BC + AC = C(A'B + A) = C(A' + A)(B + A) = (A + B)C$

(d)  $A'B + ABC' + ABC = A'B + AB(C' + C) = A'B + AB = B(A' + A) = B$

1-4

(a)  $AB + A(CD + CD') = AB + AC(D + D') = A(B + C)$

(b)  $(BC' + A'D)(AB' + CD') =$   

$$= \underbrace{ABB'C'}_0 + \underbrace{A'AB'D}_0 + \underbrace{BCC'D'}_0 + \underbrace{A'CD'D}_0 = 0$$

1-5 (a)  $(A+B)'(A'+B')' = (A'B')(AB) = 0$

(b)  $A + A'B + A'B' = A + A'(B+B') = A + A' = 1$

1-6  $F = x'y + xy'z$

(a)  $F' = (x+y')(x'+y'+z) = x'y' + xy' + y'z + y'z$   
 $= y'(1+x'+x+z) + xz = y' + xz$

(b)  $F \cdot F' = (x'y + xy'z)(y' + xz) = 0 + 0 + 0 + 0 = 0$

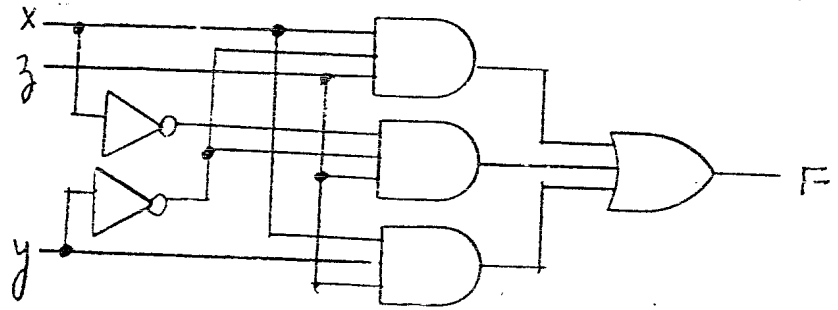
(c)  $F + F' = x'y + xy'z + y' + xz(y+y')$   
 $= x'y + xy(z'+z) + y'(1+xz) = x'y + xy + y'$   
 $= y(x'+x) + y' = y + y' = 1$

1-7

(a)

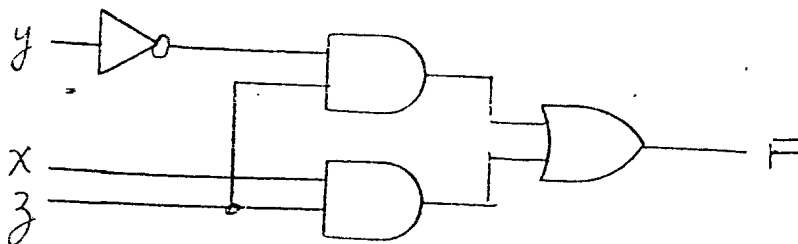
x	y	z	F
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1

(b)  $F = xy'z + x'y'z + xy'z$

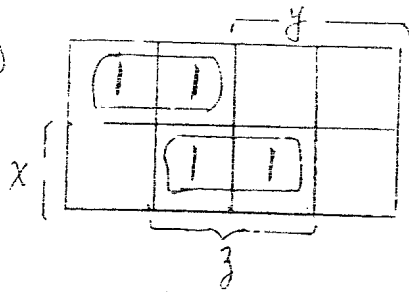


(c)  $F = xy'z + x'y'z + xy'z$   
 $= y'z(x+x') + xz(y+y')$   
 $= y'z + xz$

(d) Same as (a)

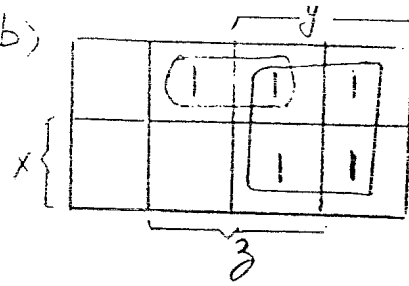


1-8  
(a)



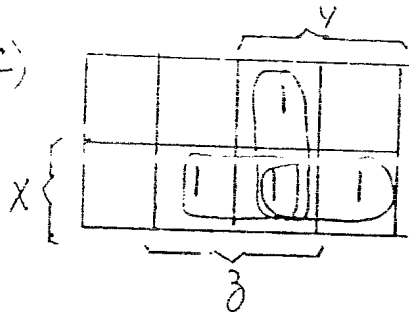
$$F = x'y' + xz$$

(b)



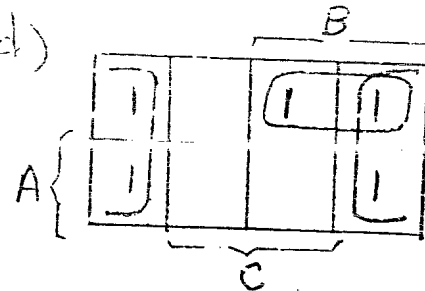
$$F = y + x'z$$

(c)



$$F = xy + xz + yz$$

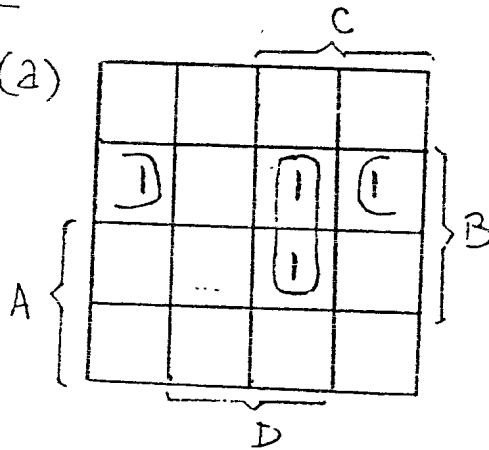
(d)



$$F = C' + A'B$$

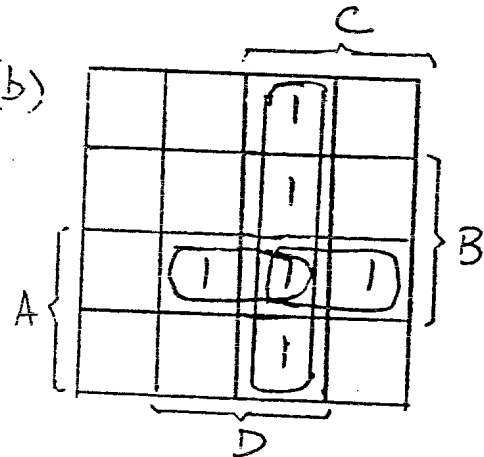
1-9

(a)



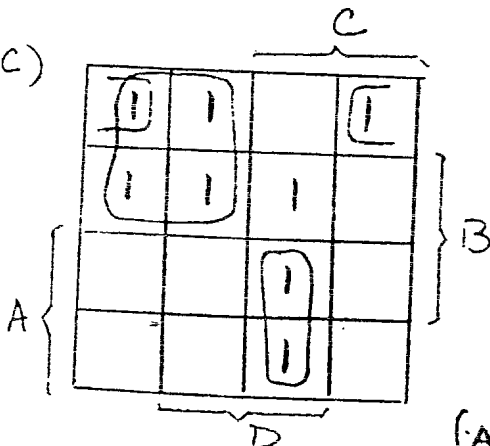
$$F = BCD + A'BD'$$

(b)



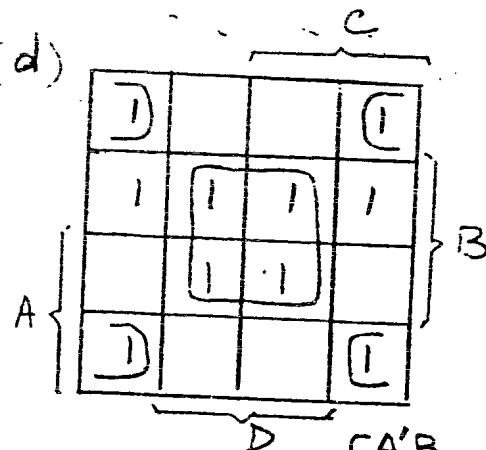
$$F = CD + ABC + ABD$$

(c)



$$F = A'C' + A'B'D' + ACD + \begin{cases} A'BD \\ \text{or} \\ BCD \end{cases}$$

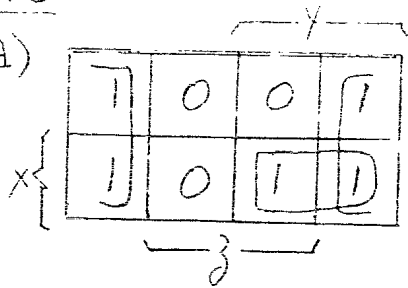
(d)



$$F = BD + B'D' + \begin{cases} A'B \\ \text{or} \\ A'D' \end{cases}$$

1-10

(a)

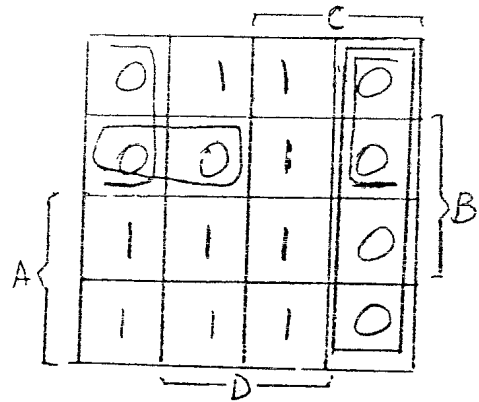


$$(1) F = xy + z'$$

$$F' = x'z + y'z$$

$$(2) F = (x + z')(y + z')$$

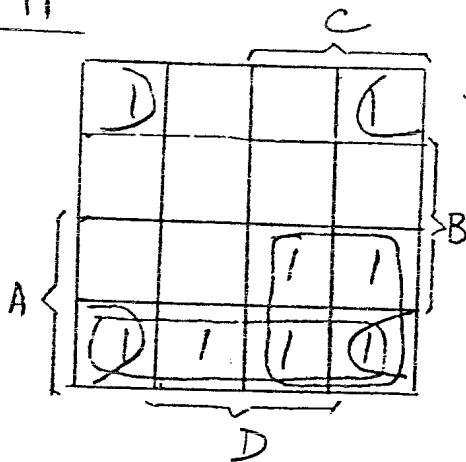
(b)



$$(1) F = AC' + CD + B'D$$

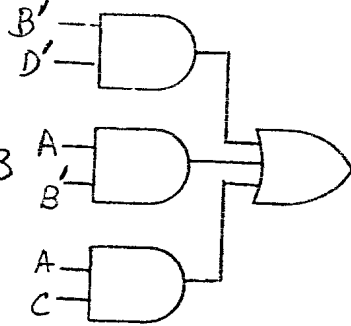
$$(2) F = (A + D)(C' + D)(A + B' + C)$$

1-11

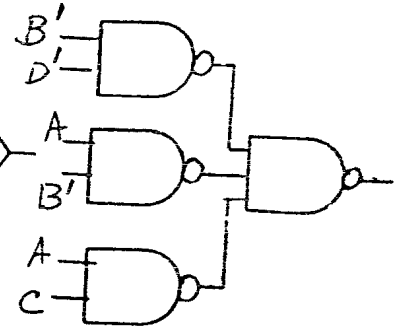


$$F = B'D' + AC$$

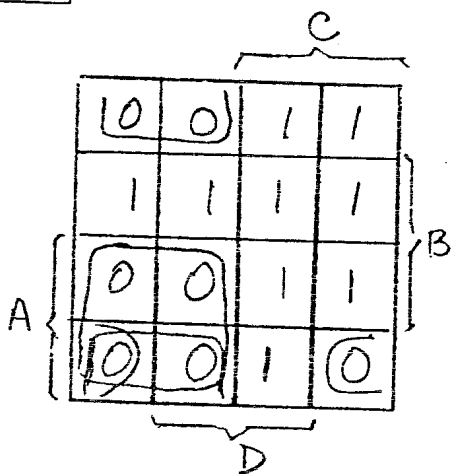
(a)



(b)

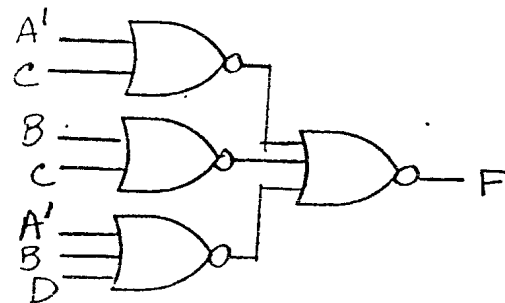
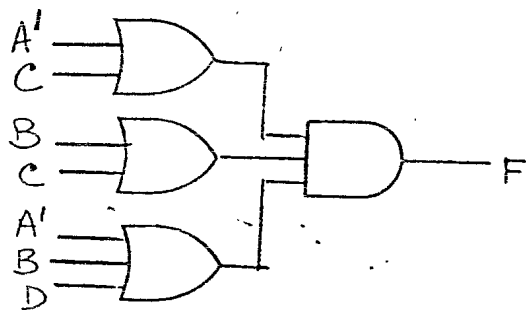


1-12

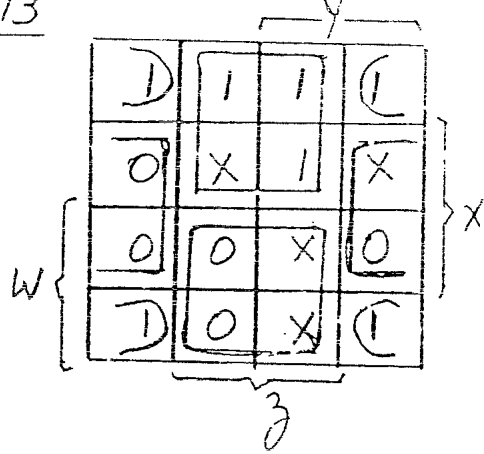


$$F' = AC' + B'C' + AB'D'$$

$$F = (A' + C)(B + C)(A' + B + D)$$



1-13



$$(a) F = x'z' + w'z$$

$$(b) = (x' + z)(w' + z')$$

1-14

$$S = x'y'z + x'y'z' + xy'z' + xy'z$$

$$= x'(y'z + y'z') + x(y'z' + y'z)$$

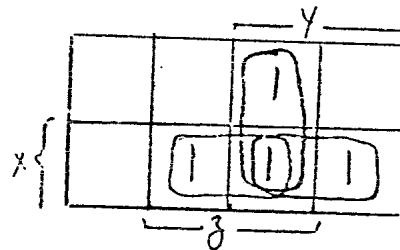
$$= x'(y \oplus z) + x(y \oplus z)'$$

See Fig 1-2  
(Exclusive-OR)

$$= x \oplus y \oplus z$$

1-15

x	y	z	F
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

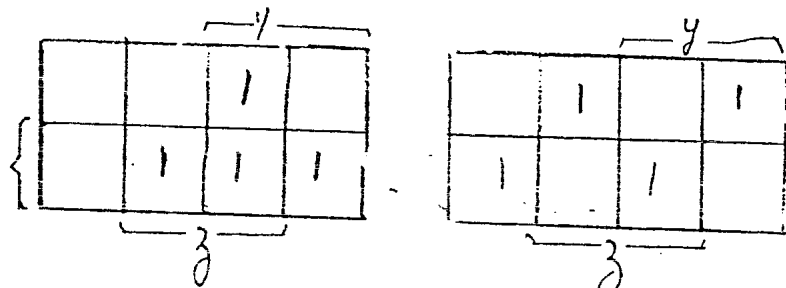


$$F = xy + xz + yz$$

1-16

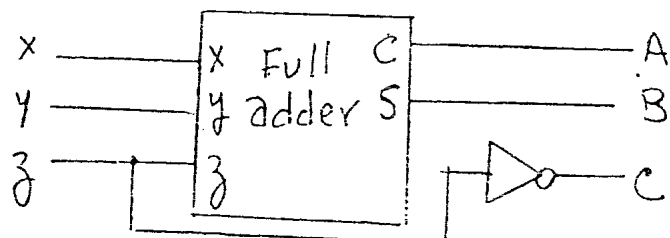
x	y	z	A	B	C
0	0	0	0	0	1
0	0	1	0	1	0
0	1	0	0	1	1
0	1	1	1	0	0
1	0	0	0	1	1
1	0	1	1	0	0
1	1	0	1	0	1
1	1	1	1	1	1

$C = z'$   
By inspection

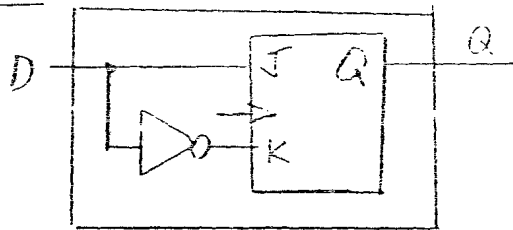


$$A = xy + xz + yz$$

$$B = x \oplus y \oplus z$$



1-17



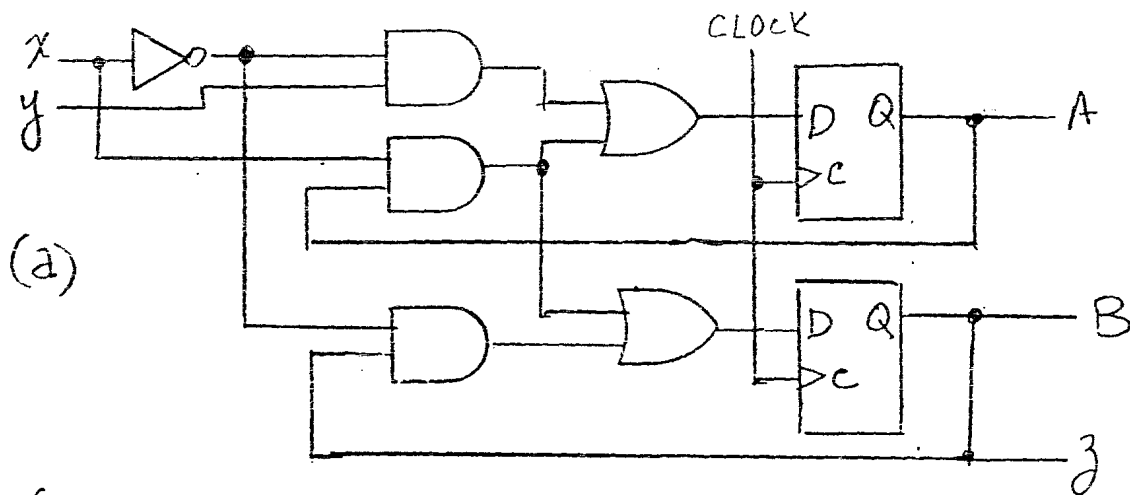
When  $D=0$ ;  $J=0, K=1, Q \rightarrow 0$

When  $D=1$ ;  $J=1, K=0, Q \rightarrow 1$

1-18

See text; Section 1-6 for derivation.

1-19  $D_A = x'y + xA$ ;  $D_B = x'B + xA$ ;  $z = B$



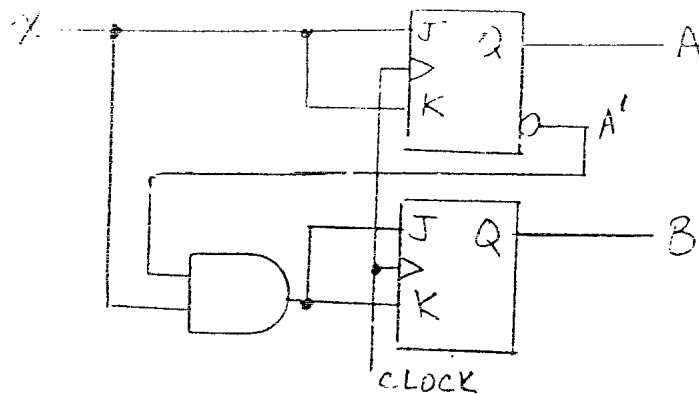
(b)

Present state	Inputs	Next state	Output
AB	x y	AB	z
00	00	00	0
00	01	10	0
00	10	00	0
00	11	00	0
01	00	01	1
01	01	11	1
01	10	00	1
01	11	00	1
10	00	00	0
10	01	10	0
10	10	11	0
10	11	11	0
11	00	01	1
11	01	11	1
11	10	11	1
11	11	11	1

1-20

$$J_A = K_A = X$$

$$J_B = K_B = A'X$$



1-21 Count up-down binary counter with enable E

Present state		Inputs		Next state		Flip-flop inputs			
A	B	E	X	A	B	$J_A$	$K_A$	$J_B$	$K_B$
0	0	0	0	0	0	0	X	0	X
0	0	0	1	0	0	0	X	0	X
0	0	1	0	1	1	1	X	1	X
0	0	1	1	0	1	0	X	1	X
0	1	0	0	0	1	0	X	X	0
0	1	0	1	0	1	0	X	X	0
0	1	1	0	0	0	0	X	X	1
0	1	1	1	1	0	1	X	X	1
1	0	0	0	1	0	X	0	0	X
1	0	0	1	1	0	X	0	0	X
1	0	1	0	0	1	X	1	1	X
1	0	1	1	1	1	X	0	1	X
1	1	0	0	1	1	X	0	X	0
1	1	0	1	1	1	X	0	X	0
1	1	1	0	1	0	X	0	X	1
1	1	1	1	0	0	X	1	X	1

			1
		1	
X	X	X	X
X	X	X	X

$$J_A = (Bx + B'x')E$$

			1
X	X	X	X
X	X	X	X
		1	

$$K_A = (Bx + B'x')E$$

		1	1
X	X	X	X
X	X	X	X
		1	1

$$J_B = E$$

X	X	X	X
		1	1
		1	1
X	X	X	X

$$K_B = E$$

## CHAPTER 2

2-1

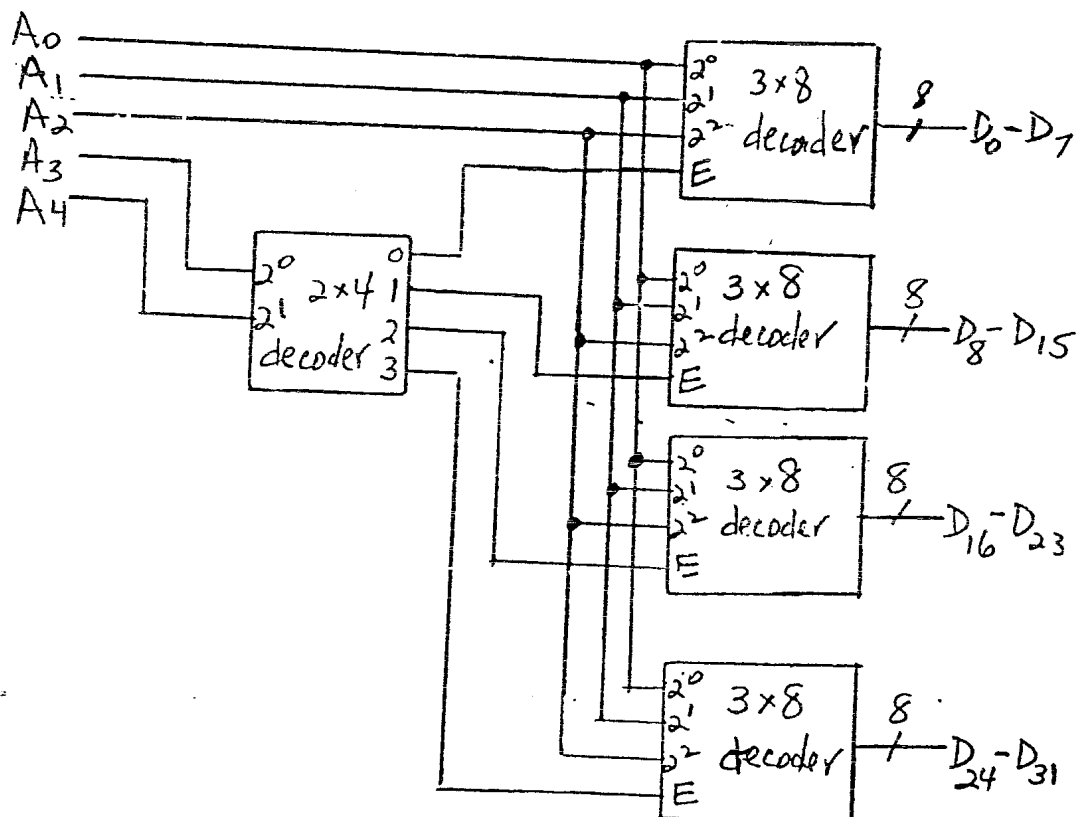
TTL IC

- |                                |                  |       |
|--------------------------------|------------------|-------|
| (a) Inverters - 2 pins each    | $12/2 = 6$ gates | 7404  |
| (b) 2-input XOR - 3 pins each  | $12/3 = 4$ gates | 7486  |
| (c) 3-input OR - 4 pins each   | $12/4 = 3$ gates |       |
| (d) 4-input AND - 5 pins each  | $12/5 = 2$ gates | 7421  |
| (e) 5-input NOR - 6 pins each  | $12/6 = 2$ gates | 74260 |
| (f) 8-input NAND - 9 pins      | 1 gate           | 7430  |
| (g) JK flip-flop - 6 pins each | $12/6 = 2$ FFs   | 74107 |

2-2

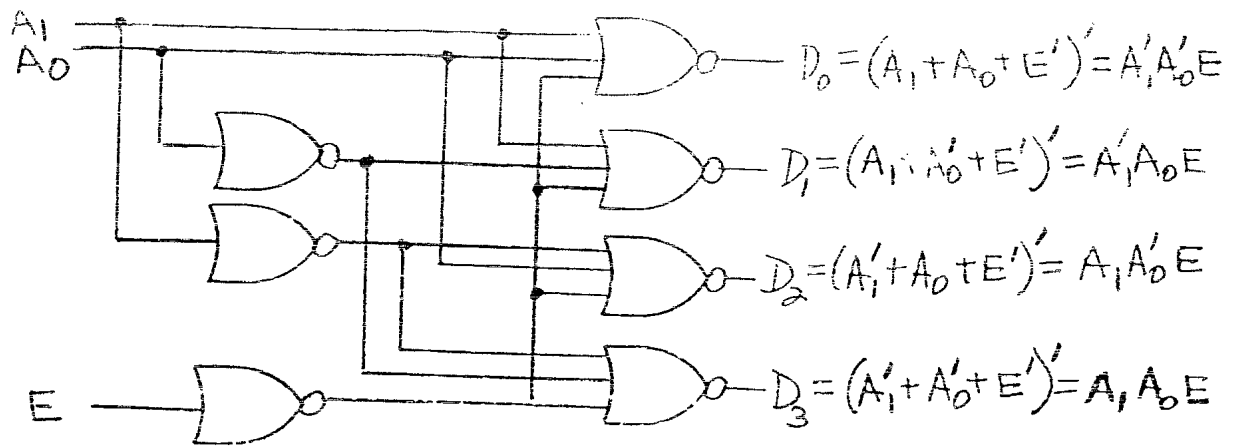
- (a) 74155 - Similar to two decoders as in Fig 2-2.  
 (b) 74157 - Similar to multiplexers of Fig. 2-5.  
 (c) 74194 - Similar to register of Fig. 2-9.  
 (d) 74163 - Similar to counter of Fig. 2-11.

2-3



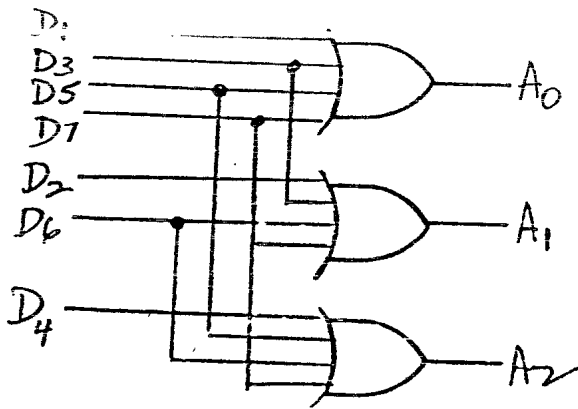


2-4



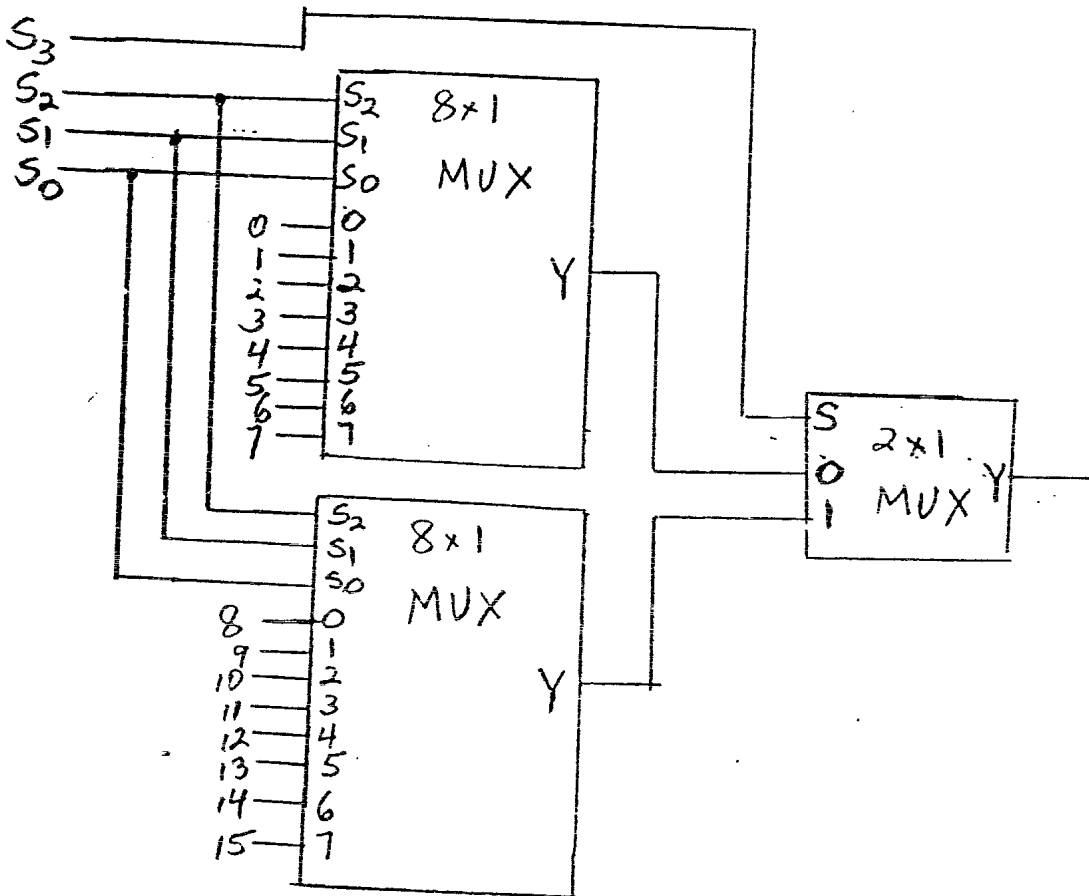
2-5 Remove the inverter from the E input in Fig. 2-2(a).

2-6

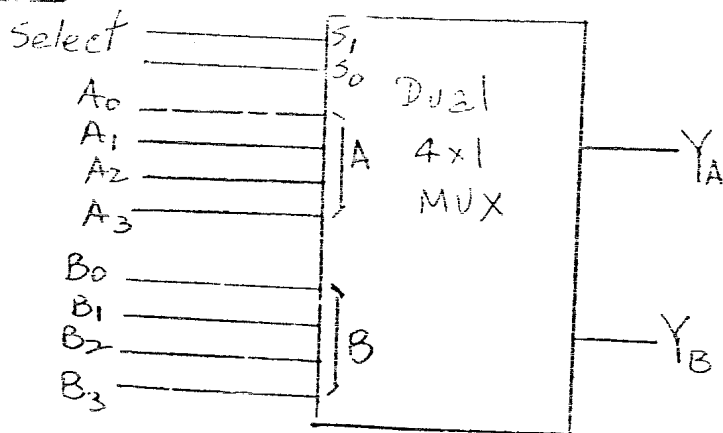


If all inputs equal 0  
 or if only  $D_0 = 1$ :  
 the outputs  $A_2A_1A_0 = 000$   
 Needs one more output  
 to recognize the all  
 zeros input condition.

2-7



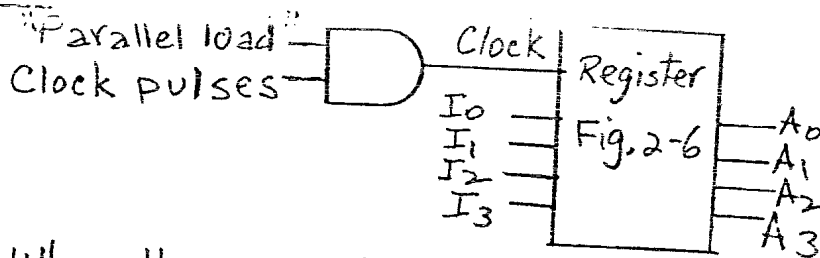
2-8



$S_1 S_0$	$Y_A Y_B$
0 0	$A_0 B_0$
0 1	$A_1 B_1$
1 0	$A_2 B_2$
1 1	$A_3 B_3$

Function table

2-9

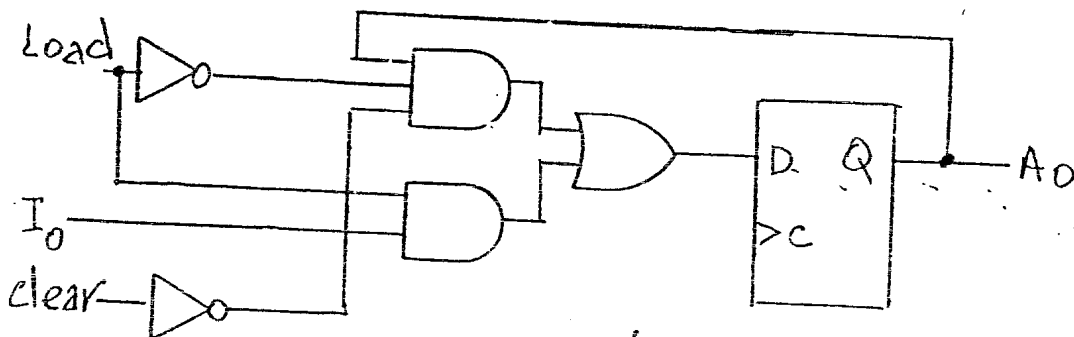


When the parallel load input = 1, the clock pulses go through the AND gate and the data inputs are loaded into the register. When the parallel load input = 0, the output of the AND gate remains at 0.

2-10

The buffer gate does not perform logic. It is used for signal amplification of the clock input.

2-11



One stage of Register Fig. 2-7

Load	clear	D	Operation
0	0	X	No change
0	1	0	clear to 0
1	X	$I_0$	load $I_0$

Function table

2-12

Input bits

4-bit register

1	→	1101	← Initial value
0	→	1110	
1	→	0111	
1	→	1011	
0	→	1101	
1	→	0110	
	→	1011	

2-13

Serial transfer: One bit at a time by shifting.

Parallel transfer: All bits at the same time.

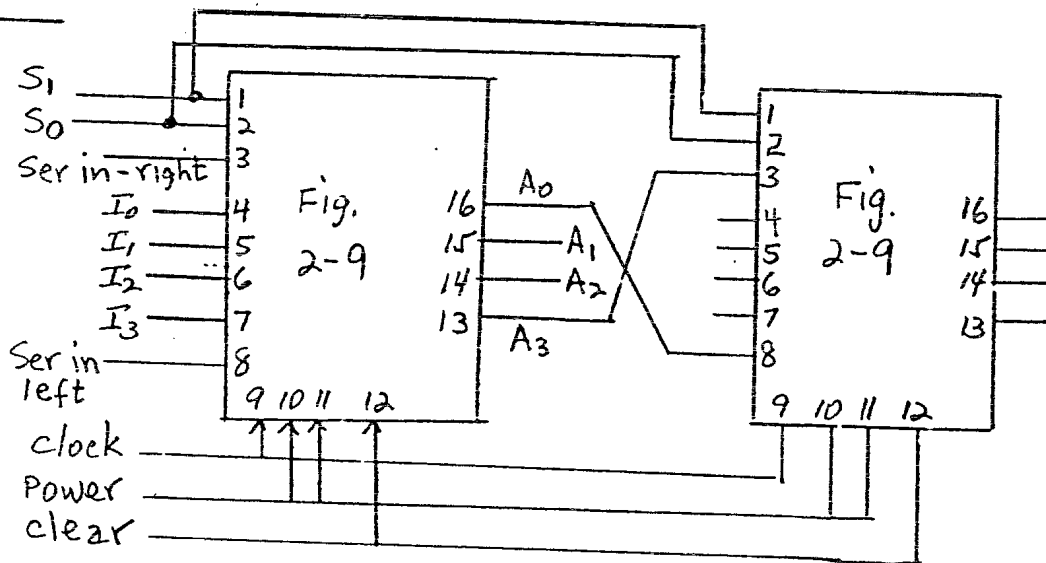
Input serial data by shifting - output data in parallel.

Input data with parallel load - Output data by shifting.

2-14

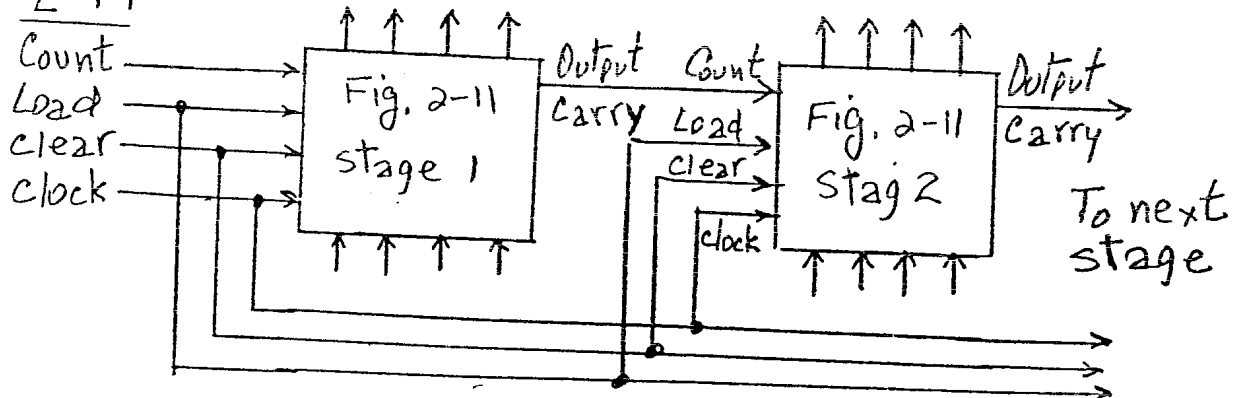
→ 1000 → 0100 → 0010 → 0001 →

2-15



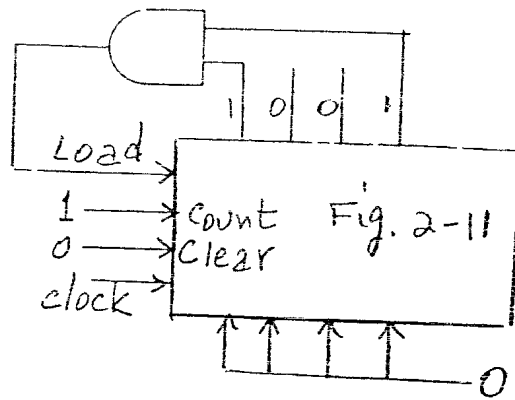
2-16 (a) 4 ; (b) 9

2-17



2-18

After the count reaches  $N-1=1001$ , the register loads 0000 from inputs.



2-19

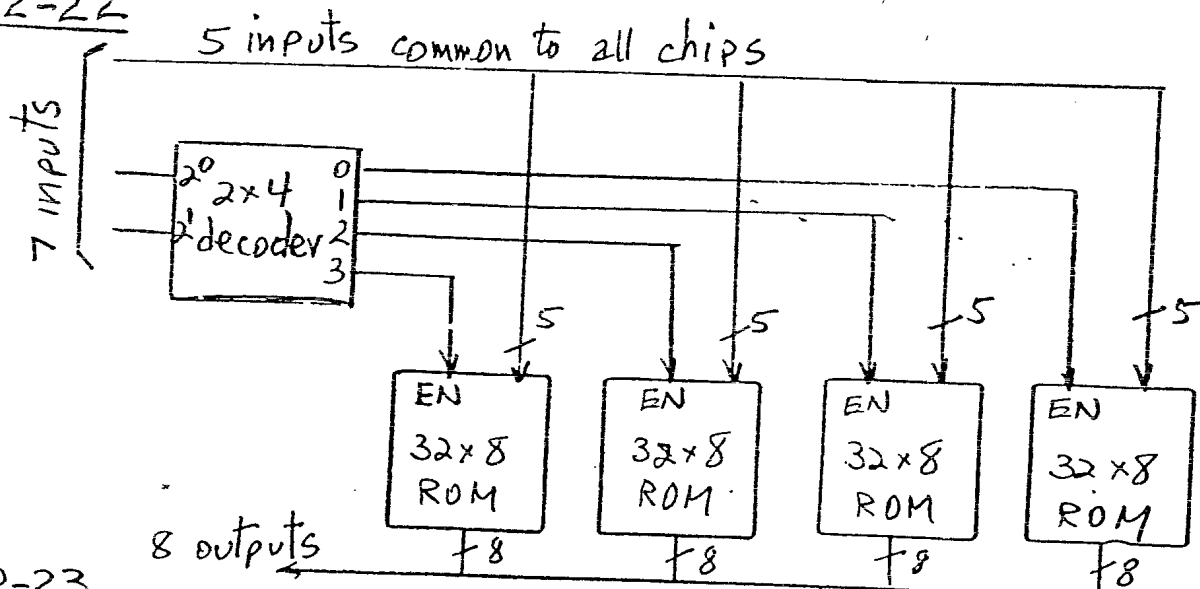
	Address lines	Data lines
(a) $2K \times 16 = 2^{11} \times 16$	11	16
(b) $64K \times 8 = 2^{16} \times 8$	16	8
(c) $16M \times 32 = 2^{24} \times 32$	24	32
(d) $4G \times 64 = 2^{32} \times 64$	32	64

2-20

- (a)  $2K \times 2 = 4K = 4096$  bytes  
 (b)  $64K \times 1 = 64K = 2^{16}$  bytes  
 (c)  $2^{24} \times 4 = 2^{26}$  bytes  
 (d)  $2^{32} \times 8 = 2^{35}$  bytes

2-21 
$$\frac{4096 \times 16}{128 \times 8} = \frac{2^{12} \times 2^4}{2^7 \times 2^3} = 2^6 = 64 \text{ chips}$$

2-22



2-23

$$12 \text{ data inputs} + 2 \text{ enable inputs} + 8 \text{ data outputs} + 2 \text{ for power} = 24 \text{ pins}$$

### CHAPTER 3

3-1

$$(101110)_2 = 32 + 8 + 4 + 2 = 46$$

$$(1110101)_2 = 64 + 32 + 16 + 4 + 1 = 117$$

$$(110110100)_2 = 256 + 128 + 32 + 16 + 4 = 436$$

3-2

$$(12121)_3 = 3^4 + 2 \times 3^3 + 3^2 + 2 \times 3 + 1 = 81 + 54 + 9 + 6 + 1 = 151$$

$$(4310)_5 = 4 \times 5^3 + 3 \times 5^2 + 5 = 500 + 75 + 5 = 580$$

$$(50)_7 = 5 \times 7 = 35$$

$$(198)_{12} = 12^2 + 9 \times 12 + 8 = 144 + 108 + 8 = 260$$

3-3

$$(1231)_{10} = 1024 + 128 + 64 + 15 = 2^{10} + 2^7 + 2^6 + 2^3 + 2^2 + 2 + 1 = (10011001111)_2$$

$$(673)_{10} = 512 + 128 + 32 + 1 = 2^9 + 2^7 + 2^5 + 1 = (1010100001)_2$$

$$(1998)_{10} = 1024 + 512 + 256 + 128 + 64 + 8 + 4 + 2 \\ = 2^{10} + 2^9 + 2^8 + 2^7 + 2^6 + 2^3 + 2^2 + 2^1 = (11111001110)_2$$

3-4

$$(7562)_{10} = (16612)_8$$

$$(1938)_{10} = (792)_{16}$$

$$(175)_{10} = (10101111)_2$$

3-5

$$(F3A7C2)_{16} = (1111\ 0011\ 1010\ 0111\ 1100\ 0010)_2$$

$$= (74723702)_8$$

3-6

$$(x^2 - 10x + 31)_r = [(x-5)(x-8)]_{10}$$

$$= x^2 - (5+8)_{10}x + (40)_{10}$$

$$\text{Therefore : } (10)_r = (13)_{10} \quad \underline{\underline{r=13}}$$

$$\text{Also } (31)_{\underset{(r=13)}{r}} = 3 \times 13 + 1 = (40)_{10}$$

3-7  $(215)_{10} = 128 + 64 + 16 + 7 = (11010111)_2$

(a) 0000 1101 0111 Binary

(b) 000 011 010 111 Binary coded octal  
           0      3      2      7

(c) 0000 1101 0111 Binary coded hexadecimal  
           0      D      7

(d) 0010 0001 0101 Binary coded decimal  
           2      1      5

3-8  $(295)_{10} = 256 + 32 + 7 = (100100111)_2$

(a) 0000 0000 0000 0001 0010 0111

(b) 0000 0000 0000 0010 1001 0101

(c) 10110010 00111001 00110101

3-10 JOHN DOE

3-11 87650123; 99019899; 09990048; 999999.

3-12 876100; 909343; 900000; 000000

3-13 01010001; 01111110; 01111111; 11111110; 11111111  
 01010010; 01111111; 10000000; 11111111; 00000000

3-14

(a) 5250 + 8679 1) 3929	(b) 1753 + 1360 0) 3113 ↓ 10's complement - 6887	(c) 020 + 900 0) 920 ↓ - 080	(d) 1200 + 9750 1) 0950
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3-15

(a) 11010 + 10000 1) 01010 (26-16=10)	(b) 11010 10011 1) 01101 (26-13=13)	(c) 000100 010000 0) 010100 ↓ - 101100 (4-48=-44)	(d) 1010100 0101100 1) 00000000 (84-84=0)
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3-16

$$+42 = 0101010$$

$$-42 = 1010110$$

$$(+42) \ 0101010$$

$$(-13) \ 1110011$$

$$(29) \ 0011101$$

$$+13 = 0001101$$

$$-13 = 1110011$$

$$(-42) \ 1010110$$

$$(+13) \ 0001101$$

$$(-29) \ 1100011$$

3-17  $01 \leftarrow$  last two carries  $\rightarrow 10$

$$+70 \ 01000110$$

$$+80 \ 01010000$$

$$+150 \ 10010110$$

greater than +127  
negative

$$-70 \ 10111010$$

$$-80 \ 10110000$$

$$-150 \ 01101010$$

less than -128  
positive

3-18

$$(a) \ (-638) \ 9362$$

$$(+785) \ +0785$$

$$(+147) \ 0147$$

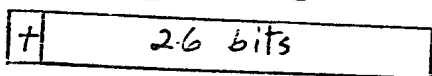
$$(b) \ (-638) \ 9362$$

$$(-185) \ +9815$$

$$(-823) \ 9177$$

3-19

Mantissa



Largest:  $+0.1111\dots1$   
 $1 - 2^{-26}$

Smallest:  $+0.1000\dots0$   
(normalized)  $2^{-1}$

Exponent



$$+11111111$$

$$+255 \quad (1 - 2^{-26}) \times 2^{+255}$$

$$-11111111$$

$$-255 \quad 2^{-256}$$

3-20

$$46.5 = 32 + 8 + 4 + 2 + 0.5 = (101110.1)_2$$

Sign

$$0 \ 1011101000000000$$

24-bit mantissa

$$00000110$$

8-bit exponent (+6)

3-21 (a)

Decimal	Gray code
16	1 1000
17	1 1001
18	1 1011
19	1 1010
20	1 1110
21	1 1111
22	1 1101
23	1 1100
24	1 0100
25	1 0101
26	1 0111
27	1 0110
28	1 0010
29	1 0011
30	1 0001
31	1 0000

(b)

Decimal	Excess-3 Gray
9	0010 1010
10	0110 1010
11	0110 1110
12	0110 1111
13	0110 1101
14	0110 1100
15	0110 0100
16	0110 0101
17	0110 0111
18	0110 0110
19	0110 0010
20	0111 0010

3-22 8620

(a) BCD 1000 0110 0010 0000

(b) XS-3 1011 1001 0101 0011

(c) 2421 1110 1100 0010 0000

(d) Binary 10000110101100 (8192+256+128+32+8+4)

3-23

Decimal	BCD with even parity	BCD with odd parity
0	0 0000	1 0000
1	1 0001	0 0001
2	1 0010	0 0010
3	0 0011	1 0011
4	1 0100	0 0100
5	0 0101	1 0101
6	0 0110	1 0110
7	1 0111	0 0111
8	1 1000	0 1000
9	0 1001	1 1001



3-24

$$3984 = 0011 \ 1111 \ 1110 \ 0100 \\ 1100 \ 0000 \ 0001 \ 1011 = 6015$$

3-25

A	B	$y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

C	D	$z = C \oplus D$
0	0	0
0	1	1
1	0	1
1	1	0

y	z	$x = y \oplus z$
0	0	0
0	1	1
1	0	1
1	1	0

ABCD

0001, 0010, 1101, 1110

0100, 0111, 1000, 1011

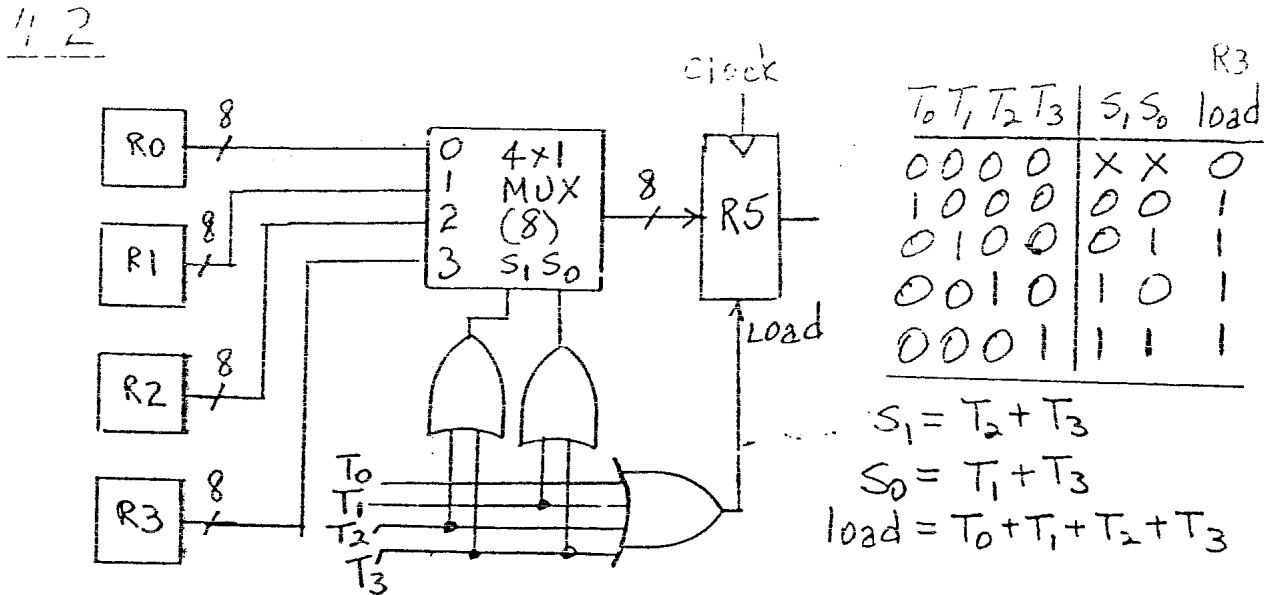
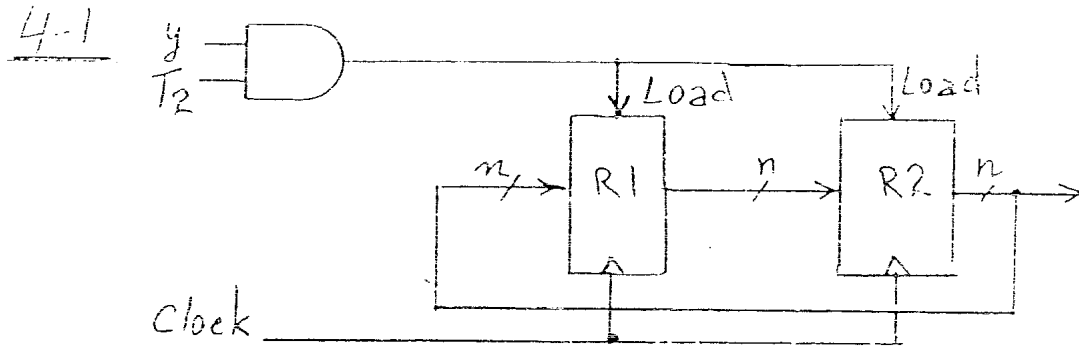
Always odd number of 1's

3-26

Same as in Fig. 3-3 but without the complemented circles in the outputs of the gates.

$$P = x \oplus y \oplus z \\ \text{Error} = x \oplus y \oplus z \oplus P$$

# CHAPTER 4



4-3

P:  $R1 \leftarrow R2$   
 P'Q:  $R1 \leftarrow R3$

4-4

Connect the 4-line common bus to the four inputs of each register.

Provide a "load" control input in each register.

Provide a clock input for each register.

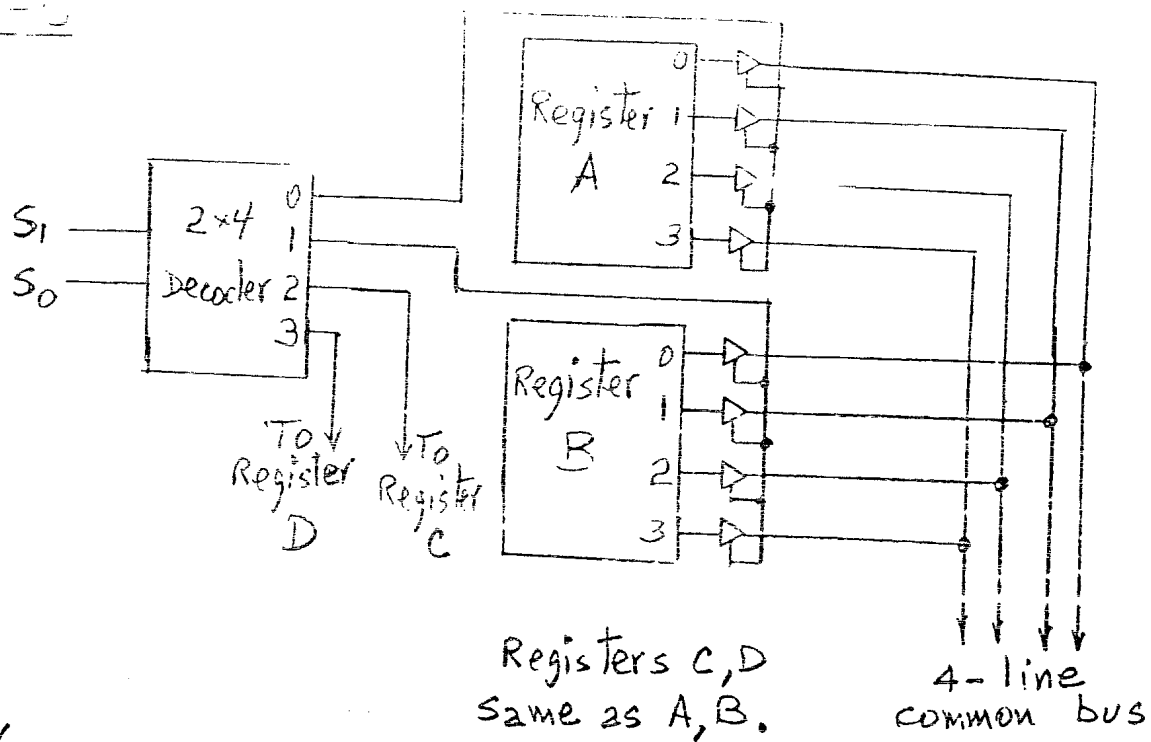
To transfer from register C to register A:

Apply  $S_1, S_0 = 10$  (to select C for the bus.)

Enable the load input of A

Apply a clock pulse.

4-5



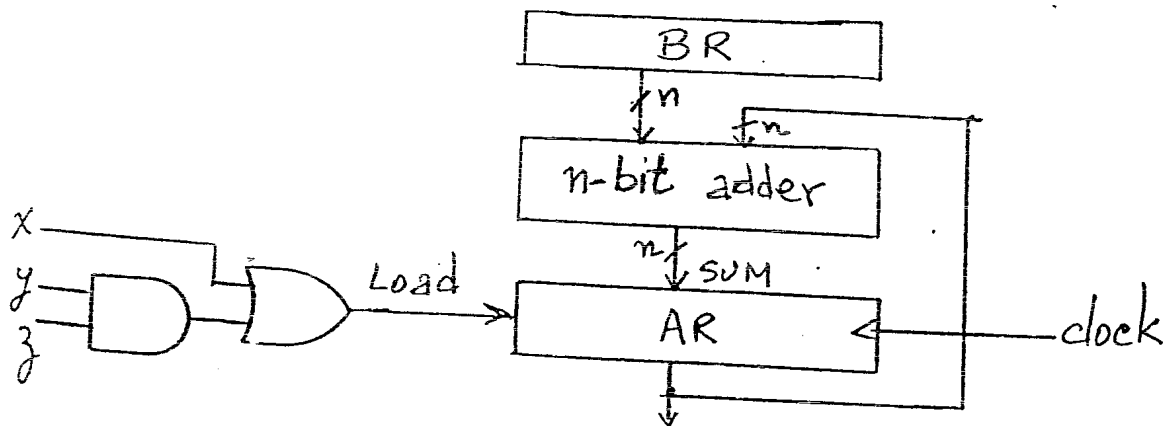
4-6

- (a) 4 selection lines to select one of 16 registers.
- (b)  $16 \times 1$  multiplexers
- (c) 32 multiplexers, one for each bit of the registers.

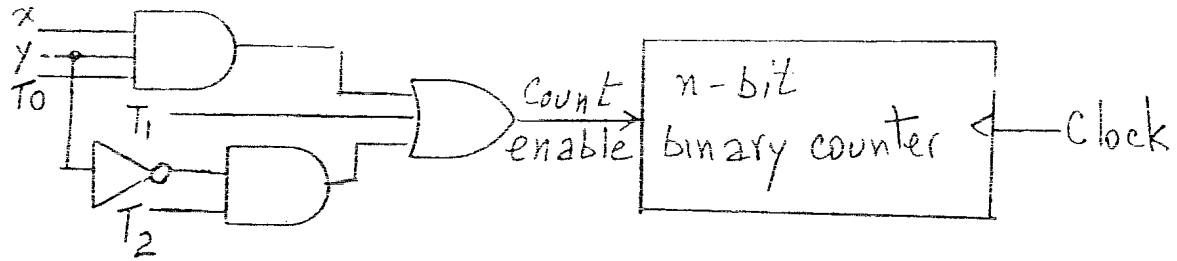
4-7

- (a) Read memory word specified by the address in AR into register R2.
- (b) Write content of register R3 into the memory word specified by the address in AR.
- (c) Read memory word specified by the address in R5 and transfer content to R5 (destroys previous value)

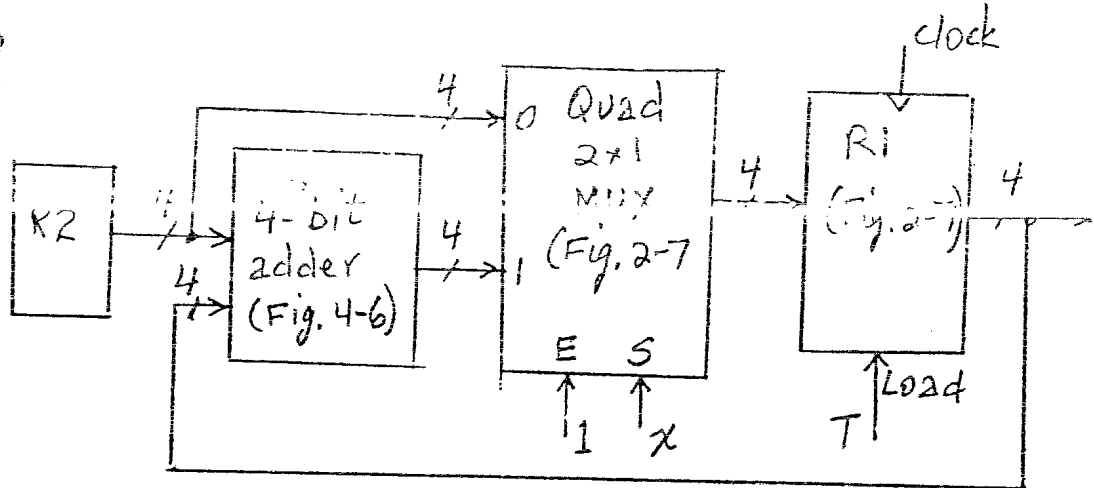
4-8



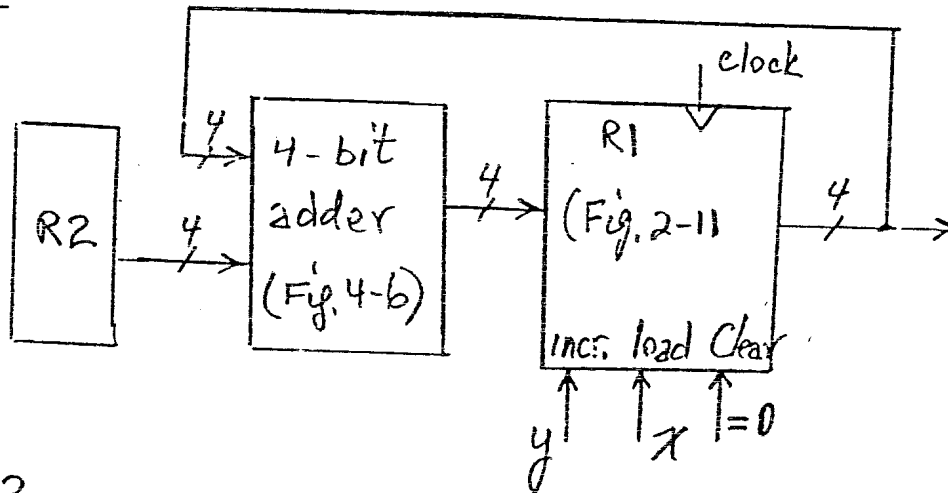
4-9



4-10



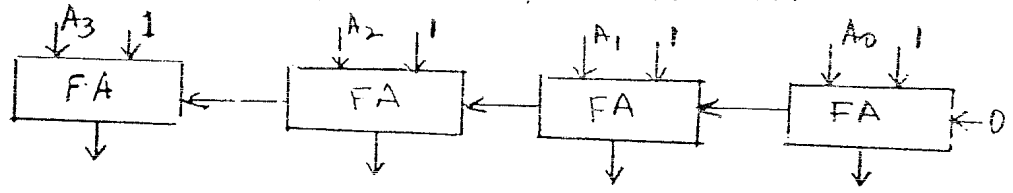
4-11



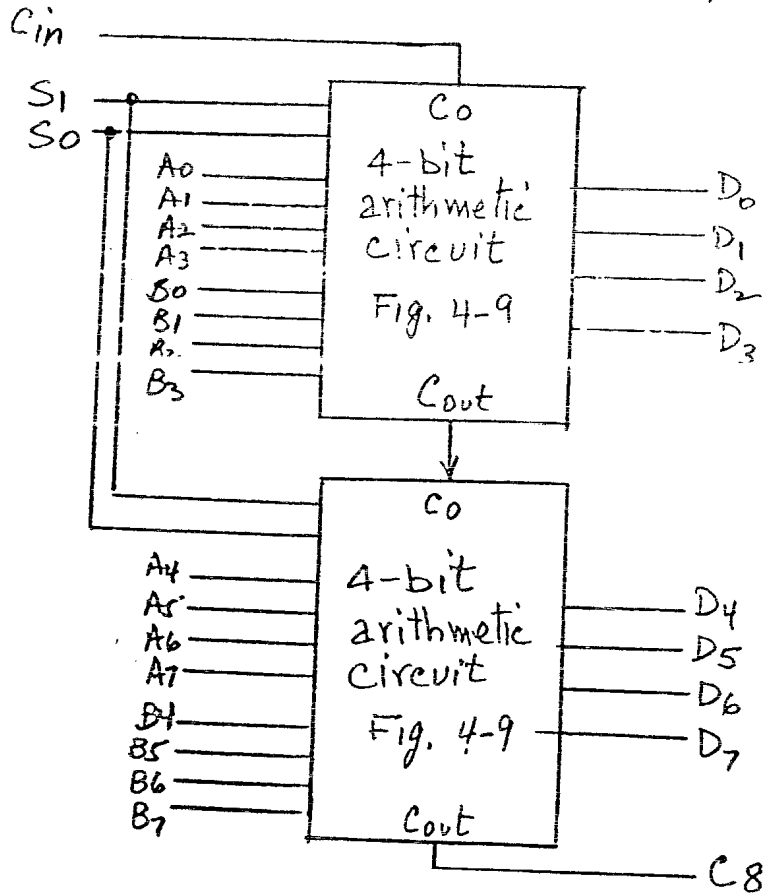
4-12

M	A	B	Sum	C <sub>4</sub>	
0	0111 + 0110		1101	0	7+6=13
0	1000 + 1001		0001	1	8+9=16+1
1	1100 - 1000		0100	1	12-8=4
1	0101 - 1010		1011	0	5-10=-5 (in 2's comp.)
1	0000 - 0001		1111	0	0-1=-1 (in 2's comp.)

4-13  $A-1 = A+2$ 's complement of 1 =  $A+1111$

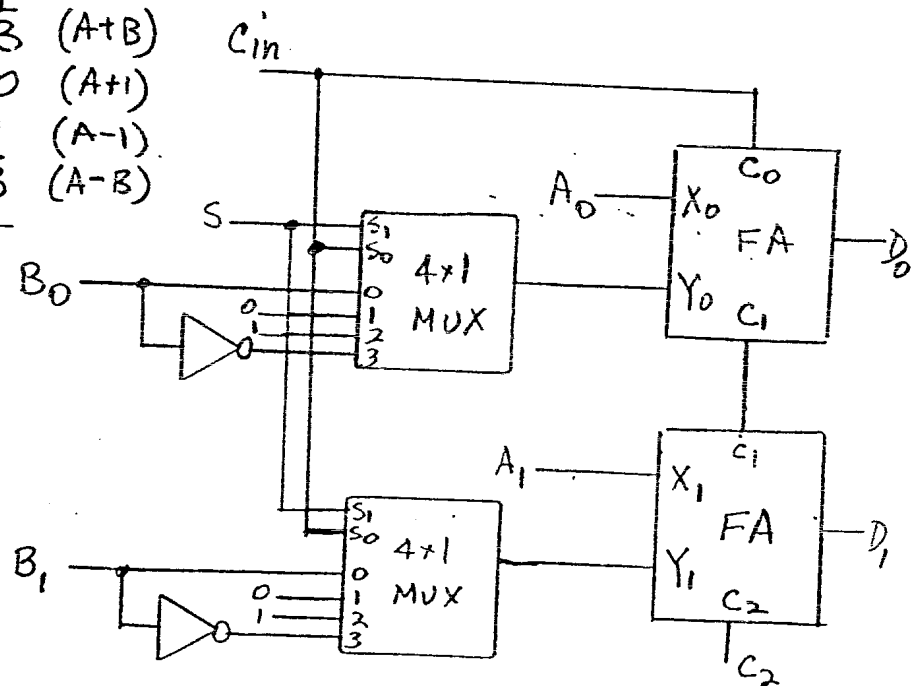


4-14

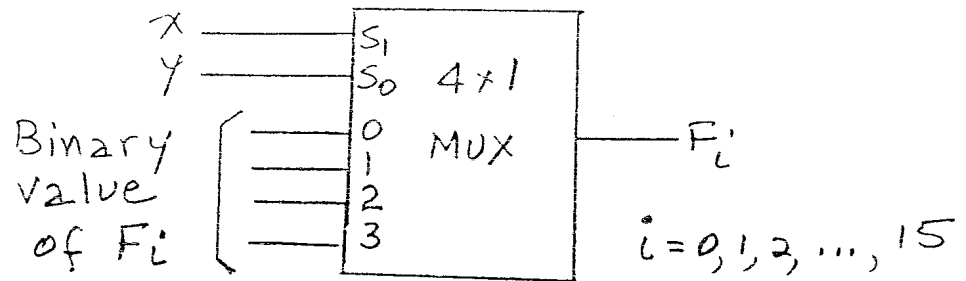


4-15

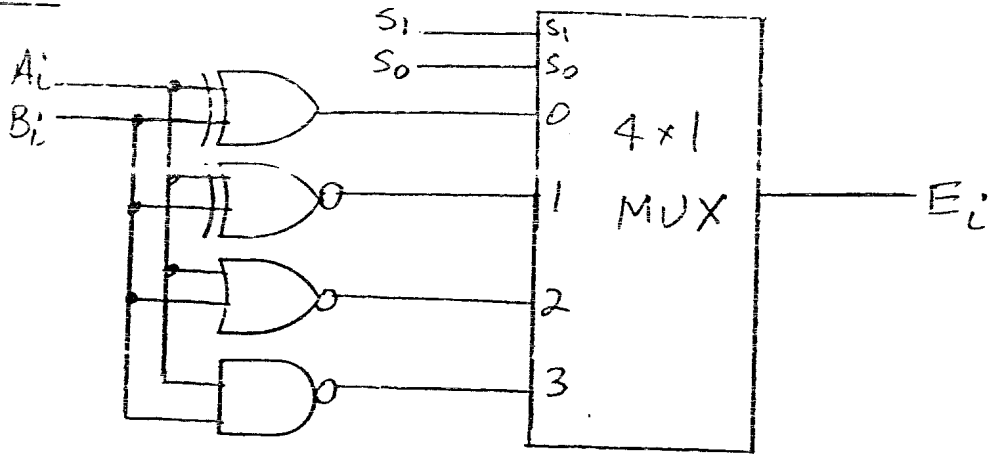
S	Cin	X	Y	
0	0	A	B	(A+B)
0	1	A	0	(A+1)
1	0	A	1	(A-1)
1	1	A	$\bar{B}$	(A-B)



4-16



4-17



4-18

$$\begin{aligned} (a) \quad & A = 11011001 \\ & B = 10110100 \oplus \\ \hline & A \leftarrow A \oplus B \quad 01101101 \end{aligned}$$

$$\begin{aligned} & A = 11011001 \\ & B = 11111101 \text{ (OR)} \\ \hline & 11111101 \quad A \leftarrow A \vee B \end{aligned}$$

4-19

$$\begin{aligned} (a) \quad & AR = 11110010 \\ & BR = 11111111 \text{ (+)} \\ \hline \end{aligned}$$

$$AR = 11110001 \quad BR = 11111111 \quad CR = 10111001 \quad DR = 11101010$$

$$\begin{aligned} (b) \quad & CR = 10111001 \\ & DR = 11101010 \text{ (AND)} \\ & BR = 11111111 \\ & \quad \quad \quad + 1 \end{aligned}$$

$$CR = 10101000 \quad BR = 00000000 \quad AR = 11110001 \quad DR = 11101010$$

$$\begin{aligned} (c) \quad & AR = 11110001 \\ & CR = 10101000 \text{ (-)} \end{aligned}$$

$$AR = 01001001; \quad BR = 00000000; \quad CR = 10101000; \quad DR = 11101010$$

4-20

$R = 10011100$

Arithmetic shift right:  $11001110$

Arithmetic shift left:  $00111000$  overflow because a negative number changed to positive

4-21

logical shift left:  $R = 11011101$   
 $10111010$  ←

Circular shift right:  $01011101$

logical shift right:  $00101110$

Circular shift left:  $01011100$

4-22

$S=1$  Shift left

$A_0 A_1 A_2 A_3 I_L$   
 $H = \begin{matrix} & 1 & 0 & 0 & 1 & 0 \\ & \swarrow & \swarrow & \swarrow & \swarrow & \\ 0 & 0 & 1 & 0 & 0 \end{matrix}$  shift left

4-23

- (a) Cannot complement and increment the same register at the same time.
- (b) Cannot transfer two different values ( $R_2$  and  $R_3$ ) to the same register ( $R_1$ ) at the same time.
- (c) Cannot transfer a new value into a register (PC) and increment the original value by one at the same time.

## CHAPTER 5

5-1

$$256K = 2^8 \times 2^{10} = 2^{18}$$

$$64 = 2^6$$

(a) Address: 18 bits  
 Register code: 6 bits  
 Indirect bit: 1 bit  
25

32 - 25 = 7 bits for opcode.

(b) 

1	7	6	18
I	opcode	Register	Address

 = 32 bits

(c) Data: 32 bits; address: 18 bits.

5-2

A direct address instruction needs two references to memory: (1) Read instruction; (2) Read operand.

An indirect address instruction needs three references to memory: (1) Read instruction; (2) Read effective address; (3) Read operand.

5-3

(a) Memory read to bus and load to IR:  $IR \leftarrow M[AR]$

(b) TR to bus and load to PC:  $PC \leftarrow TR$

(c) AC to bus, write to memory, and load to DR:

$$DR \leftarrow AC, \quad M[AR] \leftarrow AC$$

(d) Add DR (or INPR) to AC:  $AC \leftarrow AC + DR$

5-4

	(1) <u>S<sub>2</sub> S<sub>1</sub> S<sub>0</sub></u>	(2) <u>Load (LD)</u>	(3) <u>Memory</u>	(4) <u>Adder</u>
(a) $AR \leftarrow PC$	010 (PC)	AR	—	—
(b) $IR \leftarrow M[AR]$	111 (M)	IR	Read	—
(c) $M[AR] \leftarrow TR$	110 (TR)	—	Write	—
(d) $DR \leftarrow AC$ $AC \leftarrow DR$	100 (AC)	DR and AC	—	Transfer DR to AC



5-5

(a)  $IR \leftarrow M[PC]$  PC cannot provide address to memory.  
Address must be transferred to AR first

$AR \leftarrow PC$   
 $IR \leftarrow M[AR]$

(b)  $AC \leftarrow AC + TR$  Add operation must be done with  
DR. Transfer TR to DR first.

$DR \leftarrow TR$   
 $AC \leftarrow AC + DR$

(c)  $DR \leftarrow DR : AC$  Result of addition is transferred to  
AC (not DR). To save value of AC,  
its content must be stored temporary  
in DR (or TR).

$AC \leftarrow DR, DR \leftarrow AC$  (See answer to Problem 5-4(d))  
 $AC \leftarrow AC + DR$   
 $AC \leftarrow DR, DR \leftarrow AC$

5-6

(2)  $\begin{array}{r} 0001 \ 0000 \ 0010 \ 0100 \\ \hline \end{array} = (1024)_{16}$   
ADD ...  $(024)_{16}$

ADD content of  $M[024]$  to AC      ADD 024

(b)  $\begin{array}{r} 1011 \ 0001 \ 0010 \ 0100 \\ \hline \end{array} = (B124)_{16}$   
I STA       $(124)_{16}$

store AC in  $M[M[124]]$       STA I 124

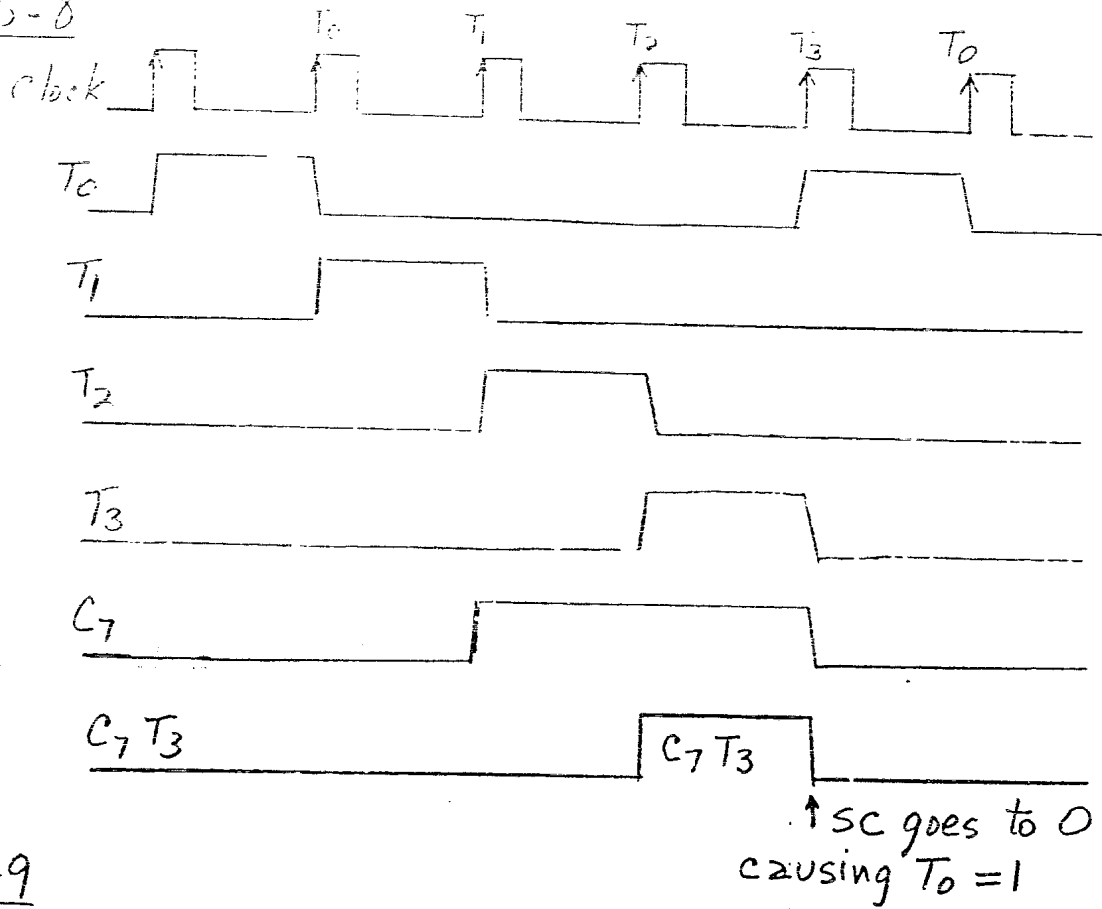
(c)  $\begin{array}{r} 0111 \ 0000 \ 0010 \ 0000 \\ \hline \end{array} = (7020)_{16}$   
Register      Increment AC      INC

5-7

CLE      clear E

CME      Complement E

5-8



5-9

	E	Ac	Pc	AR	IR
Initial!	1	A937	021	-	-
CLA	1	0000	022	800	7800
CLE	0	A937	022	400	7400
CMA	1	5608	022	200	7200
CME	0	A937	022	100	7100
CIR	1	D49B	022	080	7080
CIL	1	526F	022	040	7040
INC	1	A938	022	020	7020
SFA	1	A937	022	010	7010
SNA	1	A937	023	008	7008
SZA	1	A937	022	004	7004
SZE	1	A937	022	002	7002
HLT	1	A937	022	001	7001

5-10

	PC	AR	DR	AC	IR
Initial	021	—	—	A937	—
AND	022	083	B8F2	A832	0083
ADD	022	083	B8F2	6229	1083
LDA	022	083	B8F2	B8F2	2083
STA	022	083	—	A937	3083
BUN	083	083	—	A937	4083
BSA	084	084	—	A937	5083
ISZ	022	083	B8F3	A937	6083

5-11

	PC	AR	DR	IR	SC
Initial	7FF	—	—	—	0
T <sub>0</sub>	7FF	7FF	—	—	1
T <sub>1</sub>	800	7FF	—	EA9F	2
T <sub>2</sub>	800	A9F	—	EA9F	3
T <sub>3</sub>	800	C35	—	EA9F	4
T <sub>4</sub>	800	C35	FFFF	EA9F	5
T <sub>5</sub>	800	C35	0000	EA9F	6
T <sub>6</sub>	801	C35	0000	EA9F	0

5-12

(a)  $9 = (1001)_2$

$I=1$   $\overline{1001}$  ADD ADD I 32E

(b)

AC = 7EC3 (ADD)

DR = 8B9F  
0A62

$\textcircled{E=1}$

(c) PC = 3AF + 1 = 3B0

AR = 9AC

DR = 8B9F

AC = 0A62

IR = 932E

E = 1

I = 1

SC = 0000

Memory	
3AF	932E
32E	09AC
9AC	8B9F

AC = 7EC3

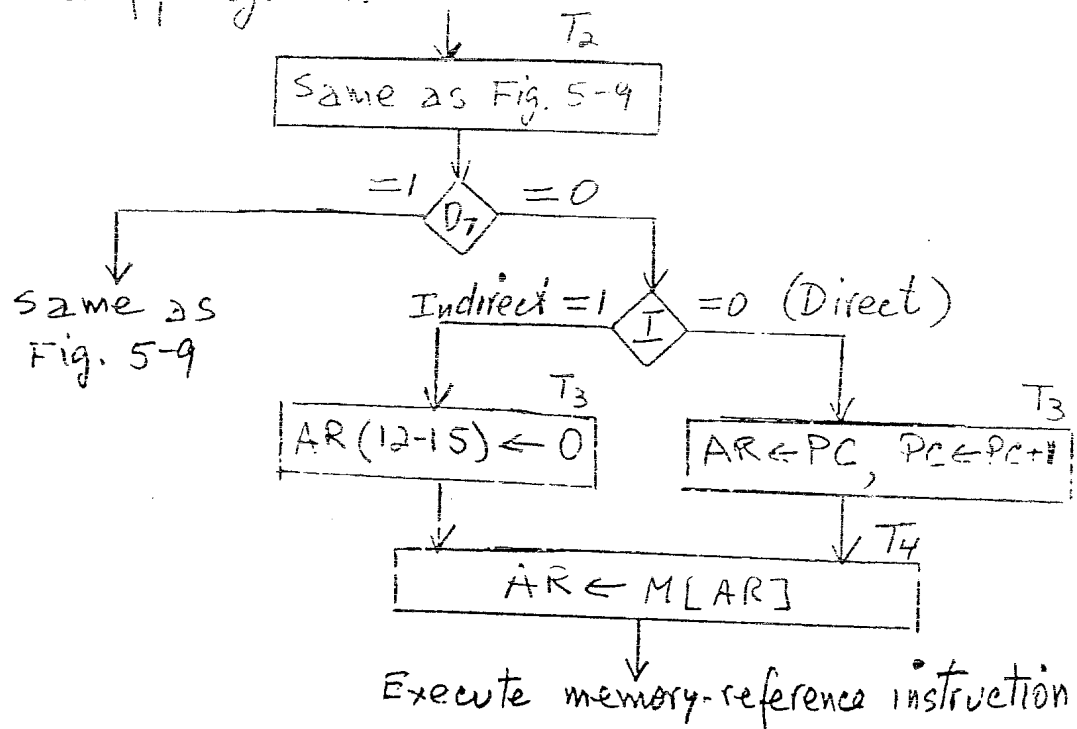
5-13

<u>XOR</u>	$D_0 T_4 :$	$DR \leftarrow M[AR]$
	$D_0 T_5 :$	$AC \leftarrow AC \oplus DR, SC \leftarrow 0$
<hr/>		
<u>ADM</u>	$D_1 T_4 :$	$DR \leftarrow M[AR]$
	$D_1 T_5 :$	$DR \leftarrow AC, AC \leftarrow AC + DR$
	$D_1 T_6 :$	$M[AR] \leftarrow AC, AC \leftarrow DR, SC \leftarrow 0$
<hr/>		
<u>SUB</u>	$D_2 T_4 :$	$DR \leftarrow M[AR]$
	$D_2 T_5 :$	$DR \leftarrow AC, AC \leftarrow DR$
	$D_2 T_6 :$	$AC \leftarrow \overline{AC}$
	$D_2 T_7 :$	$AC \leftarrow AC + 1$
	$D_2 T_8 :$	$AC \leftarrow AC + DR, SC \leftarrow 0$
<hr/>		
<u>XCH</u>	$D_3 T_4 :$	$DR \leftarrow M[AR]$
	$D_3 T_5 :$	$M[AR] \leftarrow AC, AC \leftarrow DR, SC \leftarrow 0$
<hr/>		
<u>SEQ</u>	$D_4 T_4 :$	$DR \leftarrow M[AR]$
	$D_4 T_5 :$	$TR \leftarrow AC, AC \leftarrow AC \oplus DR$
	$D_4 T_6 :$	$If (AC = 0) then (PC \leftarrow PC + 1), AC \leftarrow TR, SC \leftarrow 0$
<hr/>		
<u>BPA</u>	$D_5 T_4 :$	$If (AC = 0 \wedge AC(15) = 0)$ $then (PC \leftarrow AR), SC \leftarrow 0$

5-14

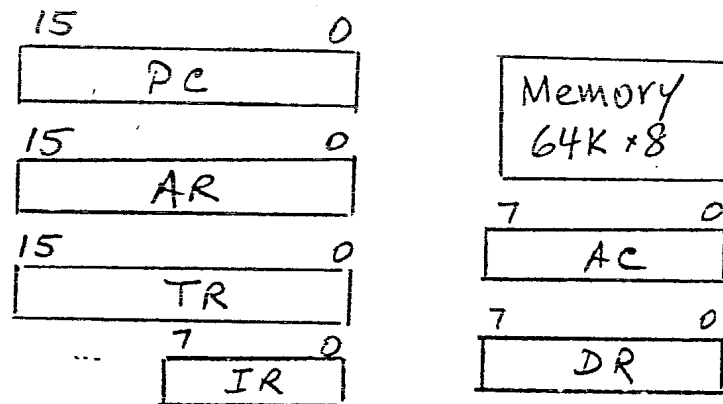
Converts the ISZ instruction from a memory-reference instruction to a register-reference instruction. The new instruction ICSZ can be executed at time  $T_3$  instead of time  $T_6$ , a saving of 3 clock cycles.

5-15 Modify Fig. 5-4:

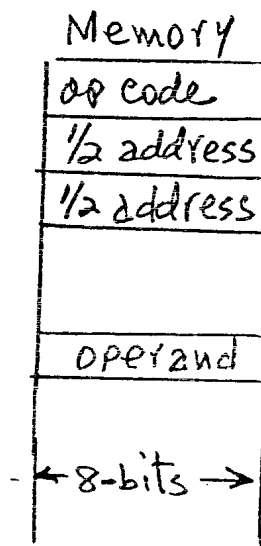


5-16

(a)

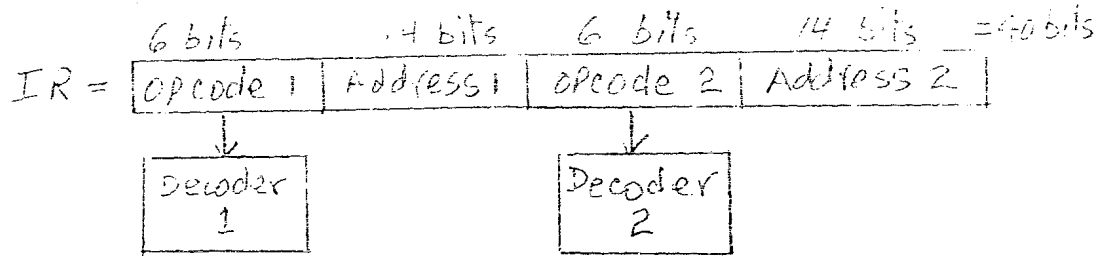


(b)



(c)  $T_0: IR \leftarrow M[PC], PC \leftarrow PC+1$   
 $T_1: AR(0-7) \leftarrow M[PC], PC \leftarrow PC+1$   
 $T_2: AR(8-15) \leftarrow M[PC], PC \leftarrow PC+1$   
 $T_3: DR \leftarrow M[AR]$

5-11



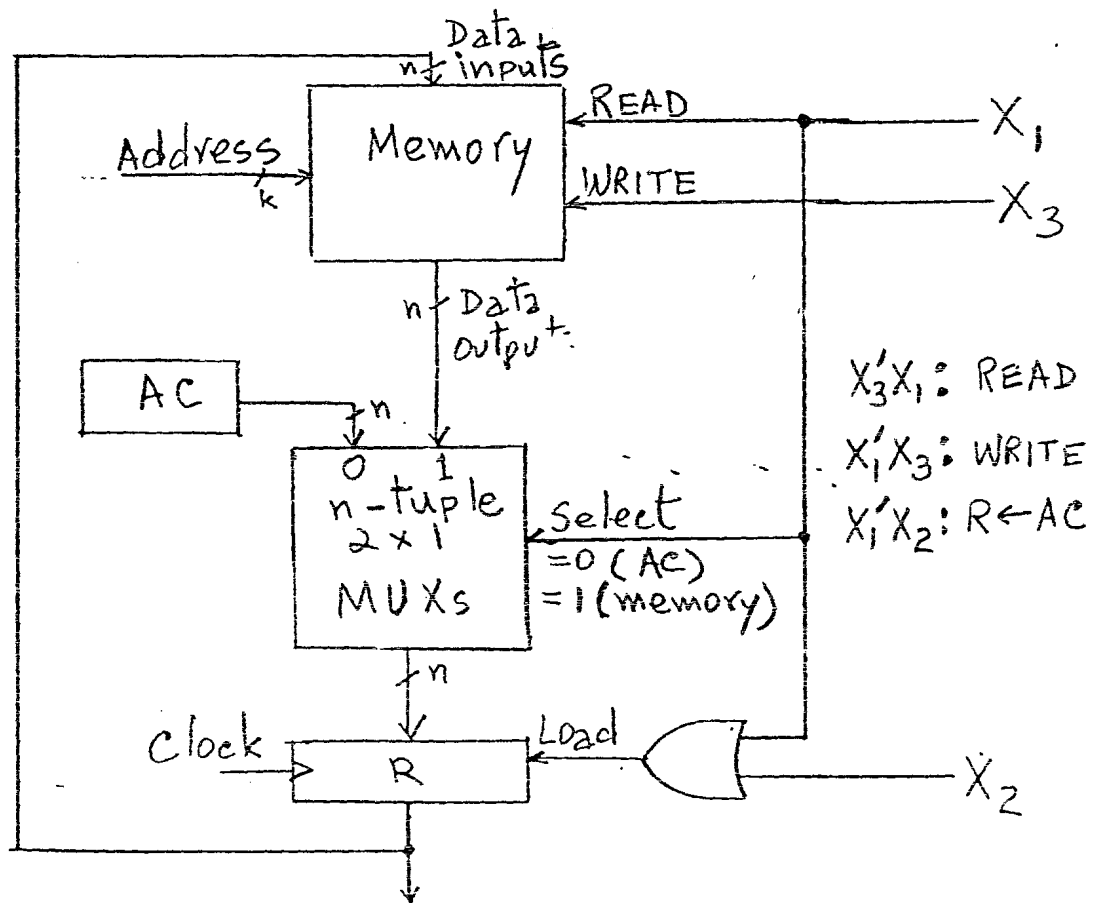
1. Read 40-bit double instruction from memory to IR and then increment PC,
2. Decode opcode 1.
3. Execute instruction 1 using address 1.
4. Decode opcode 2.
5. Execute instruction 2 using address 2.
6. Go back to step 1.

5-18

(a) BUN 2300

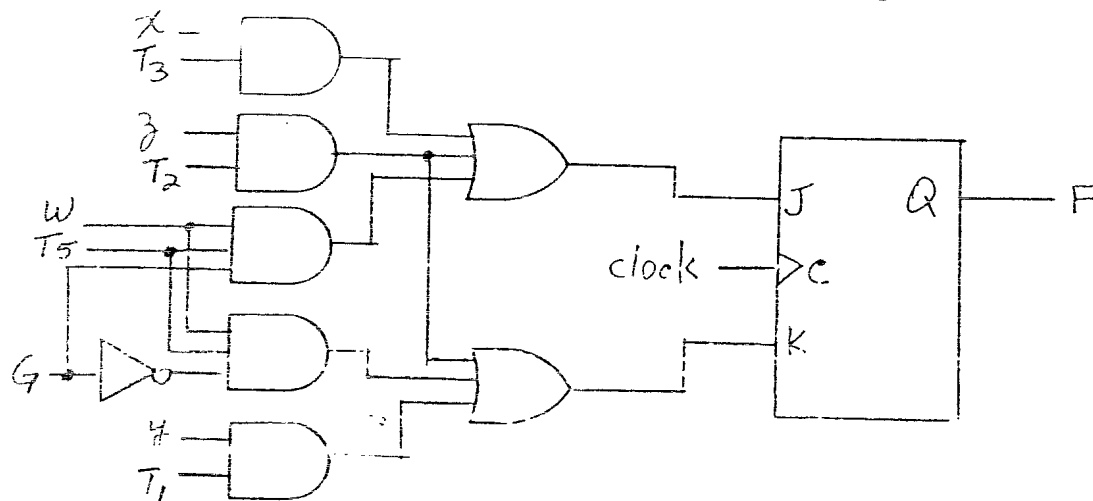
(b) ION  
BUN 0 I (Branch indirect with address 0)

5-19



5-20

$$J_F = xT_3 + 3T_2 + wT_5G \quad K_F = yT_1 + 3T_2 + wT_5G'$$



5-21 From Table 5-6: ( $Z_{DR}=1$  if  $DR=0$ ;  $Z_{AC}=1$  if  $AC=0$ )

$$INR(PC) = R'T_1 + RT_2 + D_6T_6Z_{DR} + PB_9(FGI) + PB_8(FG0) \\ + YB_4(AC_{15})' + YB_3(AC_{15}) + YB_2Z_{AC} + YB_1E'$$

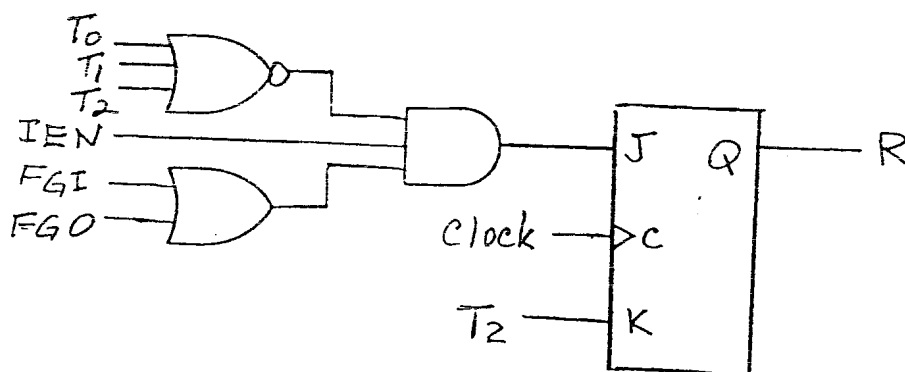
$$LD(PC) = D_4T_4 + D_5T_5$$

$$CLR(PC) = RT_1$$

The logic diagram is similar to the one in Fig. 5-16,

5-22 Write =  $D_3T_4 + D_5T_4 + D_6T_6 + RT_1$  ( $M[AR] \leftarrow xx$ )

5-23  $(T_0 + T_1 + T_2)'(IEN)(FGI + FG0); R \leftarrow 1$   
 $RT_2 : R \leftarrow 0$



5-24

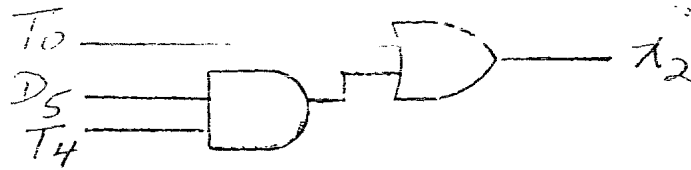
$\pi_2$  places PC onto the bus. From Table 5-6:

$R'T_0 : AR \leftarrow PC$

$RT_0 : TR \leftarrow PC$

$D_5T_4 : M[AR] \leftarrow PC$

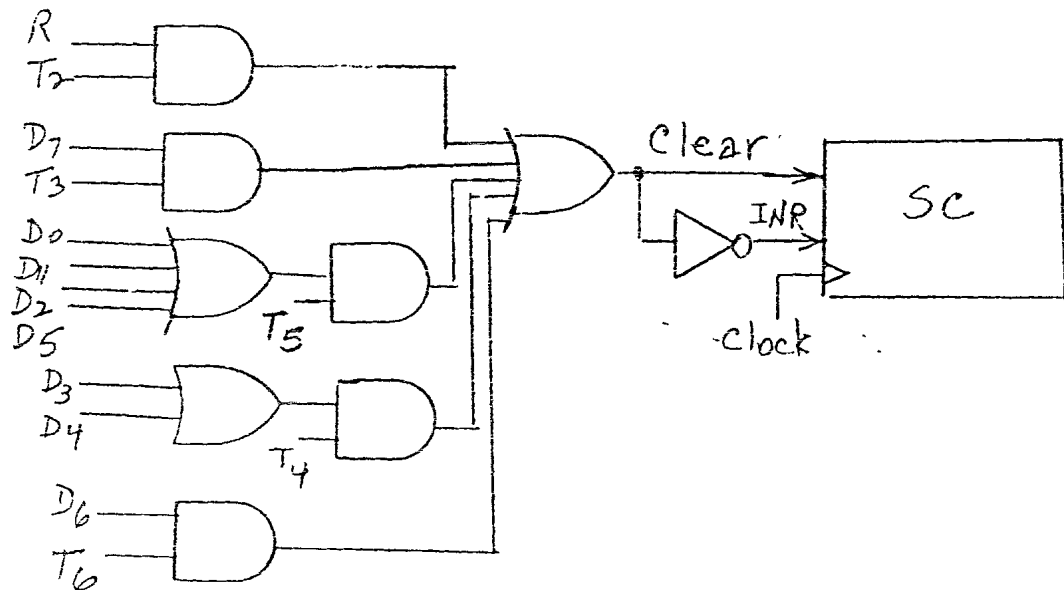
$$\pi_2 = R'T_0 + RT_0 + D_5T_4 = (R' + R)T_0 + D_5T_4 = T_0 + D_5T_4$$



5-25

From Table 5-6:

$$\begin{aligned} \text{CLR}(SC) = & RT_2 + D_7T_3(I' + I) + (D_0 + D_1 + D_2 + D_5)T_5 \\ & + (D_3 + D_4)T_4 + D_6T_6 \end{aligned}$$





# CHAPTER 6

6-1

		AC	PC	IR
010	CLA	0000	011	7800
011	ADD 016	C1A5	012	1016
012	BUN 014	C1A5	014	4014
013	HLT	8184	014	7001
014	AND 017	8184	015	0017
015	BUN 013	8184	013	4013
016	C1A5			
017	93C6			

$$\begin{aligned}
 (C1A5)_{16} &= 1100 \ 0001 \ 1010 \ 0101 \\
 (93C6)_{16} &= 1001 \ 0011 \ 1100 \ 0110 \quad \text{AND} \\
 &= 1000 \ 0001 \ 1000 \ 0100 = (8184)_{16}
 \end{aligned}$$

6-2

		AC
100	5103	
101	7200	
102	7001	
103	0000	
104	7800	0000
105	7020	0001
106	C103	

← BSA 103  
 → CMA  
 HLT  
 → 5101 ← Answer  
 → CLA  
 → INC  
 → BUN 103 I

FFFE ← Answer

6-3

CLA  
 STA SUM } SUM = 0  
 LDA SUM  
 ADD A } SUM = SUM + A + B  
 ADD B  
 STA SUM  
 LDA C  
 CMA  
 INC } DIF = DIF - C  
 ADD DIF  
 STA DIF  
 LDA SUM  
 ADD DIF } SUM = SUM + DIF  
 STA SUM

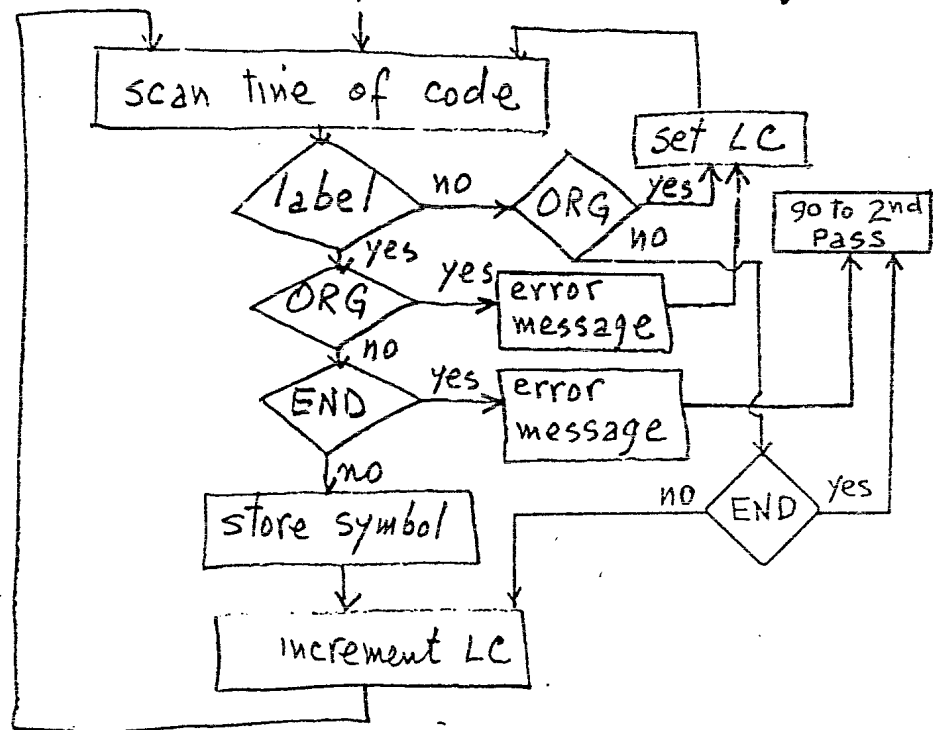
A more efficient compiler will optimize the machine code as follows:

LDA A  
 ADD B  
 STA SUM  
 LDA C  
 CMA  
 INC  
 ADD DIF  
 STA DIF  
 ADD SUM  
 STA SUM

6-4 A line of code such as: LDA I is interpreted by the assembler (Fig. 6-2) as a two symbol field with I as the symbolic address. A line of code such as: LDA I I is interpreted as a three symbol field. The first I is an address symbol and the second I as the Indirect bit. Answer: Yes, it can be used for this assembler.

6-5

The assembler will not detect an ORG or END if the line has a label; according to the flow chart of Fig. 6-1. Such a label has no meaning and constitutes an error. To detect the error, modify the flow chart of Fig. 6-1:



6-6 (a)

memory word	characters	Hex	binary
-------------	------------	-----	--------

1	D E	44 45	0100 0100 0100 0101
2	C space	43 20	0100 0011 0010 0000
3	- 3	2D 33	0010 1101 0011 0011
4	5 CR	35 0D	0011 0101 0000 1101

(b)  $(35)_{10} = (0000\ 0000\ 0010\ 0011)_2$

$-35 \rightarrow 1111\ 1111\ 1101\ 1101 = (FF\ DD)_{16}$

6-7 (2)

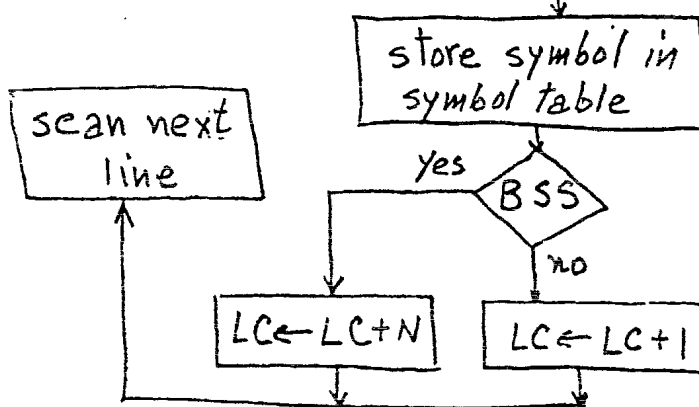
LOP	105
ADS	10B
PTR	10C
NBR	10D
CTR	10E
SUM	10F

$(100)_{10} = (0000\ 0000\ 0110\ 0100)_2$   
 $(-100)_{10} = (1111\ 1111\ 1001\ 1100)_2 = (FF9C)_{16}$   
 $(75)_{10} = (0000\ 0000\ 0100\ 1011)_2 = (004B)_{16}$   
 $(23)_{10} = (0000\ 0000\ 0001\ 0111)_2 = (0017)_{16}$

(b)

Loc	Hex	ORG	100	Loc	Hex	
100	210B	LDA	ADS	10B	0150	ADS, HEX 150
101	310C	STA	PTR	10C	0000	PTR, HEX 0
102	210D	LDA	NBR	10D	FF9C	NBR, DEC -100
103	310E	STA	CTR	10E	0000	CTR, HEX 0
104	7800	CLA		10F	0000	SUM, HEX 0
105	910C	LOP, ADD	PTR I			ORG 150
106	610C	ISZ	PTR	150	004B	DEC 150
107	610E	ISZ	CTR	:	:	:
108	4105	BUN	LOP	:	:	:
109	310F	STA	SUM	1B3	0017	DEC 23
10A	7001	HLT				END

6-8 Modify flow chart of Fig. 6-1



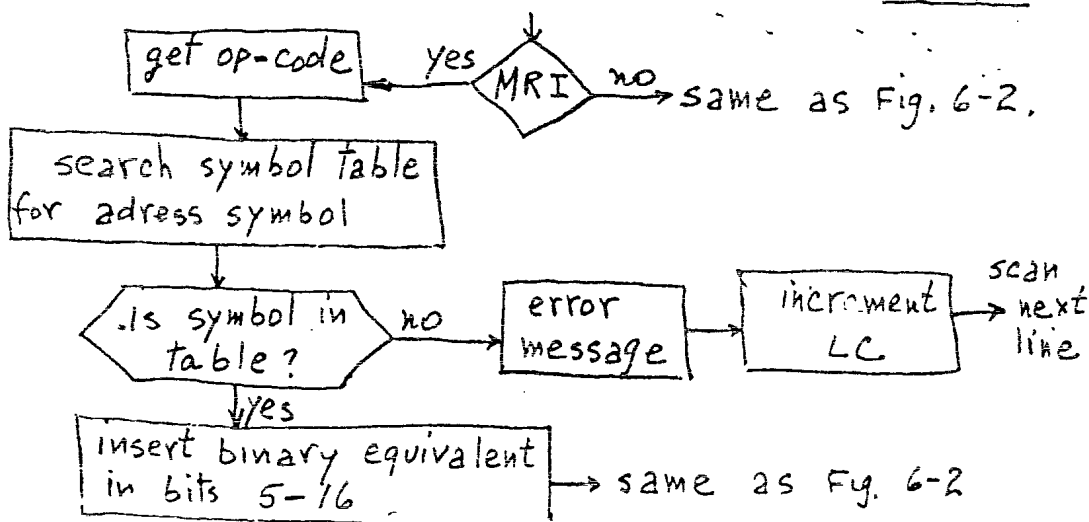
LC=1 A, BSS 10

2 A+1  
 3 A+2  
 4 A+3  
 5 A+4  
 6 A+5  
 7 A+6  
 8 A+7  
 9 A+8  
 10 A+9

→ 11 LC set to 11

example

6-9



6-10 (a) MRI table  $\rightarrow$

	memory word	symbol	HEX
AND	1	A N	41 4D
	2	D space	44 20
	3	value	00 00
ADD	4	A D	41 44
	5	D space	44 20
	6	value	10 00
		etc.	

(b) non-MRI table  $\rightarrow$

	word	symbol	HEX
CLA	1	C L	43 4C
	2	A space	41 20
	3	value	78 00
CLE	4	C L	43 4C
	5	E space	45 20
	6	value	74 00
		etc.	

6-11

```

LDA B
CMA
INC
ADD A / Form A-B
SPA / skip if AC positive
BUN N10 / (A-B) < 0, go to N10
SZA / skip if AC=0
BUN N30 / (A-B) > 0, go to N30
BUN N20 / (A-B) = 0, go to N20

```

6-12(a) The program counts the number of 1's in the number stored in location WRD. Since  $WRD = (62C1)_{16} =$

$(0110\ 0010\ 1100\ 0001)_2$   
 number of 1's is 6; so CTR will have  $(0006)_{16}$

(b)

		ORG 100	
100	7400	CLE	
101	7800	CLA	
102	3110	STA CTR	/ Initialize counter to zero
103	2111	LDA WRD	
104	7004	SZA	
105	4107	BUN ROT	
106	410F	BUN STP	/ Word is zero; stop with CTR=0
107	7040	ROT, CIL	/ Bring bit to E
108	7002	SZE	
109	410B	BUN AGN	/ bit = 1, go to count it
10A	4107	BUN ROT	/ bit = 0, repeat
10B	7400	AGN, CLE	
10C	6110	ISZ CTR	/ Increment counter

6-12 (b) Continued

10D	7004	SZA	/check if remaining bits = 0
10E	4107	BUN ROT	/No; rotate again
10F	7001	STP, HLT	/Yes; stop
110	0000	CTR, HEX 0	
111	62C1	WRD, HEX 62C1	
		END	

6-13  $(100)_{16} = (256)_{10}$  500 to 5FF  $\rightarrow (256)_{10}$  locations

	ORG	100	
	LDA	ADS	
	STA	PTR	/Initialize pointer
	LDA	NBR	
	STA	CTR	/Initialize counter to -256
	CLA		
LOP,	STA	PTR I	/store zero
	ISZ	PTR	
	ISZ	CTR	
	BUN	LOP	
	HLT		
ADS,	HEX	500	
PTR,	HEX	0	
NBR,	DEC	-256	
CTR,	HEX	0	
	END		

6-14

	LDA	A	/Load multiplier
	SZA		/Is it zero?
	BUN	NZR	
	HLT		/A=0, product=0 in AC
NZR,	CMA		
	INC		
	STA	CTR	/Store -A in counter
	CLA		/Start with AC=0
LOP,	ADD	B	/Add multiplicand
	ISZ	CTR	
	BUN	LOP	/Repeat Loop A times
	HLT		
A,	DEC	-	/multiplier
B,	DEC	-	/multiplicand
CTR,	HEX	0	/counter
	END		

6-15 The first time the program is executed, location CTR will go to 0. If the program is executed again starting from location  $(100)_{16}$ , location CTR will be incremented and will not reach 0 until it is incremented  $2^{16} = 65,536$  times, at which time it will reach 0 again.

We need to initialize CTR and P as follows:

```
LDA  NBR
STA  CTR
CLA
STA  P
```

↓  
Program

```
NBR, DEC -8
CTR, HEX 0
P,  HEX 0
```

6-16 Multiplicand is initially in location XL. Will be shifted left into XH (which has zero initially). The partial Product will contain two locations PL and PH (initially zero). Multiplier is in location Y. CTR = -16

```
LDP,  CLE
      LDA  Y
      CIR
      STA  Y
      SZE
      BUN  ONE
      BUN  ZRO
ONE,  LDA  XL
      ADD  PL
      STA  PL
      CLA
      CIL
      ADD  XH
      ADD  PH
      STA  PH
      CLE
```

same as beginning of  
Program in Table 6-14

Double-precision add

$P \leftarrow X + P$

Same as program  
in Table 6-15

Continued next page

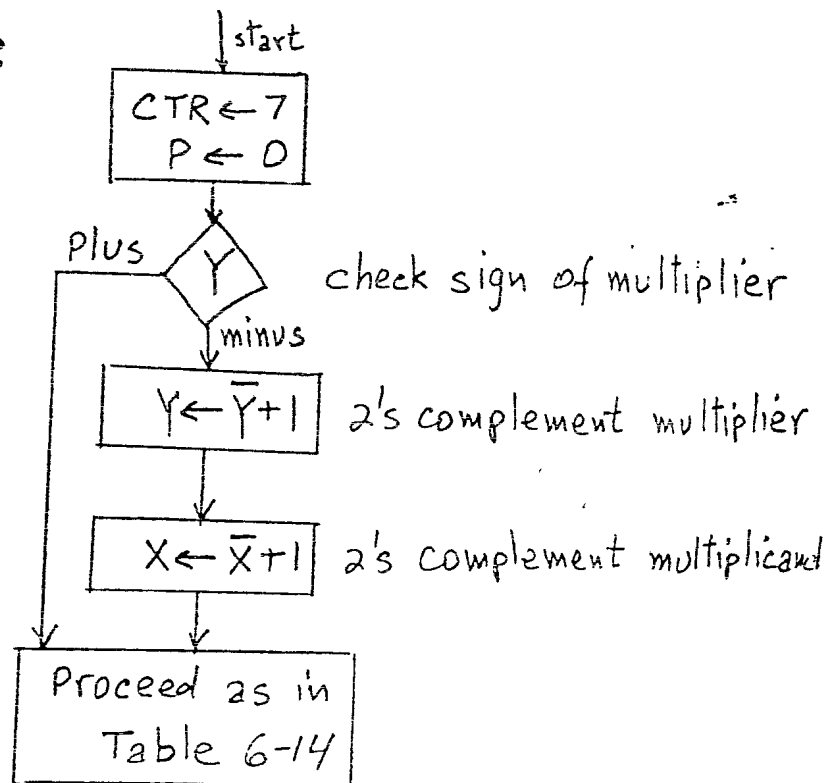
## 6-16 continued

ZRO,	LDA XL	Double-precision left-shift XH+XL
	CIL	
	STA XL	
	LDA XH	
	CIL	
	STA XH	
	ISZ CTR	Repeat 16 times
	BUN LOP	
	HLT	

## 6-17

If multiplier is negative, take the 2's complement of multiplier and multiplicand and then proceed as in Table 6-14 (with CTR=-7).

Flow-Chart :



6-18

$C \leftarrow A - B$

```

CLE
LDA BL
CMA
INC
ADD AL
STA CL
save carry [ CLA
CIL
STA TMP
LDA BH
CMA
ADD AH
add carry → ADD TMP
STA CH
HLT
TMP, HEX 0

```

To form a double-precision  
2's complement of subtrahend  
BH+BL,  
a 1's complement is  
formed and 1 added once.

Thus, BL is complemented  
and incremented while  
BH is only complemented.

Location TMP saves the  
carry from E while BH  
is complemented.

6-19  $z = x \oplus y = xy' + x'y = [(xy')' \cdot (x'y)']'$

```

LDA Y
CMA
AND X
CMA
STA TMP
LDA X
CMA
AND Y
CMA
AND TMP
CMA
STA Z
HLT

```

X, —  
Y, —  
Z, —  
TMP, —

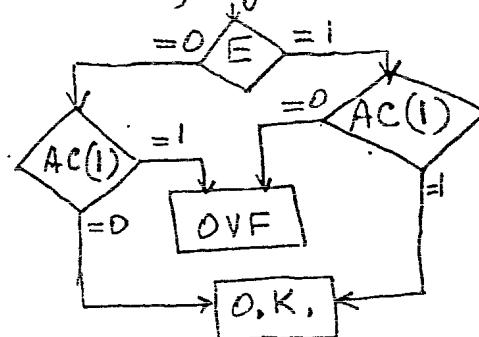
6-20

```

LDA X
CLE
CIL
SZE
BUN ONE
SPA
BUN OVF
BUN EXT
ONE, SNA
BUN OVF
EXT, HLT

```

/ zero to low order bit; sign bit in E





6-21 Calling program

BSA SUB  
 HEX 1234 /subtrahend  
 HEX 4321 /minuend  
 HEX 0 /difference

subroutine

SUB, HEX 0  
 LDA SUB I  
 CMA  
 INC  
 ISZ SUB  
 ADD SUB I  
 ISZ SUB  
 STA SUB I  
 ISZ SUB  
 BUN SUB I

6-22Calling Program

BSA CMP  
 HEX 100 /starting address  
 DEC 32 /number of words

Subroutine

CMP, HEX 0  
 LDA CMP I  
 STA PTR  
 ISZ CMP  
 LDA CMP I

CMA  
 INC  
 STA CTR  
 LOP, LDA PTR I  
 CMA  
 STA PTR I  
 ISZ PTR  
 ISZ CTR  
 BUN LOP  
 ISZ CMP  
 BUN CMP I  
 PTR, —  
 CTR, —

6-23 CR4, HEX 0

CIR  
 CIR  
 CIR  
 CIR  
 BUN CR4 I

E	AC	AC HEX
1	0000 0111 1001 1100	079C
1	1001 0000 0111 1001	9079

6-24

LDA ADS  
 STA PTR  
 LDA NBR  
 STA CTR  
 LOP, BSA IN2 /subroutine Table 6-20  
 STA PTR I  
 ISZ PTR  
 ISZ CTR

BUN LOP  
 HLT  
 ADS, HEX 400  
 PTR, HEX 0  
 NBR, DEC -512  
 CTR, HEX 0

6-25

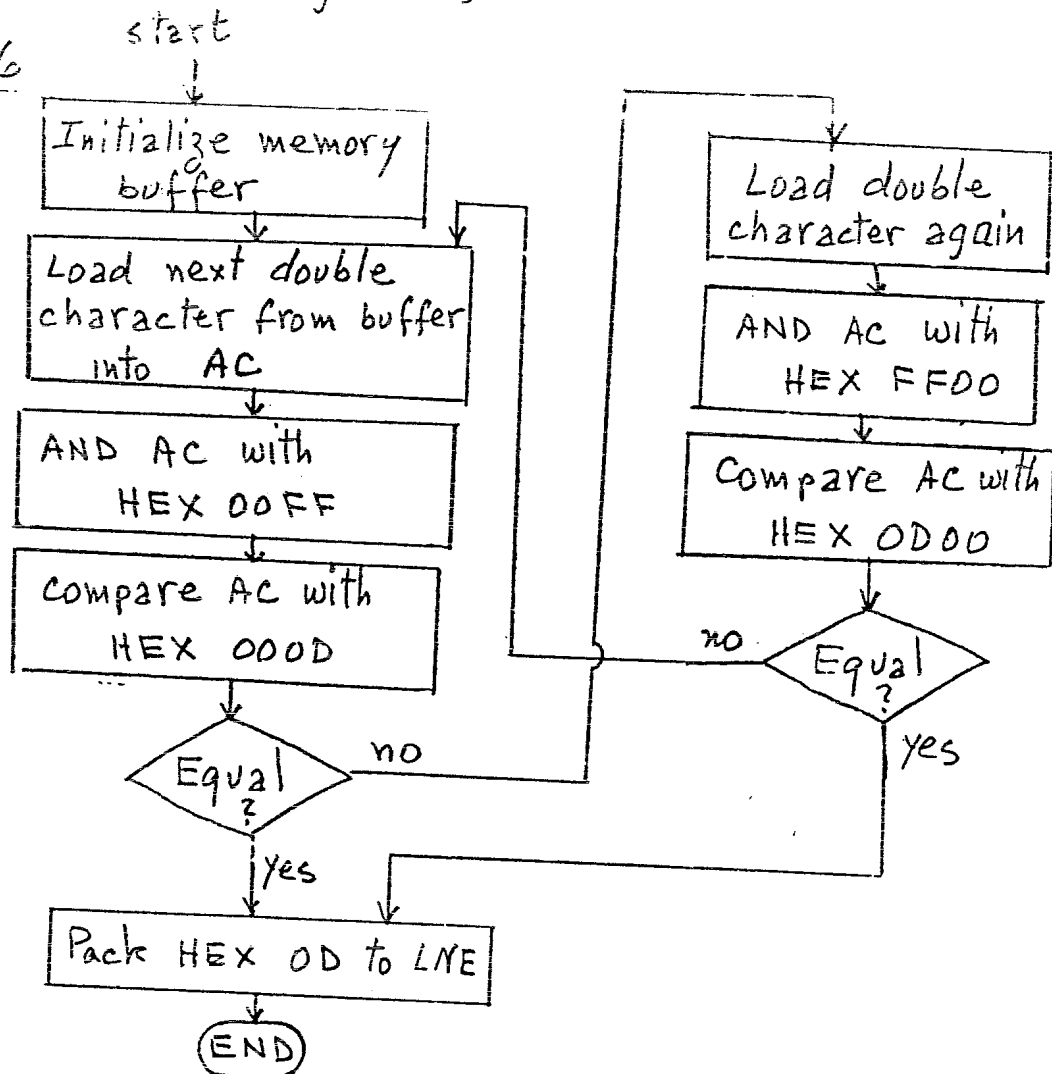
```

LDA   WRD
AND   MSI
STA   CHI
LDA   WRD
AND   MS2
CLE
BSA   SR8 /subroutine to
        shift right
        eight times
  
```

```

STA   CH2
HLT
WRD,  HEX —
CHI,  HEX —
CH2,  HEX —
MS1,  HEX 00FF
MS2,  HEX FF00
  
```

6-26



6-27

Location	Hex code	
200	3213	SRV, STA SAC
201	7080	CIR
202	3214	STA SE
203	F200	SKI
204	4209	BUN NXT
205	F800	INP
206	F400	OUT
207	B215	STA PT1 I
208	6215	ISZ PT1
209	F100	NXT, SKO
20A	420E	BUN EXT
20B	A216	LDA PT2 I
20C	F400	OUT
20D	6216	ISZ PT2
20E	2214	EXT, LDA SE
20F	7040	CIL
210	2213	LDA SAC
211	F080	IDN
212	C000	BUN ZRD I
213	0000	SAC, —
214	0000	SE, —
215	0000	PT1, —
216	0000	PT2, —

6-28

SRV, STA SAC	NXT, LDA MOD
CIR	SZA
STA SE	BUN EXT
LDA MOD /check MOD	service SKO
CMA	output BUN EXT
SZA	device LDA PT2 I
BUN NXT / MOD ≠ all 1's	OUT
SKI	ISZ PT2
BUN NXT } Service	EXT, continue as
INP } input	in Table 6-23
OUT } Device	
STA PT1 I	
ISZ PT1	
BUN EXT / MOD ≠ 0	

## CHAPTER 7

7-1

A microprocessor is a small size CPU (computer on a chip).  
Microprogram is a program for a sequence of microoperations.  
The control unit of a microprocessor can be hardwired or microprogrammed, depending on the specific design.  
A microprogrammed computer does not have to be a microprocessor.

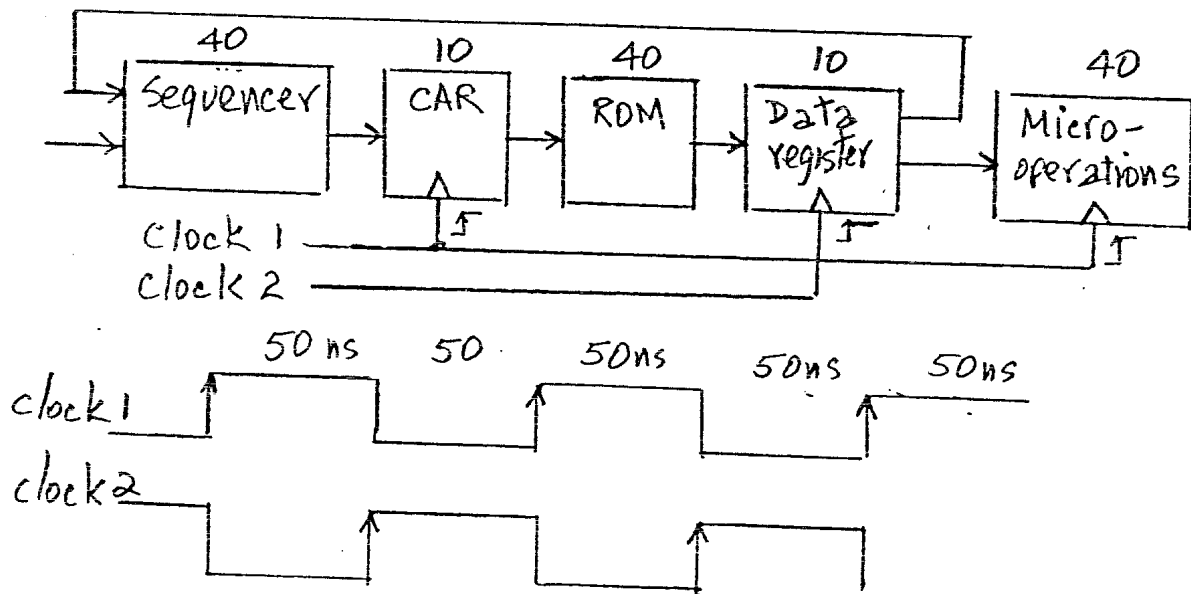
7-2

Hardwired control, by definition, does not contain a control memory.

7-3

Microoperation - an elementary digital computer operation.  
Microinstruction - an instruction stored in control memory.  
Microprogram - a sequence of microinstructions.  
Microcode - same as microprogram.

7-4

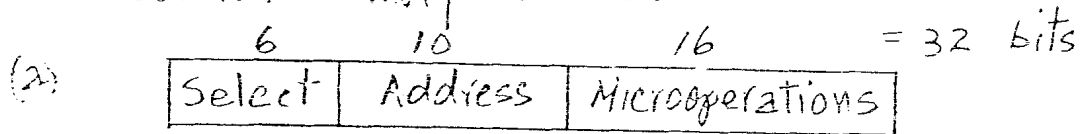


frequency of each clock =  $\frac{1}{100 \times 10^{-9}} = \frac{1000}{100} \times 10^6 = 10 \text{ MHz}$

If the data register is removed, we can use a single phase clock with a frequency of  $\frac{1}{90 \times 10^{-9}} = 11.1 \text{ MHz}$

7-5

Control memory =  $2^{10} \times 32$



(b) 4 bits

(c) 2 bits

7-6

Control memory =  $2^{12} \times 24$

(a) 12 bits

(b) 12 bits

(c) 12 multiplexers, each of size 4-to-1 line.

7-7

(a) 0001000 = 8

(b) 0101100 = 44

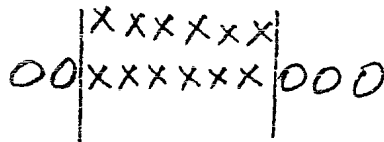
(c) 0111100 = 60

7-8

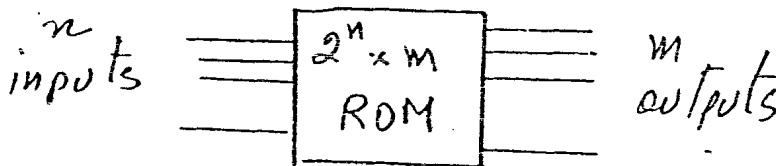
opcode = 6 bits

control memory

address = 11 bits



7-9



The ROM can be programmed to provide any desired address for a given inputs from the instruction.

7-10

Either multiplexers, three-state gates, or gate logic (equivalent to a mux) are needed to transfer information from many sources to a common destination.

7-11

	F1	F2	F3			
(a)	011	110	000	INCAC	INC DR	NOP
(b)	000	100	101	NOP	READ	INCPc
(c)	100	101	000	DRTAC	ACTDR	NOP

7-12

				Binary
(a)	READ	$DR \leftarrow M[AR]$	$F2 = 100$	000 100 101
	DRTAC	$AC \leftarrow DR$	$F3 = 101$	
(b)	ACTDR	$DR \leftarrow AC$	$F2 = 101$	000 100 101
	DRTAC	$AC \leftarrow DR$	$F1 = 100$	
(c)	ARTPC	$PC \leftarrow AR$	$F3 = 110$	
	DRTAC	$AC \leftarrow DR$	$F1 = 100$	
	WRITE	$M[AR] \leftarrow DR$	$F1 = 111$	

Impossible.  
Both use F1

7-13

If  $I=0$ , the operand is read in the first microinstruction and added to AC in the second.

If  $I=1$ , the effective address is read into DR and control goes to INDR2. The subroutine must read the operand into DR.

INDR2: DRTAR U JMP NEXT  
READ U RET ---

7-14

(a) Branch if  $S=0$  and  $Z=0$  (positive and non-zero AC) - See last instruction in Problem 7-16.

(b)	40:	000 000 000	10 00	10000000
	41:	000 000 000	11 00	10000000
	42:	000 000 000	01 01	10000111
	43:	000 000 110	00 00	10000000

7-15

```

(2) 60: CLRAC, COM  U    JMP  INDRCT
      61: WRITE, READ I    CALL  FETCH
      62: ADD, SUB  S    RET    63(NEXT)
      63: DRTAG, INCDR Z    MAP    60

```

(b)

60: Cannot increment and complement AC at the same time. With a JMP to INDRCT, control does not return to 61.

61: Cannot read and write at the same time. The CALL behaves as a JMP since there is no return from FETCH.

62: Cannot add and subtract at the same time. The RET will be executed independent of S.

63: The MAP is executed irrespective of Z or 60.

7-16

```

                ORG 16
AND:  ... NOP      I    CALL  INDRCT
      READ      U    JMP    NEXT
ANDOP: AND       U    JMP    FETCH

```

---

```

                ORG 20
SUB:  NOP      I    CALL  INDRCT
      READ     U    JMP    NEXT
      SUB      U    JMP    FETCH

```

---

```

                ORG 24
ADM:  NOP      I    CALL  INDRCT
      READ     U    JMP    NEXT
      DRTAG, ACTDR U    JMP    NEXT
      ADD      U    JMP    EXCHANGE+2
                                (Table 7-2)

```

7-16 (CONTINUED)

ORG 28

BTCL :	NOP	I	CALL	INDRCT
	READ	U	JMP	NEXT
	DRTAC, ACTDR	U	JMP	NEXT
	COM	U	JMP	ANDOP

---

ORG 32

BZ :	NOP	Z	JMP	ZERO
	NOP	U	JMP	FETCH
ZERO :	NOP	I	CALL	INDRCT
	ARTPC	U	JMP	FETCH

---

ORG 36

SEQ :	NOP	I	CALL	INDRCT
	READ	U	JMP	NEXT
	DRTAC, ACTDR	U	JMP	NEXT
	XOR (or SUB)	U	JMP	BEQ1

ORG 69

BEQ1 :	DRTAC, ACTDR	Z	JMP	EQUAL
	NOP	U	JMP	FETCH
EQUAL :	INCP C	U	JMP	FETCH

---

ORG 40

BPNZ :	NOP	S	JMP	FETCH
	NOP	Z	JMP	FETCH
	NOP	I	CALL	INDRCT
	ARTPC	U	JMP	FETCH

---



7-17

ISZ:	NOP	I	CALL	INDRCT
	READ	U	JMP	NEXT
	INCDR	U	JMP	NEXT
	DRTAC, ACTDR	U	JMP	NEXT (by fast INDRCT)
	DRTAC, ACTDR	Z	JMP	ZERO
ZERO:	WRITE	U	JMP	FETCH
	WRITE, INCPC	U	JMP	FETCH

7-18

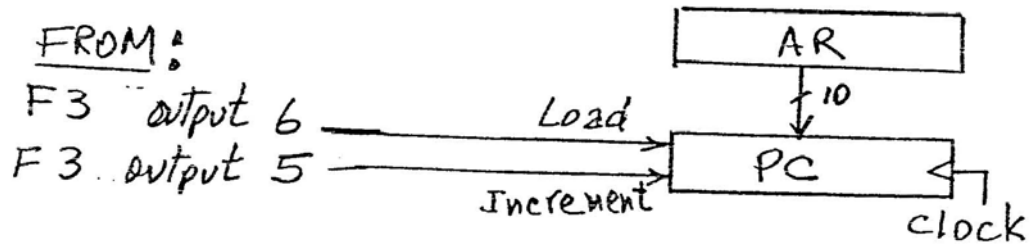
BSA:	NOP	I	CALL	INDRCT
	PCTDR, ARTPC	U	JMP	NEXT
	WRITE, INCPC	U	JMP	FETCH

7-19

From Table 7-1:

F3 = 101 (5)  $PC \leftarrow PC + 1$

F3 = 110 (6)  $PC \leftarrow AR$



7-20

A field of 5 bits can specify  $2^5 - 1 = 31$  microoperations  
 A field of 4 bits can specify  $2^4 - 1 = 15$  microoperations  
 9 bits 46 microoperations

7-21

See Fig. 8-2(b) for control word example.

(2) 16 registers need 4 bits; ALU need 5 bits, and the shifter need 3 bits, to encode all operations,  $4 \cdot 4 + 5 + 3 = 20$  bits total

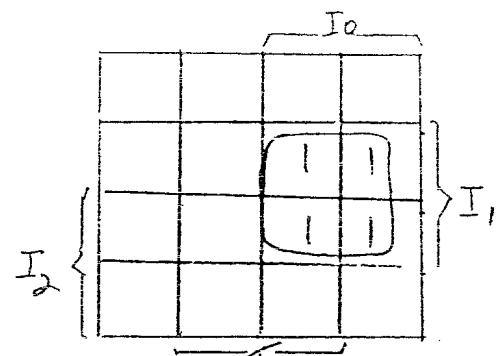
(c)

4	4	4	5	3
SRC1	SRC2	DEST	ALU	SHIFT
R5	R6	R4	ADD	SHIFT
0101	0110	0100	00100	000

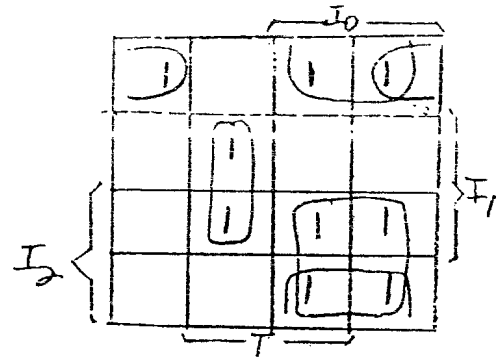
$R4 \leftarrow R5 + R6$

7-22

$I_2$	$I_1$	$I_0$	$T$	$S, S_0$	$L$		
0	0	0	0	0	1	0	AD(1)
0	0	0	1	0	0	0	INC(0)
0	0	1	0	0	1	0	AD(1)
0	0	1	1	0	1	0	AD(1)
0	1	0	0	0	0	0	INC(0)
0	1	0	1	0	1	0	AD(1)
0	1	1	0	1	0	0	RET(2)
0	1	1	1	1	0	0	RET(2)
1	0	0	0	0	0	0	INC(0)
1	0	0	1	0	0	0	INC(0)
1	0	1	0	0	1	0	AD(1)
1	0	1	1	0	1	0	AD(1)
1	1	0	0	0	0	0	INC(0)
1	1	0	1	0	1	1	CALL(1)
1	1	1	0	1	1	0	MAP(3)
1	1	1	1	1	1	0	MAP(3)



$$S_0 = I_1 I_0$$



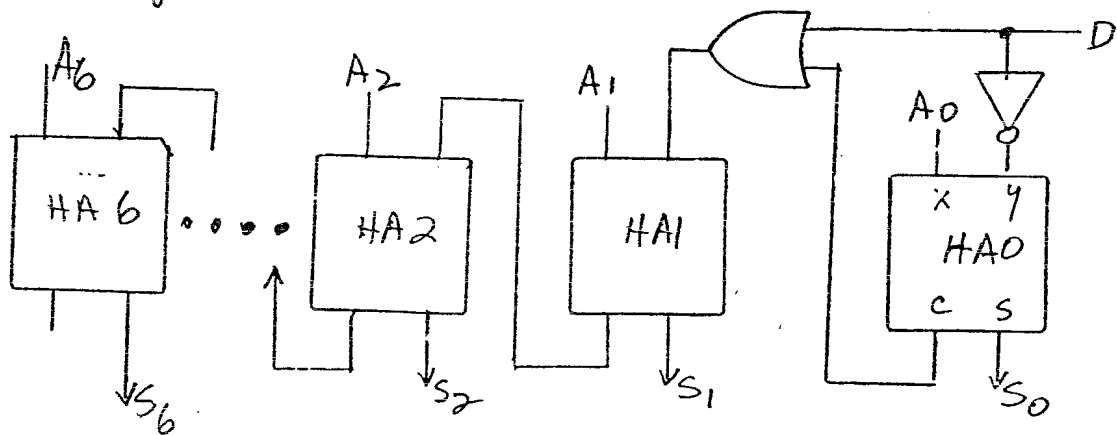
$$S_0 = I_2 I_0 + I_1 I_0 + I_1 I_0' T + I_2 I_1 T'$$

$$L = I_2 I_1 I_0' T$$

7-23

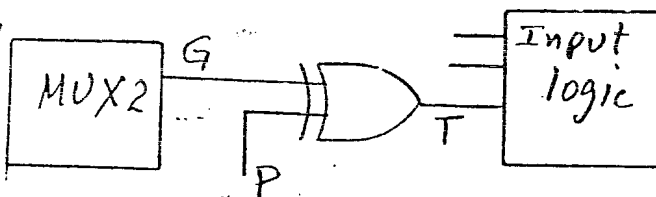
(2) See Fig. 4-8 (chapter 4)

(b)



7-24

P is used to determine the polarity of the selected status bit.



When  $P=0$ ,  $T=G$  because  $G \oplus 0 = G$

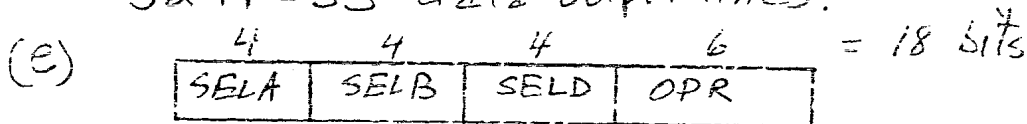
When  $P=1$ ,  $T=G'$  because  $G \oplus 1 = G'$

where  $G$  is the value of the selected bit in MUX2

# CHAPTER 8

8-1

- (a) 32 multiplexers, each of size  $16 \times 1$ .
- (b) 4 inputs each, to select one of 16 registers.
- (c) 4-to-16-line decoder
- (d)  $32 + 32 + 1 = 65$  data input lines  
 $32 + 1 = 33$  data output lines.



8-2

$$30 + 80 + 10 = 120 \text{ nSec.}$$

(The decoder signals propagate at the same as the muxs.)

8-3

	SELA	SELB	SELD	OPR	Control word
(a) $R1 \leftarrow R2 + R3$	R2	R3	R1	ADD	010 011 001 00010
(b) $R4 \leftarrow \overline{R4}$	R4	-	R4	COMA	100 xxx 100 01110
(c) $R5 \leftarrow R5 - 1$	R5	-	R5	DECA	101 xxx 101 00110
(d) $R6 \leftarrow \text{shl } R1$	R1	-	R6	SHLA	001 xxx 110 11000
(e) $R7 \leftarrow \text{Input}$	Input	-	R7	TSFA	000 xxx 111 00000

8-4

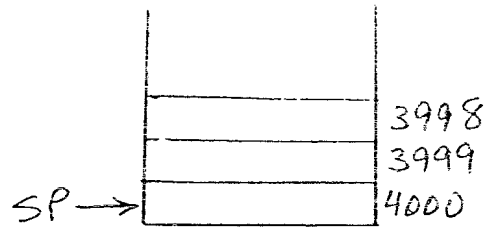
Control word	SELA	SELB	SELD	OPR	Microoperation
(a) 001 010 011 00101	R1	R2	R3	SUB	$R3 \leftarrow R1 - R2$
(b) 000 000 000 00000	Input	Input	None	TSFA	$\text{Output} \leftarrow \text{Input}$
(c) 010 010 010 01100	R2	R2	R2	XOR	$R2 \leftarrow R2 \oplus R2$
(d) 000 001 000 00010	Input	R1	None	ADD	$\text{Output} \leftarrow \text{Input} + R1$
(e) 111 100 011 10000	R7	R4	R3	SHRA	$R3 \leftarrow \text{shr } R7$

8-5

- (a) Stack full with 64 items.
- (b) Stack empty.

8-6 PUSH :  $M[SP] \leftarrow DR$   
 $SP \leftarrow SP - 1$

POP :  $SP \leftarrow SP + 1$   
 $DR \leftarrow M[SP]$



8-7

(a)  $AB * CD * EF * + +$

(b)  $AB * ABD * CE * + * +$

(c)  $FG + E * CD * + B * A +$

(d)  $ABCDE + * + * FGH + * /$

8-8

(a)  $\frac{A}{B - (D + E) * C}$  (b)  $A + B - \frac{C}{D * E}$

(c)  $\frac{A}{B * C} - D + \frac{E}{F}$  (d)  $((((F + G) * E + D) * C + B) * A$

8-9

$(3 + 4) [10(2 + 6) + 8] = 616$

RPN : 3 4 + 2 6 + 10 \* 8 + \*

				6		10		8		
	4		2	2	8	8	80	80	88	
3	3	7	7	7	7	7	7	7	7	616
3	4	+	2	6	+	10	*	8	+	*

8-10

WRITE (if not full):

$M[WC] \leftarrow DR$

$WC \leftarrow WC + 1$

$ASC \leftarrow ASC + 1$

READ : (if not empty)

$DR \leftarrow M[RC]$

$RC \leftarrow RC + 1$

$ASC \leftarrow ASC - 1$

Memory may wrap-around

Read from 7 to 0

RC

Write

WC

3 bits

ASC

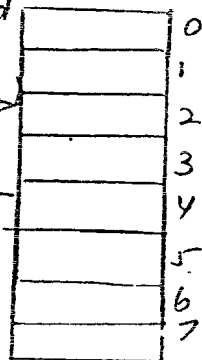
Empty

all 0's

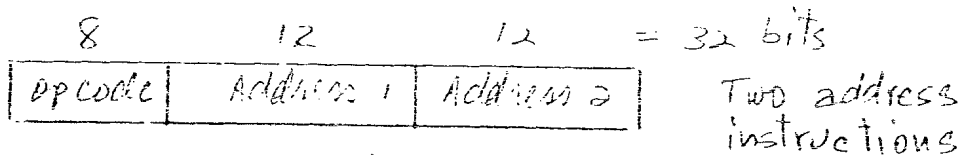
all 1's

Full

FIFO

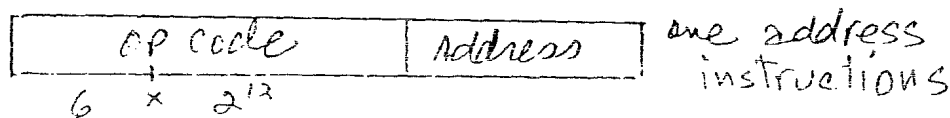


8-11



$2^8 = 256$  combinations.

$256 - 250 = 6$  combinations can be used for one address



Maximum number of one address instruction:

$$= 6 \times 2^{12} = 24,576$$

8-12

(d) RPN:  $XAB - C + DE * F - * GHK * + / =$

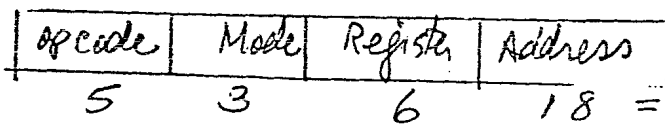
8-13

$$256K = 2^8 \times 2^{10} = 2^{18}$$

address = 18 bits

Mode = 3 "

Register = 6 "



$$= 32$$

Op code  $\frac{27 \text{ bits}}{5} = 32 \text{ bits}$

8-14

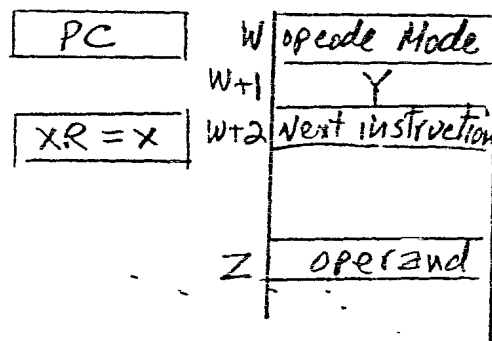
$Z = \text{Effective address}$

(a) Direct:  $Z = Y$

(b) Indirect:  $Z = M[Y]$

(c) Relative:  $Z = Y + W + 2$

(d) Indexed:  $Z = Y + X$



8-15

(a) Relative address =  $500 - 751 = -251$

(b)  $251 = 00001111011$ ;  $-251 = 111100000101$

(c)  $PC = 751 = 00101110111$ ;  $500 = 00011110100$

$$PC = 751 = 00101110111$$

$$RA = -251 = 111100000101$$

$$EA = 500 = 00011110100$$

8-16 Assuming one word per instruction or operand.

Computational type

Fetch instruction

Fetch effective address

Fetch operand

3 memory references

Branch type

Fetch instruction

Fetch effective address  
and transfer to PC

2 memory references.

8-17

The address part of the indexed mode instruction must be set to zero.

8-18

Effective address

(a) Direct : 400

(b) Immediate : 301

(c) Relative :  $302 + 400 = 702$

(d) Reg. Indirect : 200

(e) Indexed :  $200 + 400 = 600$

PC  $\rightarrow$  300

R1 = 200

301

302

Memory

op code	Mode
400	
Next instruction	

8-19

1=C 0=C 1=C 0 = Reset initial carry

6E C3 56 7A

13 55 6B 8F

82

18

C2

09

Add with carry

8-20

10011100  
10101010  
AND  
10001000

10011100  
10101010  
OR  
11111110

10011100  
10101010  
XOR  
00110110

8-21

(a) AND with : 0000000011111111

(b) OR with : 0000000011111111

(c) XOR with : 0000111111110000

8-22 Initial: 01111011 C=1

SHR: 00111101  
SHL: 11110110  
SHRA: 00111101  
SHLA: 11110110 (overflow)  
ROR: 10111101  
ROL: 11110110  
RDEC: 10111101  
POLC: 11110111

8-23

183-01010011 -83-10101101

$$+68 = 01000100 \quad -68 = 1011100$$
$$\begin{array}{r} (2) \quad -83 \quad 10101101 \\ +68 \quad + \quad 01000100 \\ \hline -15 \quad 11110001 \end{array}$$

(in 2's complement)

$$\begin{array}{r} \text{(b)} \quad -68 \\ \quad -83 \\ \hline -151 \\ \quad \wedge \\ -128 \end{array} \quad \begin{array}{r} 10 \leftarrow \text{carries} \\ 10111100 \\ + 10101101 \\ \hline 01101001 \\ \text{(overflow)} \end{array}$$

(c)  $-68 = 10111100$   
 $-34 = 11011110$

(d)  $-83 = 10101101$   
 $-166 \neq 01011010$   
 overflow

8-24

$$\underline{Z} = F_0' F_1' F_2' F_3' F_4' F_5' F_6' F_7' = (F_0 + F_1 + F_2 + F_3 + F_4 + F_5 + F_6 + F_7)'$$

8-25

$$\begin{array}{r} \text{(a)} \quad 72 \quad 0111 \ 0010 \\ \quad \quad C6 \quad 1100 \ 0110 \\ \hline 138 \quad 0011 \ 1000 \\ C=1 \ S=0 \ Z=0 \ V=0 \end{array}$$

(b)  $72 \xrightarrow{01} 01110010$   
 $\underline{1E} \quad \underline{00011110}$   
 $90 \quad 10010000$   
 $C=0 \quad S=1 \quad Z=0 \quad V=1$

(C)  $9A = 10011010$   $\xrightarrow{2's \text{ comp.}}$   
 $\quad \quad \quad 01100110$   
 $\quad \quad \quad \underline{01110010}$   
 $\frac{72}{D8} \quad \quad \underline{11011000}$

(d)  $72 \quad 01110010$   
 $8D \quad 10001100$   
                      
 $00 \quad 00000000$   
 $C=0 \quad S=0 \quad Z=1 \quad V=0$

$C=0 \quad S=1 \quad Z=0 \quad V=1$   
(Borrow = 1)

(e)  $C=0$   $S=0$   $Z=1$   $V=0$

8-26

$C=1$  if  $A < B$ , therefore  $C=0$  if  $A \geq B$

$Z=1$  if  $A=B$ , therefore  $Z=0$  if  $A \neq B$

For  $A > B$  we must have  $A \geq B$  provided  $A \neq B$

or  $C=0$  and  $Z=0$  ( $C'Z'=1$ )

For  $A \leq B$  we must have  $A < B$  or  $A=B$

or  $C=1$  or  $Z=1$  ( $C+Z=1$ )

8-27

$A \geq B$  implies that  $A-B \geq 0$  (positive or zero)

sign  $S=0$  if no overflow (positive)

or  $S=1$  if overflow (sign reversal)

Boolean expression:  $S'V' + SV = 1$  or  $(S \oplus V) = 0$

$A < B$  is the complement of  $A \geq B$  ( $A-B$  negative)

then  $S=1$  if  $V=0$

or  $S=0$  if  $V=1$

$(S \oplus V) = 1$

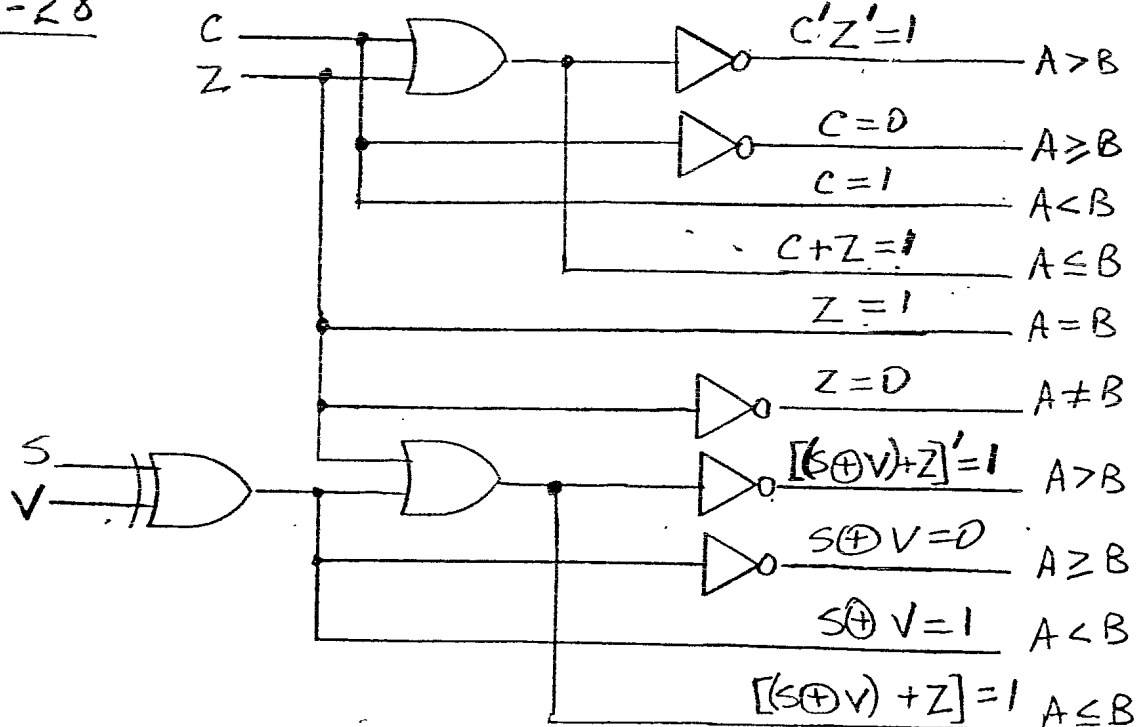
$A > B$  Implies  $A \geq B$  but not  $A=B$

$(S \oplus V) = 0$  and  $Z=0$

$A \leq B$  Implies  $A < B$  or  $A=B$

$S \oplus V = 1$  or  $Z=1$

8-28





8-29

	Unsigned	Signed
A = 01000001	65	+65
B = 10000100	132	-124
A+B = 11000101	197	-59

(c) C=0 Z=0 S=1 V=0

(d) BNC BNZ BM BN V

8-30

(a) A = 01000001 = 65

B = 10000100 = 132

A-B = 10111101 = -67 (2's comp. of 01000011)

(b) C (borrow) = 1; Z=0 65 < 132  
A < B

(c) BL, BLE, BNE

8-31

(a) A = 01000001 = +65

B = 10000100 = -124

A-B = 10111101 +189 = 01011101  
9 bits

(b) S=1 (sign reversal)

Z=0

V=1 (overflow)

65 &gt; -124

A &gt; B

(c) BGT, BGE, BNE

8-32

	PC	SP	Top of Stack
Initial	1120	3560	5320
After CALL	6720	3559	1122
After RETURN	1122	3560	5320

8-33

Branch instruction - Branch without being able to return.

Subroutine call - Branch to subroutine and then return to calling program.

Program interrupt - Hardware initiated branch with possibility to return.

8-34

See Sec. 8-7 under "Types of Interrupts".

8-35

(a)  $SP \leftarrow SP - 1$

$M[SP] \leftarrow PSW$

$SP \leftarrow SP - 1$

$M[SP] \leftarrow PC$

$TR \leftarrow IAD$  (TR is a temporary register)

$PSW \leftarrow M[TR]$

$TR \leftarrow TR + 1$

$PC \leftarrow M[TR]$

Go to fetch phase.

(b)  $PC \leftarrow M[SP]$

$SP \leftarrow SP + 1$

$PSW \leftarrow M[SP]$

$SP \leftarrow SP + 1$

8-37

$$\text{Window size} = L + 2C + G$$

$$\text{Computer 1: } 10 + 12 + 10 = 32$$

$$\text{Computer 2: } 8 + 16 + 8 = 32$$

$$\text{Computer 3: } 16 + 32 + 16 = 64$$

$$\text{Register file} = (L + C)W + G$$

$$\text{Computer 1: } (10 + 6)8 + 10 = 16 \times 8 + 10 = 138$$

$$\text{Computer 2: } (8 + 8)4 + 8 = 16 \times 4 + 8 = 72$$

$$\text{Computer 3: } (16 + 16)16 + 16 = 32 \times 16 + 16 = 528$$

### 8-38

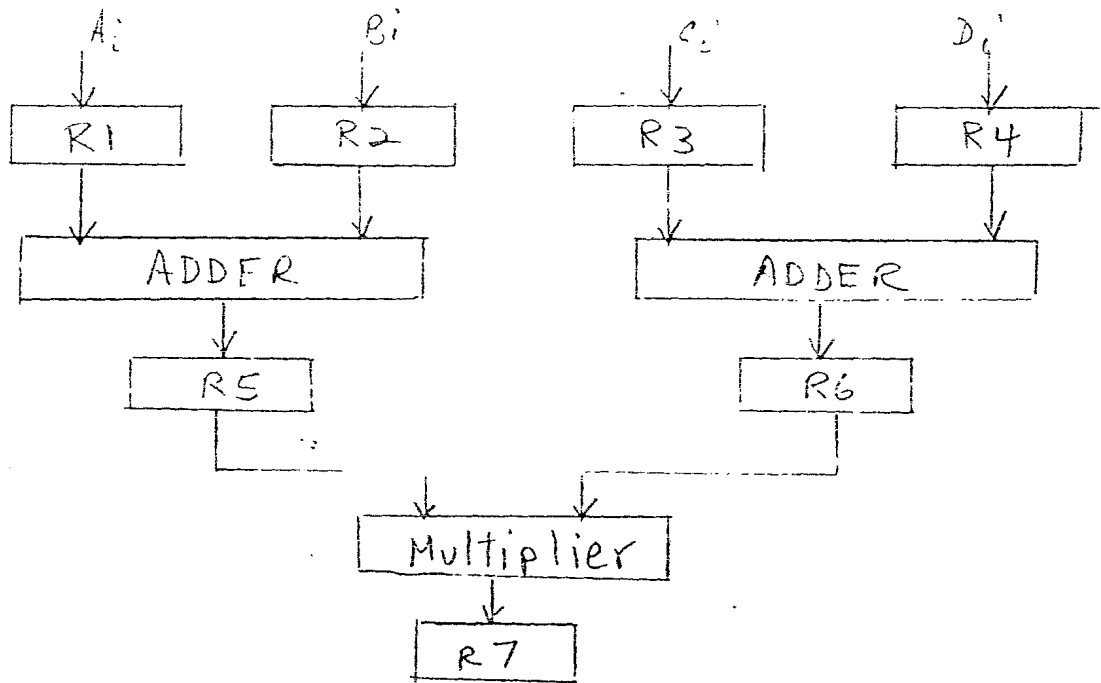
- |                       |  |
|-----------------------|--|
| (a) SUB R22, #1, R22  | $R22 \leftarrow R22 - 1$ (Subtract 1)                            |
| (b) XOR R22, #-1, R22 | $R22 \leftarrow R22 \oplus \text{all 1's}$ ( $x \oplus 1 = x'$ ) |
| (c) SUB R0, R22, R22  | $R22 \leftarrow 0 - R22$   |
| (d) ADD R0, R0, R22   | $R22 \leftarrow 0 + 0$   |
| (e) SRA R22, #2, R22  | Arithmetic shift right twice                                     |
| (f) OR R1, R1, R1     | $R1 \leftarrow R1 \vee R1$                                       |
| or ADD R1, R0, R1     | $R1 \leftarrow R1 + 0$   |
| or SLL R1, #0, R1     | shift left 0 times   |

### 8-39

- |                        |                               |
|------------------------|-------------------------------|
| (a) JMP Z, #3200, (R0) | $PC \leftarrow 0 + 3200$      |
| (b) JMPR Z, -200       | $PC \leftarrow 3400 + (-200)$ |

# CHAPTER 9

9-1



9-2

Segment	1	2	3	4	5	6	7	8	9	10	11	12	13
1	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	T <sub>5</sub>	T <sub>6</sub>	T <sub>7</sub>	T <sub>8</sub>					
2		T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	T <sub>5</sub>	T <sub>6</sub>	T <sub>7</sub>	T <sub>8</sub>				
3			T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	T <sub>5</sub>	T <sub>6</sub>	T <sub>7</sub>	T <sub>8</sub>			
4				T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	T <sub>5</sub>	T <sub>6</sub>	T <sub>7</sub>	T <sub>8</sub>		
5					T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	T <sub>5</sub>	T <sub>6</sub>	T <sub>7</sub>	T <sub>8</sub>	
6						T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	T <sub>5</sub>	T <sub>6</sub>	T <sub>7</sub>	T <sub>8</sub>

$$(k-n-1)t_p = 6+8-1 = 13 \text{ cycles} \rightarrow$$

9-3

$$k=6 \text{ segment} \\ n=200 \text{ tasks} \quad (k+n-1) = 6+200-1 = 205 \text{ cycles}$$

9-4

$$t_n = 50 \text{ ns}$$

$$k=6$$

$$t_p = 10 \text{ ns}$$

$$n=100$$

$$S = \frac{nt_n}{(k+n-1)t_p} = \frac{100 \times 50}{(6+99) \times 10} = 4.76$$

$$S_{\max} = \frac{t_n}{t_p} = \frac{50}{10} = 5$$

9-5

(a)  $t_p = 45 + 5 = 50 \text{ ns}$        $k = 3$

(b)  $t_n = 40 + 45 + 15 = 100 \text{ ns}$

(c)  $S = \frac{nt_n}{(k+n-1)t_p} = \frac{10 \times 100}{(3+9)50} = 1.67$       for  $n=10$

$$= \frac{100 \times 100}{(3+99)50} = 1.96 \quad \text{for } n=100$$

(d)  $S_{\max} = \frac{t_n}{t_p} = \frac{100}{50} = 2$

9-6

(a) See discussion in Sec. 10-3 on array multipliers. There are  $8 \times 8 = 64$  AND gates in each segment and an 8-bit binary adder (in each segment).

(b) There are 7 segments in the pipeline

(c) Average time  $= \frac{k+n-1}{n} t_p = \frac{(n+6)30}{n}$

For  $n=10$   $t_{AV} = 48 \text{ ns}$

For  $n=100$   $t_{AV} = 31.8 \text{ ns}$

For  $n \rightarrow \infty$   $t_{AV} = 30 \text{ ns}$

To increase the speed of multiplication, a carry-save (Wallace tree) adder is used to reduce the propagation time of the carries.

9-7

(a) Clock cycle  $= 95 + 5 = 100 \text{ ns}$  (time for segment 3)

for  $n=100$ ;  $k=4$ ,  $t_p=100 \text{ ns}$ .

Time to add 100 numbers  $= (k+n-1)t_p = (4+99)100$   
 $= 10,300 \text{ ns} = 10.3 \mu\text{s}$

(b) Divide segment 3 into two segments of  $50+5=55$  and  $45+5=50 \text{ ns}$ . This makes  $t_p=55 \text{ ns}$ ;  $k=5$   
 $(k+n-1)t_p = (5+99)55 = 5,720 \text{ ns} = 5.72 \mu\text{s}$

9-8 Connect output of adder to input  $B \times 2^b$  in a feedback path and use input  $A \times 2^a$  for the data  $X_1$  through  $X_{100}$ . Then use a scheme similar to the one described in conjunction with the adder pipeline in Fig. 9-12.

9-9 One possibility is to use the six operations listed in the beginning of Sec. 9-4.

9-10 See Sec. 9-4: (1) prefetch target instruction; (b) use a branch target buffer; (c) use a loop buffer; (d) use branch prediction. (Delayed branch is a software procedure.)

9-11

1. Load $R1 \leftarrow M[312]$	1	2	3	4 <sup>th</sup> step
2. Add $R2 \leftarrow R2 + M[313]$	FI	DA	FO	EX
3. Increment $R3$		FI	DA	FO
4. Store $M[314] \leftarrow R3$			FI	DA
				FI

Segment EX : Transfer memory word to  $R1$ .

Segment FO : Read  $M[313]$ .

Segment DA : Decode (increment) instruction.

Segment FI : Fetch (the store) instruction from memory.

9-12

Load:  $R1 \leftarrow \text{Memory}$

Increment:  $R1 \leftarrow R1 + 1$

$R1$  is loaded in E

It's too early to increment it in A

1	2	3	4
I	A	E	
	I	A	E

9-13

Insert a No-op instruction between the two instructions in the example of Problem 9-12 (above).

9-14

101 Add R2 to R3  
 102 Branch to 104  
 103 Increment R1  
 104 Store R1

1	2	3	4	5	6	7
I	A	E				
	I	A	E			
		-	-			
				I	A	E

9-15 Use example of Problem 9-14.

101 Branch to 105  
 102 Add R2 to R3  
 103 No-operation  
 104 Increment R1  
 105 Store R1

1	2	3	4	5	6
I	A	E	↓		
	I	A	E		
		I	A	E	
			↓		
			I	A	E

9-16

(a) There are 40 product terms in each inner product,  $40^2 = 1,600$  inner products must be evaluated, one for each element of the product matrix.

(b)  $40^3 = 64,000$

9-17

$8 + 60 + 4 = 72$  clock cycles for each inner product.

There are  $60^2 = 3600$  inner products. Product matrix takes  $3600 \times 72 = 259,200$  clock cycles to evaluate.

9-18

memory array 1 use addresses: 0, 4, 8, 12, ..., 1020.

Array 2: 1, 5, 9, 13, ..., 1021; Array 3: 2, 6, 10, ..., 1022.

Array 4: 3, 7, 11, ..., 1023.

9-19

$$\frac{250 \times 10^9}{100 \times 10^6} = 2,500 \text{ sec} = 41.67 \text{ minutes}$$

9-20

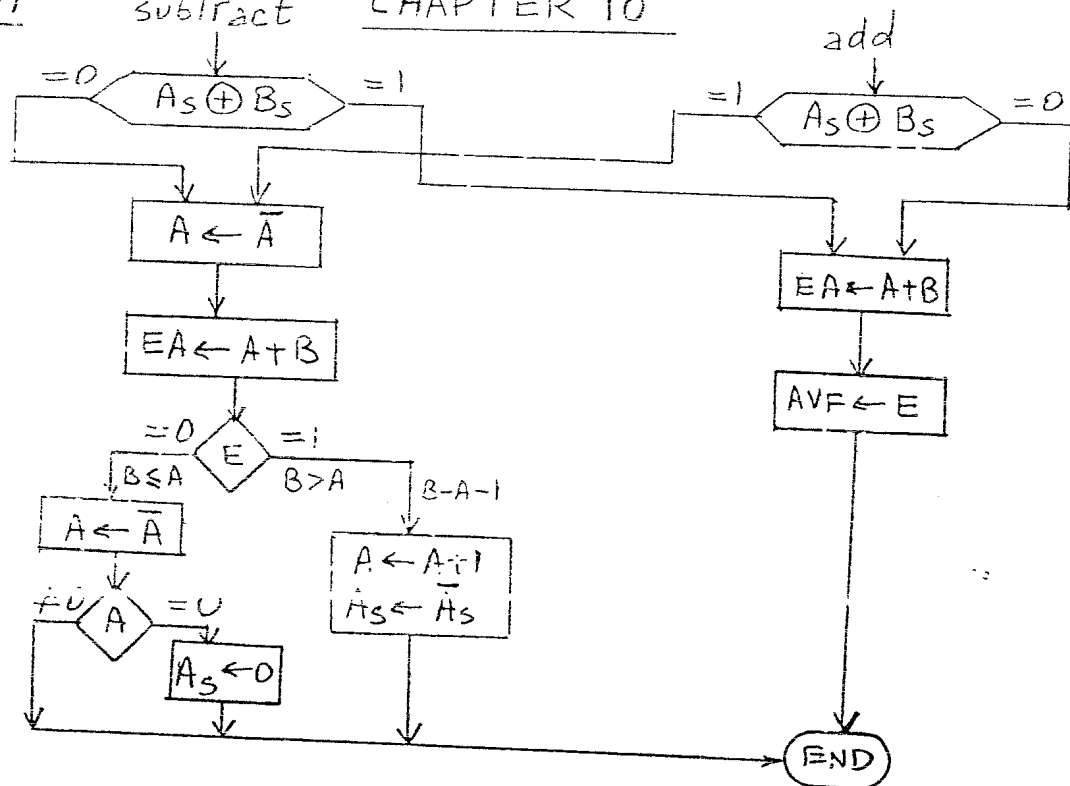
Divide the 400 operations into each of the four processors, Processing time is:  $\frac{400}{4} \times 40 = 4,000 \text{ nsec}$

Using a single pipeline, processing time is  $= 400 \times 10 = 4,000 \text{ nsec}$

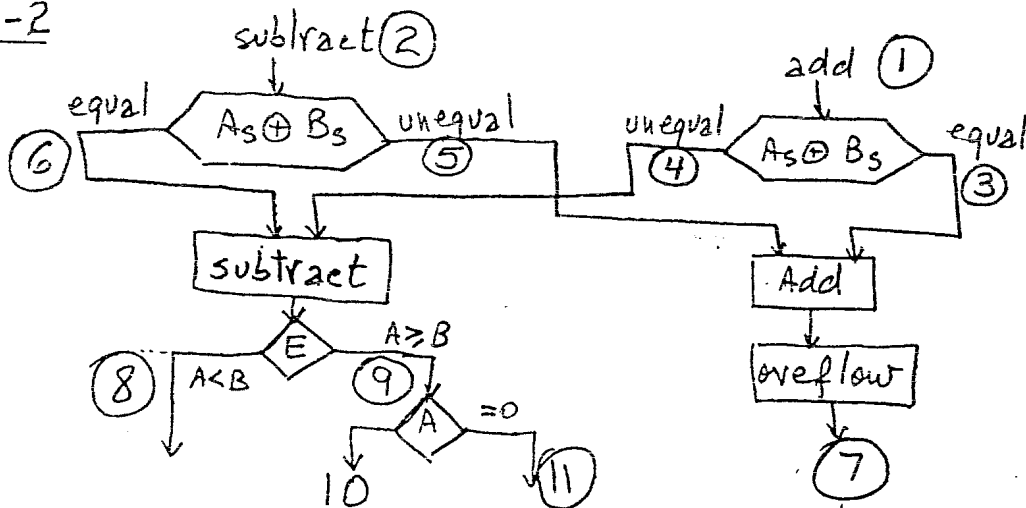
10-1

subtract

CHAPTER 10



10-2



$2^6 - 1 = 63$ , Overflow if sum greater than  $|63|$

- (a)  $(+45) + (+31) = 76$     ① ③ ⑦ ← path.    AVF=1  
 (b)  $(-31) + (-45) = -76$     ① ③ ⑦    AVF=1  
 (c)  $(+45) - (+31) = 14$     ② ⑥ ⑨ ⑩    AVF=0  
 (d)  $(+45) - (+45) = 0$     ② ⑥ ⑨ ⑪    AVF=0  
 (e)  $(-31) - (+45) = -76$     ② ⑤ ⑦    AVF=1



10-3

$$\begin{array}{r} (a) \quad +35 \quad 0 \ 100011 \\ +40 \quad 0 \ 101000 \\ \hline +75 \quad 1 \ 001011 \\ \swarrow \quad \searrow \\ F=0 \quad E=1 \end{array}$$

$F \oplus E = 1$  ; overflow

$$\begin{array}{r} (b) \quad -35 \quad 1 \ 011101 \\ -40 \quad 1 \ 011000 \\ \hline -70 \quad 0 \ 110101 \\ \swarrow \quad \searrow \\ F=1 \quad E=0 \end{array}$$

$F \oplus E = 1$  ; overflow

10-4

case	operation in sign-magnitude	operation in sign-2's complement	required result in sign-2's complement
1.	$(+X) + (+Y)$	$(0+X) + (0+Y)$	$0 + (X+Y)$
2.	$(+X) + (-Y)$	$(0+X) + 2^k + (2^k - Y)$	$0 + (X-Y)$ if $X \geq Y$ $2^k + 2^k - (Y-X)$ if $X < Y$
3.	$(-X) + (+Y)$	$2^k + (2^k - X) + (0+Y)$	$0 + (Y-X)$ if $Y \geq X$ $2^k + 2^k - (X-Y)$ if $Y < X$
4.	$(-X) + (-Y)$	$(2^k + 2^k - X) + (2^k + 2^k - Y)$	$2^k + 2^k - (X+Y)$

It is necessary to show that the operations in column (b) produce the results listed in column (c).

case 1. column (b) = column (c)

case 2. If  $X \geq Y$  then  $(X-Y) \geq 0$  and consists of  $k$  bits. operation in column (b) gives:  $2^{2k} + (X-Y)$ . Discard carry  $2^{2k} = 2^n$  to get  $0 + (X-Y)$  as in column (c)

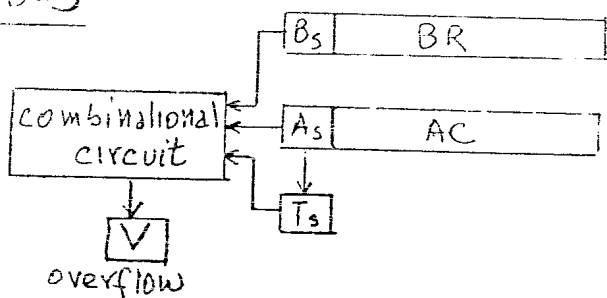
If  $X < Y$  then  $(Y-X) > 0$ . Operation gives  $2^k + 2^k - (Y-X)$  as in column (c).

case 3. is the same as case 2 with  $X$  and  $Y$  reversed

case 4. Operation in column (b) gives:  $2^{2k} + 2^k + 2^k - (X+Y)$

Discard carry  $2^{2k} = 2^n$  to obtain result of (c):  
 $2^k + (2^k - X - Y)$

10-5



Transfer Augend sign into  $T_s$ .  
Then add:  $AC \leftarrow AC + BR$   
 $A_s$  will have sign of sum.

Truth Table for combin. circuit

$T_s$	$B_s$	$A_s$	$V$	
0	0	0	0	
0	0	1	1	change of sign
0	1	0	0	
0	1	1	0	quantities subtracted
1	0	0	0	
1	0	1	0	
1	1	0	1	change of sign
1	1	1	0	

10-6 (a)

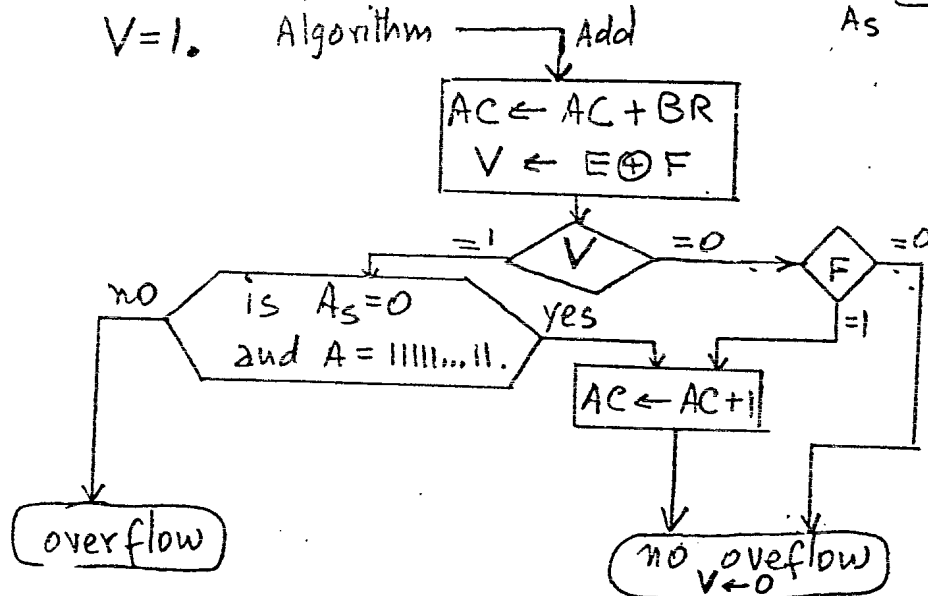
$-9 \quad 1 \ 0110$   
 $-6 \quad 1 \ 1001$   
 $-15 \quad 0 \ 1111$   
 $F=1 \quad E=0 \leftarrow \text{Carries}$

Add end around carry F as needed in signed-1's complement addition:

$0 \ 1111$   
 $+1$   
 $1 \ 0000 = -15$

$E \oplus F = 1$  but there should be no overflow since result is -15

(b) The procedure  $V \leftarrow E \oplus F$  is valid for 1's complement numbers provided we check the result  $0 \ 1111 \dots 11$  when  $V=1$ . Algorithm



10-7 Add algorithm flowchart is shown above (Prob. 10-6b)

10-8 Maximum value of numbers is  $r^{2n-1}$ . It is necessary to show that maximum product is less than or equal to  $r^{2n-1}$ . Maximum product is:

$$(r^n - 1)(r^n - 1) = r^{2n} - 2r^n + 1 \leq r^{2n} - 1$$

which gives :  $2 \leq 2r^n$  or  $1 \leq r^n$

This is always true since  $r \geq 2$  and  $n \geq 1$

10-9 multiplicand  $B = 1111 = (31)_{10}$   $31 \times 21 = 651$

Multiplier in Q	E	A	Q	sc	
$Q_n=1$ , add E	0	00000	10101	101	$Q=(21)_{10}$
		11111			
shr EAQ	0	11111			
$Q_n=0$ , shr EAQ		01111	11010	100	
$Q_n=1$ , add B		00111	11101	011	
		11111			
	1	00110			
shr EAQ	0	10011	01110	010	
$Q_n=0$ , shr EAQ		01001	10111	001	
$Q_n=1$ , add B		11111			
	1	01000			
shr EAQ		10100	01011	000	
		<u>1010001011</u>			
		$(651)_{10}$			

$$\underline{10-10(a)} \quad \frac{10100011}{1011} = 1110 + \frac{1001}{1011} \qquad \frac{163}{11} = 14 + \frac{9}{11}$$

$$B = 1011 \quad \overline{B} + 1 = 0101 \quad DVF = 0$$

Dividend in AQ	<u>E</u>	<u>A</u>	<u>Q</u>	<u>sc</u>
shl EAQ	0	1010	0011	100
add B+1, suppress carry	1	0100	0110	
E=1, set Q <sub>n</sub> to 1	1	0101	0111	011
shl EAQ	1	0010	1110	
add B+1, suppress carry	1	0101	1111	010
E=1, set Q <sub>n</sub> to 1	1	0111	1111	
shl EAQ	0	1111	1110	001
add B+1, carry to E	1	0101	1111	
E=1, set Q <sub>n</sub> to 1	1	0100	1111	000
shl EAQ	0	1001	1110	
add B+1, carry to E	1	0101	1111	
E=0, leave Q <sub>n</sub> =0	0	1110	1110	
add B	1	1011	1110	
restore remainder	1	1001	1110	000

remainder
quotient

$$\underline{10-10(b)} \quad \frac{1111}{0011} = 0101 \quad B = 0011 \quad \bar{B}+1 = 1101$$

	E	A	Q	SC
Dividend in Q, A=0	----	0000	1111	100
shl EAQ	0	0001	1110	
add $\bar{B}+1$	----	1101		
E=0, leave $Q_n=0$	0	1110	1110	
add B	----	0011		
restore partial remainder	1	0001		011
shl EAQ	0	0011	1100	
add $\bar{B}+1$	----	1101		
E=1, set $Q_n$ to 1	1	0000	1101	010
shl EAQ	0	0001	1010	
add $\bar{B}+1$	----	1101		
E=0, leave $Q_n=0$	0	1110	1010	
add B	----	0011		
restore partial remainder	1	0001		001
shl EAQ	0	0011	0100	
add $\bar{B}+1$	----	1101		
E=1, set $Q_n$ to 1	1	0000	0101	000
		remainder	quotient	

10-11

$A + \bar{B} + 1$  performs:  $A + 2^n - B = 2^n + A - B$   
 adding B:  $(2^n + A - B) + B = 2^n + A$   
 remove end-carry  $2^n$  to obtain A.

10-12

To correspond with correct result. In general:

$$\frac{A}{B} = Q + \frac{R}{B}$$

Where A is dividend, Q the quotient and R the remainder.  
 Four possible signs for A and B:

$$\frac{+52}{+5} = +10 + \frac{+2}{+5} = +10.4 \quad \frac{-52}{+5} = -10 + \frac{-2}{+5} = -10.4$$

$$\frac{+52}{-5} = -10 + \frac{+2}{-5} = -10.4 \quad \frac{-52}{-5} = +10 + \frac{-2}{-5} = +10.4$$

The sign of the remainder (2) must be same as sign of dividend (52).

10-13

Add one more stage to Fig. 10-10 with 4 AND gates and a 4-bit adder.

$$10-14 (a) (+15) \times (+13) = +195 = (0011000011)_2$$

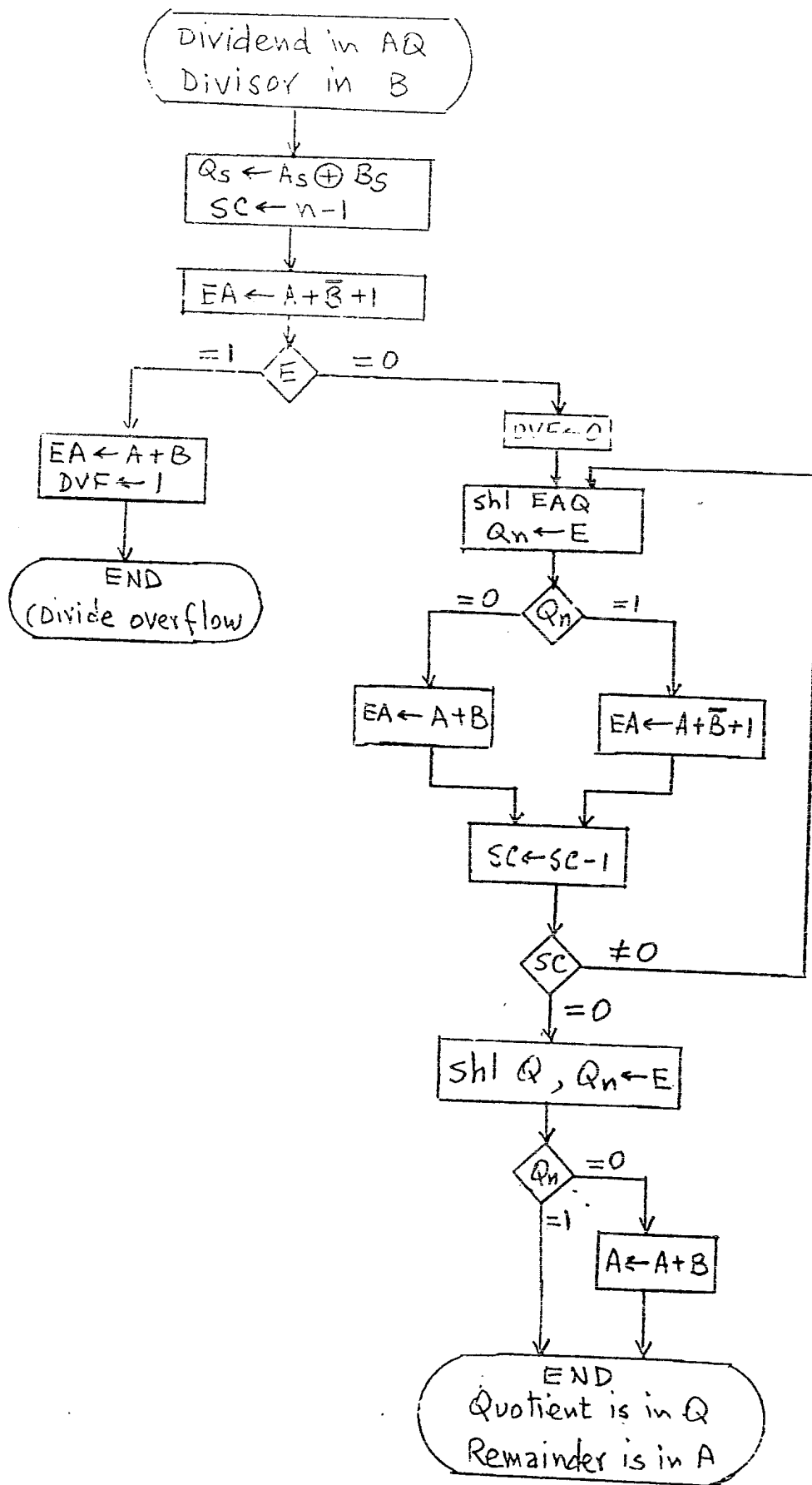
$$BR = 01111 (+15); \overline{BR}+1 = 10001 (-15); QR = 01101 (+13)$$

$Q_n Q_{n+1}$		AC	QR	$Q_{n+1}$	SC
	Initial	00000	01101	0	101
1 0	Subtract BR	10001			
		10001			
	ashr	11000	10110	1	100
0 1	Add BR	01111			
		00111			
	ashr	00011	11011	0	011
1 0	Subtract BR	10001			
		10100			
	ashr	11010	01101	1	010
1 1	ashr	11101	00110	1	001
0 1	Add BR	01111			
		01100			
	ashr	00110	00011	0	000
		+ 195			

(b)  $(+15) \times (-13) = -195 = (1100111101)_2$  2's comp.  
 $BR = 01111 (+15); \overline{BR}+1 = 10001 (-15); QR = 10011 (-13)$

$Q_n Q_{n+1}$		AC	QR	$Q_{n+1}$	SC
	Initial	00000	10011	0	101
1 0	Subtract BR	10001			
		10001			
	ashr	11000	11001	1	100
1 1	ashr	11100	01100	1	011
0 1	Add BR	01111			
		01011			
	ashr	00101	10110	0	010
0 0	ashr	00010	11011	0	001
1 0	Subtract BR	10001			
		10011			
	ashr	11001	11101	1	000
		- 195			

10-15



10-16 The algorithm for square-root is similar to division with the radicand being equivalent to the dividend and a "test value" being equivalent to the divisor.

Let  $A$  be the radicand,  $Q$  the square-root, and  $R$  the remainder such that  $Q^2 + R = A$  or:

$$\sqrt{A} = Q \text{ and a remainder}$$

General comments:

1. For  $k$  bits in  $A$  ( $k$  even),  $Q$  will have  $k/2$  bits:

$$Q = q_1 q_2 q_3 \dots q_{k/2}$$

2. The first test value is 01

The second test value is 09, 01

The third test value is 009, 92, 01

The fourth test value is 0009, 9293, 01 etc.

3. Mark the bits of  $A$  in groups of two starting from left.

4. The procedure is similar to the division restoring method as shown in the following example:

$\begin{array}{cccc} q_1 & q_2 & q_3 & q_4 \\ 1 & 1 & 0 & 1 \end{array}$	$= Q = 13$
$\sqrt{10 \ 10 \ 10 \ 01}$	$= A = 169$
$\begin{array}{r} 01 \\ \hline 01 \ 10 \\ 01 \ 01 \\ \hline 00 \ 01 \\ 00 \ 01 \ 10 \\ 00 \ 11 \ 01 \\ \hline \end{array}$	<p>subtract first test value 01</p> <p>Answer positive; let <math>q_1 = 1</math></p> <p>bring down next pair</p> <p>subtract second test value 09, 01</p> <p>answer positive; let <math>q_2 = 1</math></p> <p>bring down next pair</p> <p>subtract third test value 009, 92, 01</p> <p>answer negative; let <math>q_3 = 0</math></p> <p>restore partial remainder</p> <p>bring down next pair</p> <p>subtract fourth test value 0009, 9293, 01</p>
$\begin{array}{r} 00 \ 01 \ 10 \\ \hline 00 \ 01 \ 10 \\ \hline 00 \ 01 \ 10 \ 01 \\ \hline 00 \ 01 \ 10 \ 01 \end{array}$	<p>negative</p> <p>answer positive (zero); let <math>q_4 = 1</math></p>

Remainder = 00000

10-17 (a)  $e = \text{exponent}$

$e+64 = \text{biased exponent}$

$e$	$e+64$	biased exponent
-64	$-64+64=0$	0 000 000
-63	$-63+64=1$	0 000 001
-62	$-62+64=2$	0 000 010
-1	$-1+64=63$	0 111 111
0	$0+64=64$	1 000 000
+1	$1+64=65$	1 000 001
+62	$62+64=126$	1 111 110
+63	$63+64=127$	1 111 111

(b) The biased exponent follows the same algorithm as a magnitude comparator. See Sec. 9-2

(c)  $(e_1+64) + (e_2+64) = (e_1+e_2+64) + 64$   
subtract 64 to obtain biased exponent sum

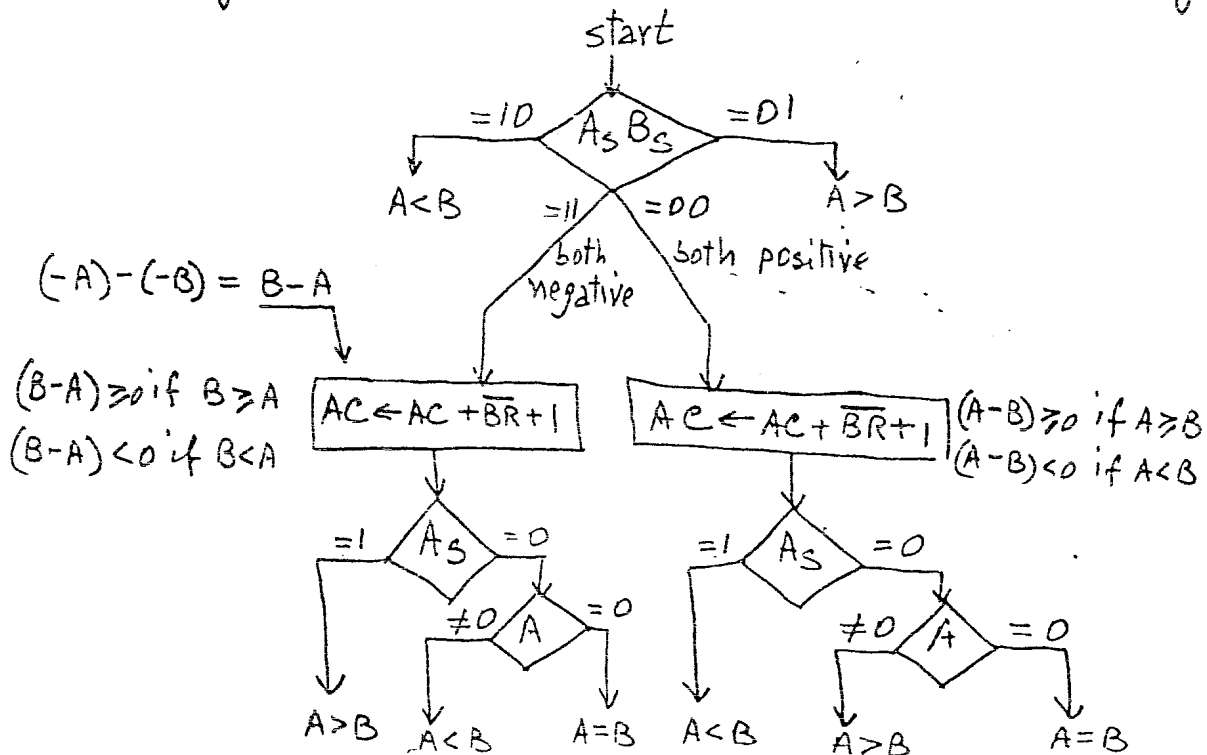
(d)  $(e_1+64) - (e_2-64) = e_1+e_2$   
add 64 to obtain biased exponent difference.

10-18

(a)  $AC = A_s A_1 A_2 A_3 \dots A_n$   
 $BS = B_s B_1 B_2 B_3 \dots B_n$

If signs are unlike - the one with a 0 (plus) is larger.

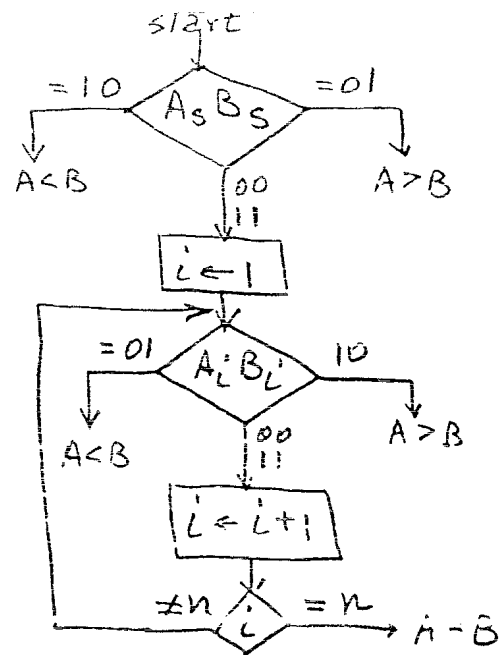
If signs are alike - both numbers are either positive or negative





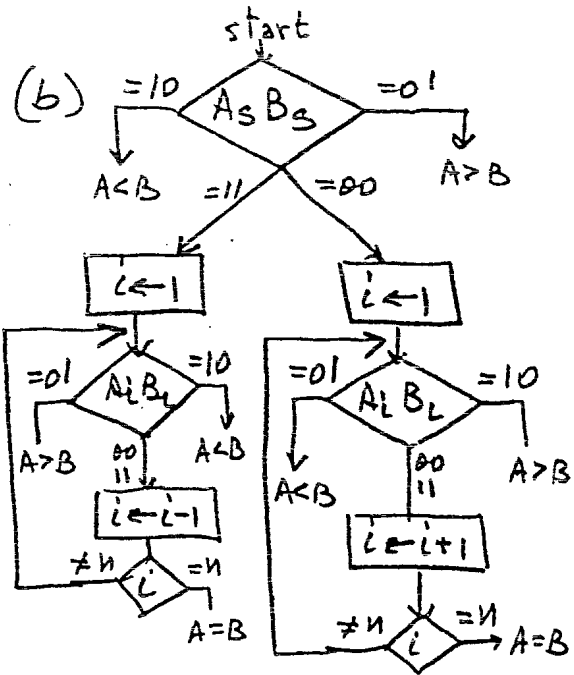
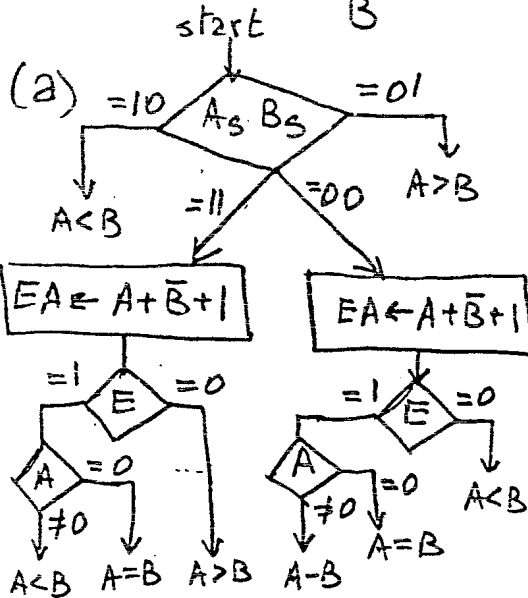
10-18(b)

	$A_5$	$A_4$	$A_3$	$A_2$	$A_1$	$A_0$	$A_n$
+2	0	0	0	0	0	1	0
+1	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0
-1	1	1	1	1	1	1	1
-2	1	1	1	1	1	1	0
-3	1	1	1	1	1	0	1



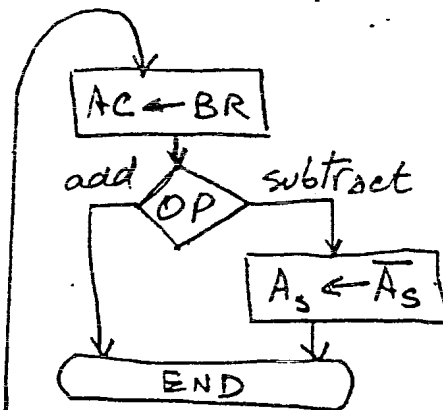
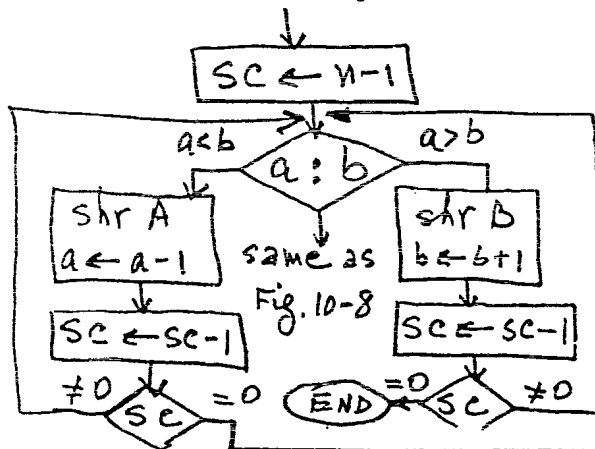
10-19

$A_5 \overbrace{A_4 A_3 A_2 \dots A_n}^A$   
 $B_5 \overbrace{B_4 B_3 \dots B_n}^B$

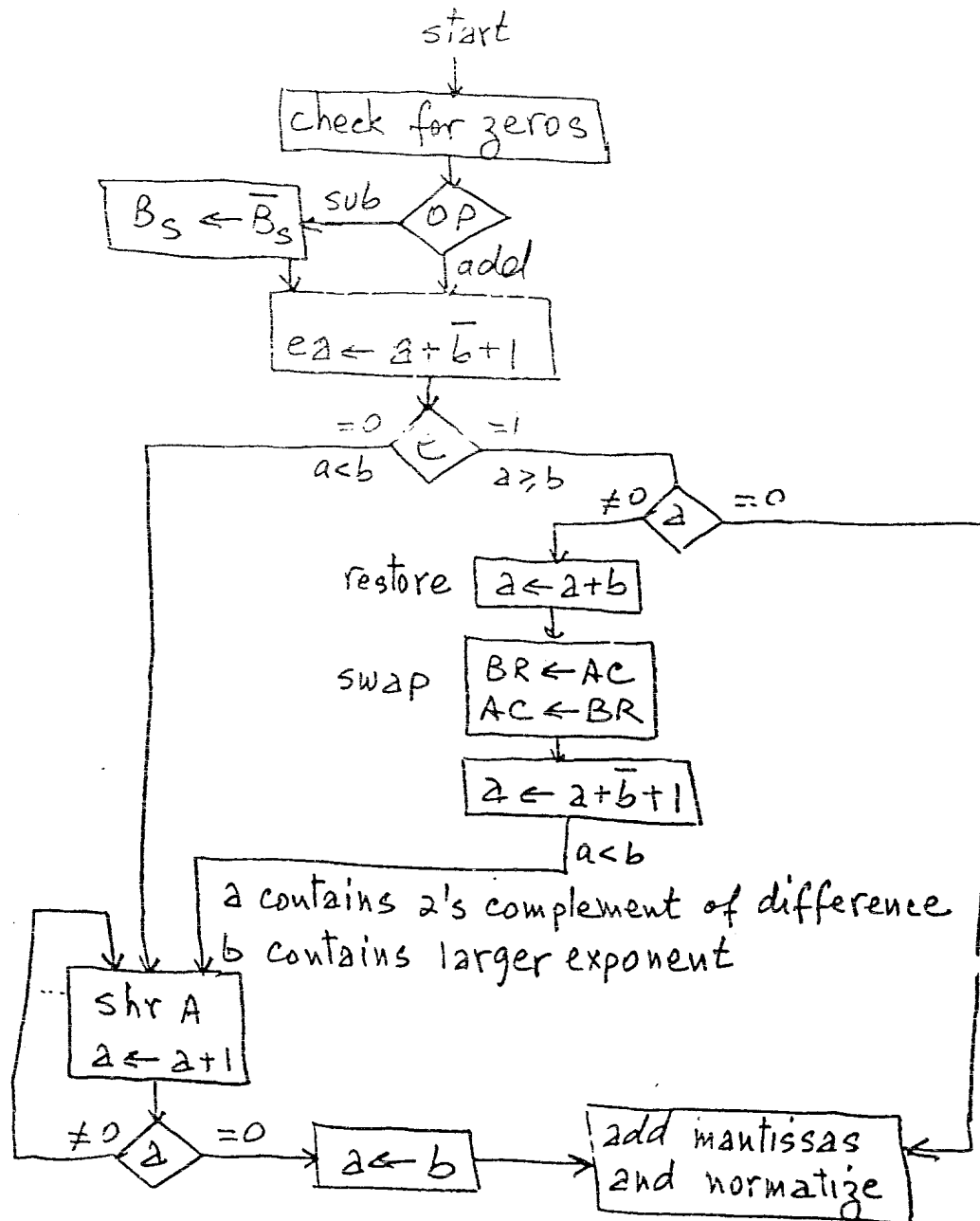


10-20

Fig 10-8  
 mantissa alignment



10-21 Let "e" be a flip-flop that holds end-carry after exponent addition,



10-22

When 2 numbers of  $n$  bits each are multiplied, the product is no more than  $2n$  bits long — see Prob. 9-7.

10-23 dividend  $A = 0.1xxxx$  where  $x = 0, 1$   
divisor  $B = 0.1xxxx$

(a) If  $A < B$  then after shift we have  $A = 1.xxxx$  and 1st quotient bit is 0.

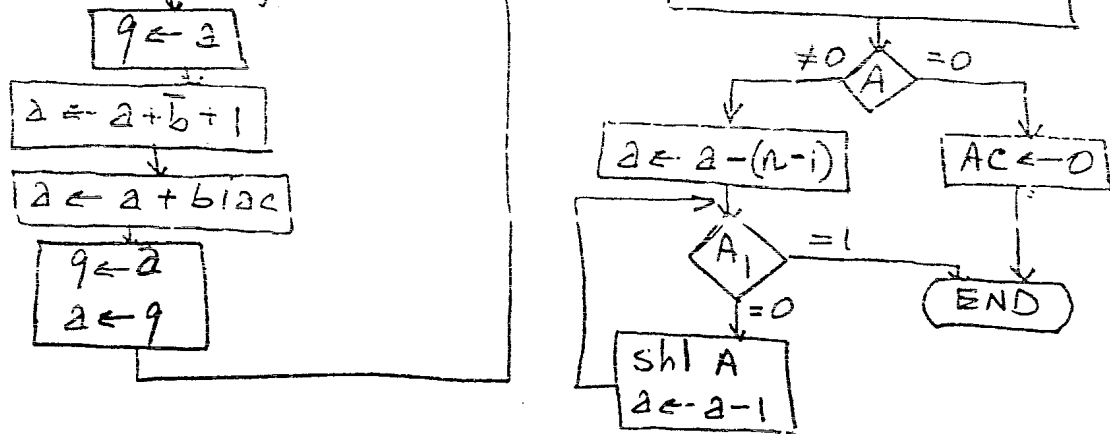
(b) if  $A \geq B$ , dividend alignment results in  $A = 0.01xxxx$  then after the left shift  $A \geq B$  and first quotient bit = 1.

10-24

$$\frac{\text{dividend}}{\text{divisor}} = \frac{\overbrace{.1xxxx}^{n-1 \text{ bits}} * 2^{e_1}}{\overbrace{.1yyyy}^{n-1 \text{ bits}} * 2^{e_2}} = .13333 * 2^{e_1 - e_2} + \frac{\overbrace{.00000rrrrr}^{\text{remainder}} * 2^{e_1}}{\overbrace{.1yyyy}^{n-1 \text{ bits}} * 2^{e_2}}$$

Remainder bits rrrrr have a binary-point (n-1) bits to the left.

Fig. 10-10 after dividend alignment



10-25

- When the exponents are added or incremented
- When the exponents are subtracted or decremented
- Check end-carry after addition and carry after increment or decrement.

10-26

Assume integer mantissa of  $n-1=5$  bits (excluding sign)

(a) Product:  $\begin{matrix} A & Q \\ xxxxx & xxxxx \end{matrix} * 2^3$

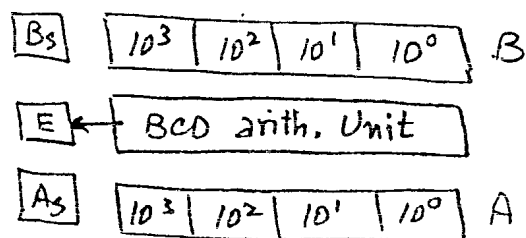
Product in AC:  $xxxxx * 2^{3+5}$  binary-point for integer

(b) Single precision normalized dividend:  $xxxxx * 2^3$

Dividend in AQ:  $\begin{matrix} A & Q \\ xxxxx & 00000 \end{matrix} * 2^{3-5}$

10-27

Neglect  $B_e$  and  $A_e$  from Fig. 10-14. Apply carry directly to E.

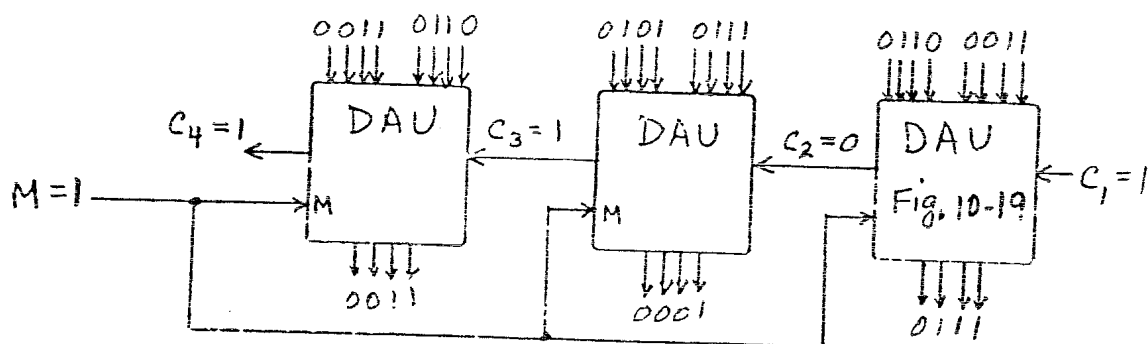


10-28

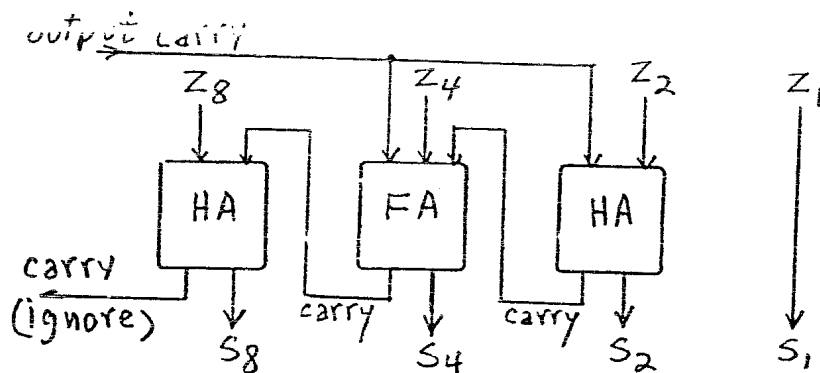
$$\begin{array}{r} 673 \\ - 356 \\ \hline 317 \end{array}$$

$$10's \text{ comp. of } 356 = 644 +$$

$$\text{carry} \rightarrow 1 \quad 317$$

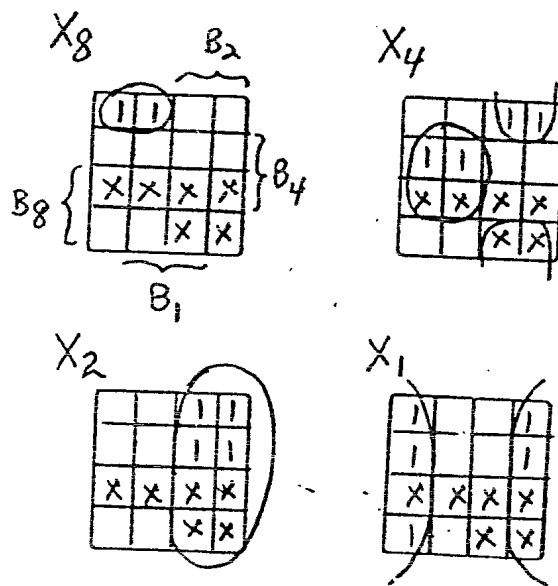


10-29



10-30

	inputs				outputs				
	$B_8$	$B_4$	$B_2$	$B_1$	$X_8$	$X_4$	$X_2$	$X_1$	
0	0	0	0	0	1	0	0	1	9
1	0	0	0	1	1	0	0	0	8
2	0	0	1	0	0	1	1	1	7
3	0	0	1	1	0	1	1	0	6
4	0	1	0	0	0	1	0	1	5
5	0	1	0	1	0	1	0	0	4
6	0	1	1	0	0	0	1	1	3
7	0	1	1	1	0	0	1	0	2
8	1	0	0	0	0	0	0	1	1
9	1	0	0	1	0	0	0	0	0



$d(B_8 B_4 B_2 B_1) = \Sigma(10, 11, 12, 13, 14, 15)$   
are don't-care conditions

$$X_8 = B_8' B_4' B_2'$$

$$X_4 = B_4 B_2' + B_4' B_2$$

$$X_2 = B_2$$

$$X_1 = B_1'$$

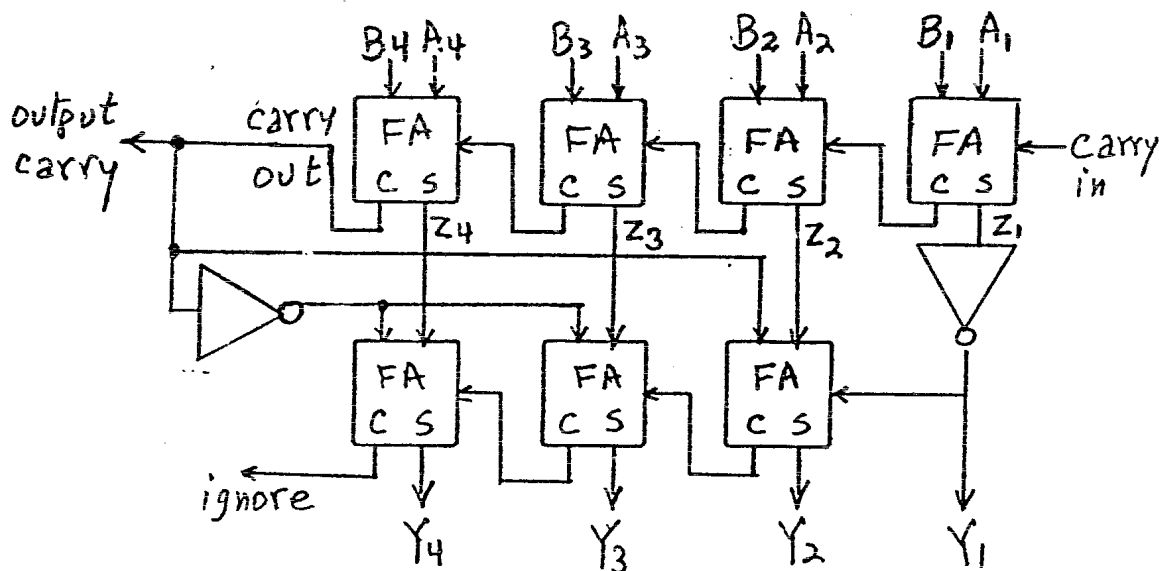
10-31

dec	Z uncorrected	Y corrected
0	0110	0011
1	0111	0100
2	1000	0101
3	1001	0110
4	1010	0111
5	1011	1000
6	1100	1001
7	1101	1010
8	1110	1011
9	1111	1100

No output carry  
 $Y = Z - 3 = Z + 13 - 16$   
 ignore carry

dec	Z uncorrected	Y corrected
10	10000	10011
11	10001	10100
12	10010	10101
13	10011	10110
14	10100	10111
15	10101	11000
16	10110	11001
17	10111	11010
18	11000	11011
19	11001	11100

Uncorrected = output carry  
 $Y = Z + 3$

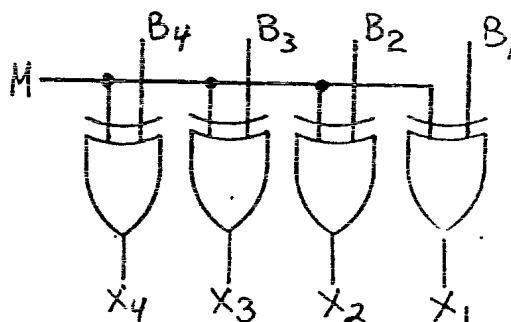


10-32. The excess-3 code is self-complementing code. Therefore, to get 9's complement we need to complement each bit.

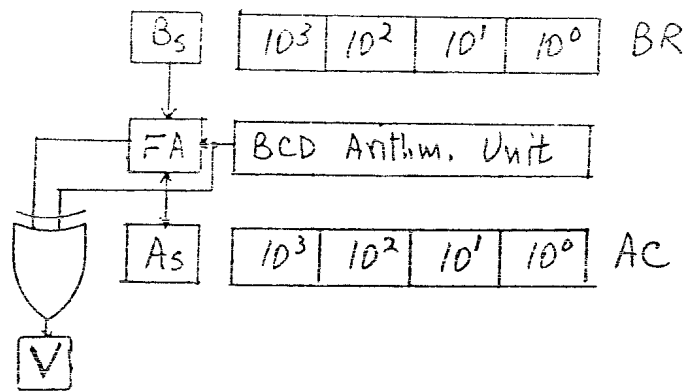
M=0 for x=B  
 M=1 for x=9's comp. of B

M	B <sub>i</sub>	x <sub>i</sub> = B <sub>i</sub> ⊕ M
0	0	0
0	1	1
1	0	1
1	1	0

$x_i = B_i$  for M=0  
 $x_i = B'_i$  for M=1



10-33



Algorithm is similar to flow chart of Fig. 10-2

10-34 (a)  $B = 410$

	$A_e$	$A$	$Q \downarrow$	$sc$
initial	0	000	152	3
$Q_L \neq 0$	0	470	151	
$Q_L \neq 0$	0	940	150	
$Q_L = 0, dshr$	0	094	015	2
$Q_L \neq 0$	0	564	014	
	1	034	013	
	1	504	012	
	1	974	011	
	2	444	010	
$Q_L = 0, dshr$	0	244	401	1
$Q_L \neq 0$	0	714	400	
$Q_L = 0, dshr$	0	071	440	0
Product				

(b)

999	
$\times 199$	
8991	- first partial product $A_e = 8$
+ 89910	
98901	- second partial product $A_e = 9$
+ 99900	
198801	- final product $A_e = 1$

$$\overline{B} + 1 = 968 \text{ (10's comp.)}$$

(Continued here)

	<u>E</u>	<u>Ae</u>	<u>A</u>	<u>Q</u>	<u>SC</u>
dshl	---	0	30	50	1
add B+1	---	9	68		
E=1	1	0	48	51	
		9	68		
	1	0	16	52	
		9	68		
E=0	0	9	84		
add B	---	0	32		
	1	0	16	52	0

remainder      quotient

## CHAPTER 11

$$11-1 \quad \begin{array}{c} A_7 \text{ --- } A_2 \quad A_1 A_0 \\ 12 = 000011 \quad 00 \end{array}$$

$$13 = 000011 \quad 01$$

$$14 = 000011 \quad 10$$

$$15 = \underbrace{000011}_{\text{To CS}} \quad \begin{array}{c} 11 \\ \uparrow \quad \uparrow \\ \text{RSI} \quad \text{RSO} \end{array}$$

$$CS = A_2 A_3 A'_4 A'_5 A'_6 A'_7$$

$$RSI = A_1$$

$$RSO = A_0$$

11-2

Interface	Port A	Port B	Control Reg	Status Reg
# 1	1000 0000	1000 0001	1000 0010	1000 0011
2	0100 0000	0100 0001	0100 0010	0100 0011
3	0010 0000	0010 0001	0010 0010	0010 0011
4	0001 0000	0001 0001	0001 0010	0001 0011
5	0000 1000	0000 1001	0000 1010	0000 1011
6	0000 0100	0000 0101	0000 0110	0000 0111

11-3

Character printer; Line printer; Laser printer;  
Digital ploller; Graphic display; Voice output;  
Digital to analog converter; Instrument indicator.

11-5

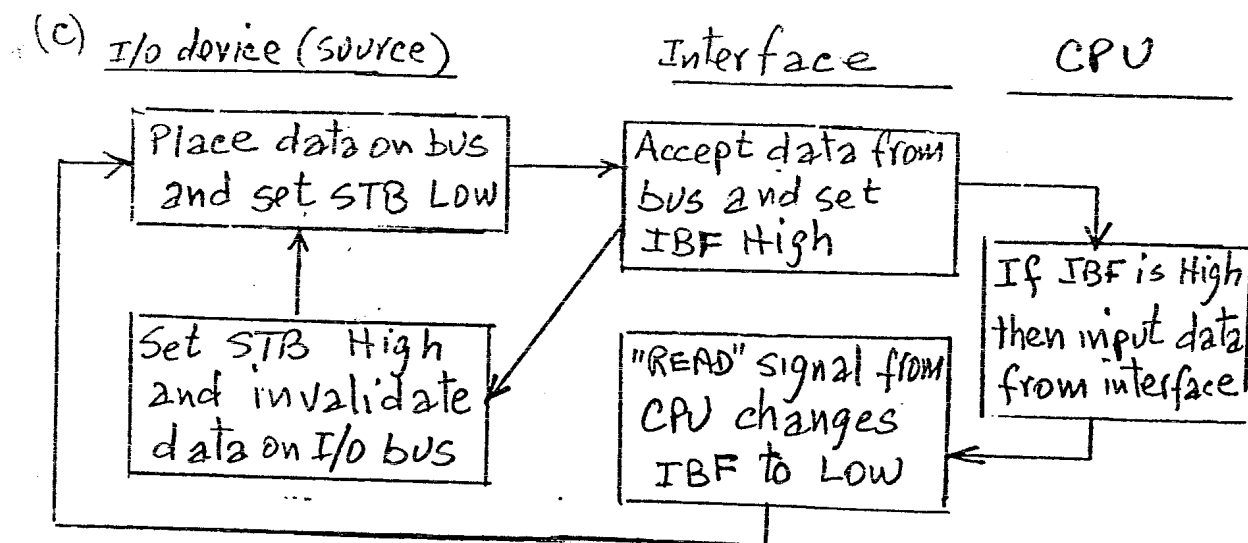
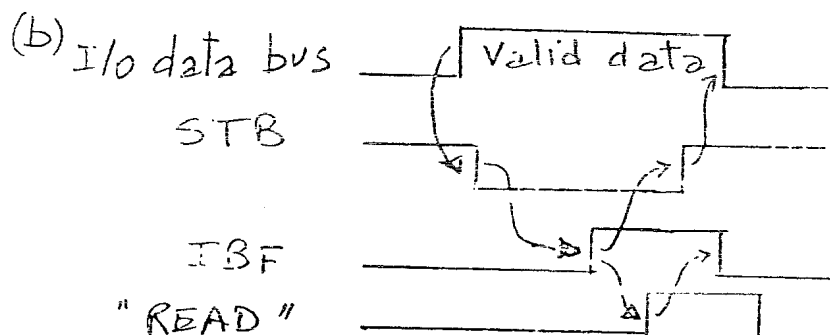
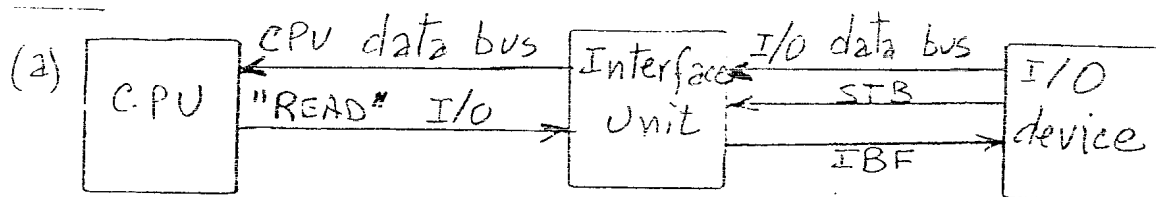
See text discussion in Sec. 11-2.

11-6

- (a) Status command - Checks status of flag bit,
- (b) Control command - Moves magnetic head in disk,
- (c) Status command - checks if device power is on,
- (d) Control command - Moves paper position,
- (e) Data input command - Reads value of a register

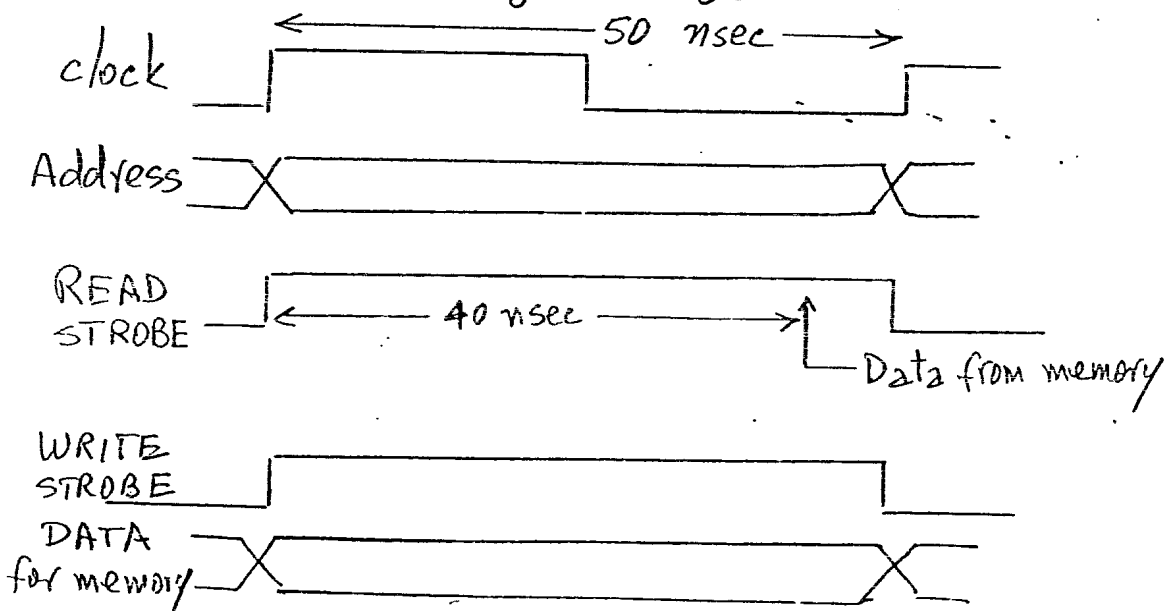


11-7

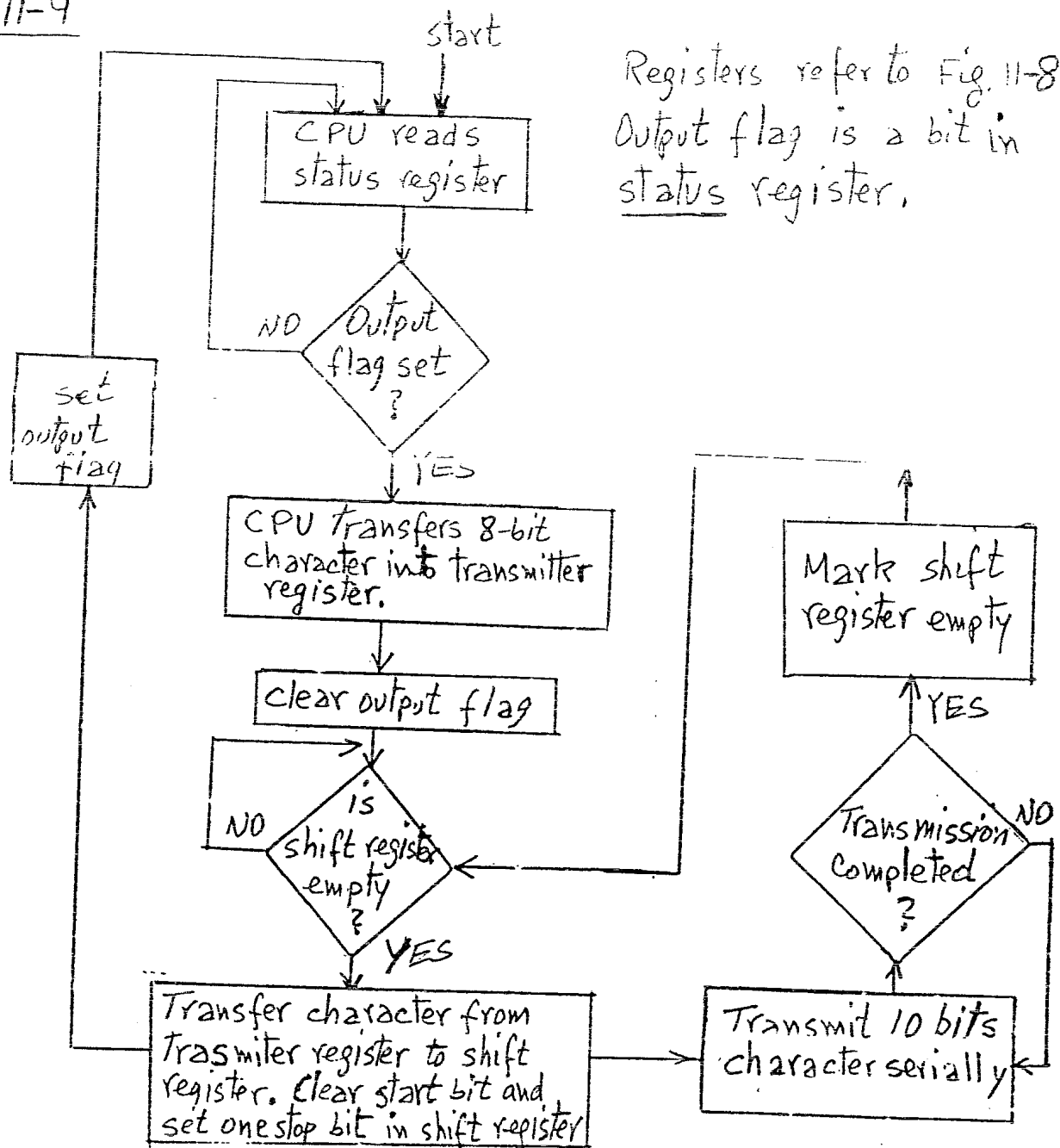


11-8

$$20\text{MHz} = 20 \times 10^6 \text{ Hz} \quad T = \frac{10^{-6}}{20} = 50 \text{ nsec.}$$



11-9



11-10

1. Output flag to indicate when transmitter register is empty.
2. Input flag to indicate when receiver register is full.
3. Enable interrupt if any flag is set.
4. Parity error; (5) Framing error; (6) Overrun error.

11-11

10 bits : start bit + 7 ASCII + parity + stop bit.

From Table 11-1 ASCII W = 1010111

with even parity = 11010111

with start and stop bits = 1110101110

11-12

(a)  $\frac{1200}{8} = 150$  characters per second (cps)

(b)  $\frac{1200}{11} = 109$  cps

(c)  $\frac{1200}{10} = 120$  cps

11-13

(a)  $\frac{k \text{ bytes}}{(m-n) \text{ bytes/sec}} = \frac{k}{m-n} \text{ sec.}$

(b)  $\frac{k}{n-m} \text{ sec.}$  (c) No need for FIFO

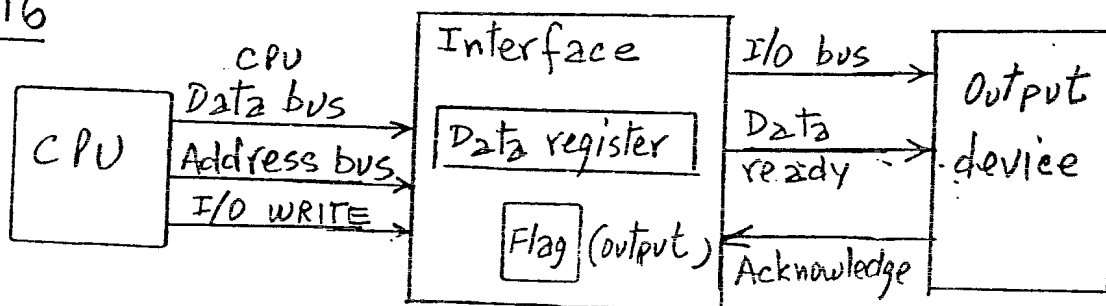
11-14

Initial	F = 0011	Output $\leftarrow$ R4
After delete = 1	F = 0010	
After delete = 0	F = 0001	R4 $\leftarrow$ R3
After insert = 1	F = 1001	R1 $\leftarrow$ Input
(Insert goes to 0)	F = 0101	R2 $\leftarrow$ R1
	F = 0011	R3 $\leftarrow$ R2

11-15

	Input ready	output ready	F <sub>1</sub> -F <sub>4</sub>
(a) Empty buffer	1	0	0000
(b) Full buffer	0	1	1111
(c) Two items	1	1	0011

11-16

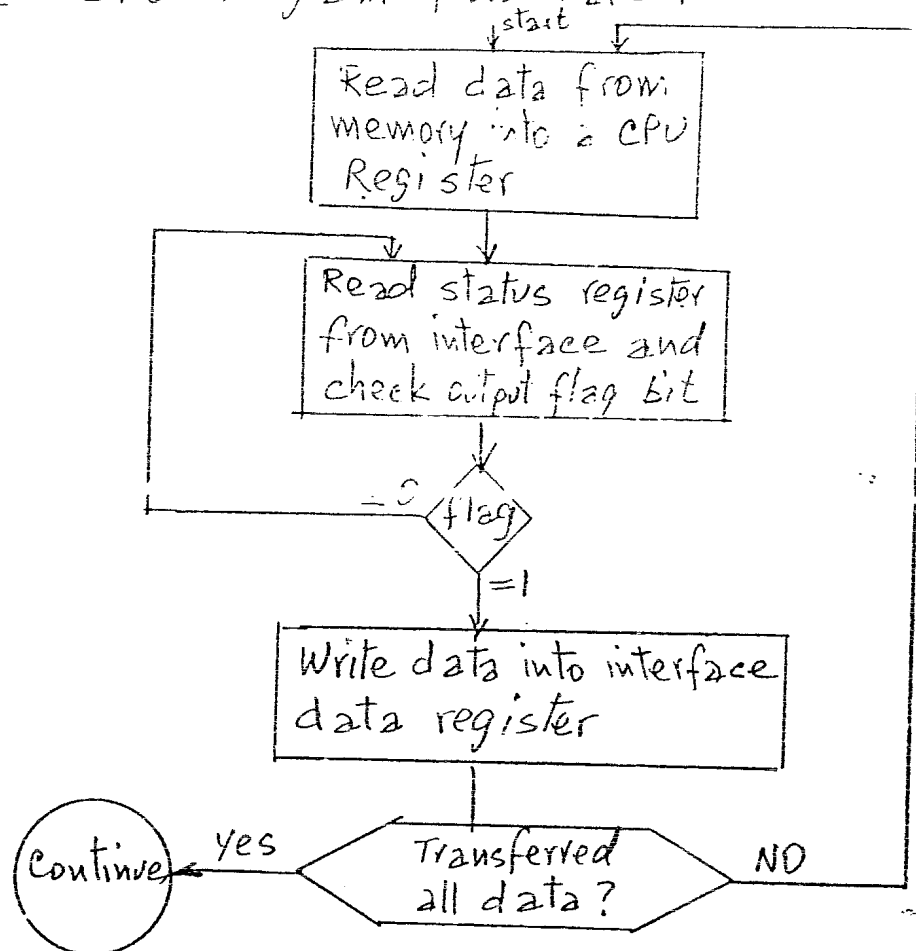


Flag = 0 if data register full (After CPU writes data)

Flag = 1 if data register empty (After the transfer to device)

When flag goes to 0, enable "Data ready" and place data on I/O bus. When "Acknowledge" is enabled, set the flag to 1 and disable "ready" handshake line.

## 11-17 CPU Program flow chart :



11-18

See text Section 11-4.

11-19

If an interrupt is recognized in the middle of an instruction execution, it is necessary to save all the information from control registers in addition to processor registers. The state of the CPU to be saved is more complex.

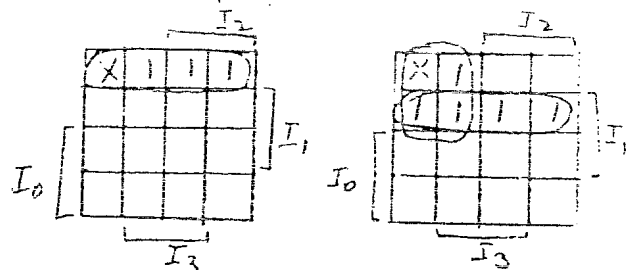
11-20

	Device 1	Device 2
(1) Initially, device 2 sends an interrupt request:	PI=0; PD=0; RF=0	PI=0; PD=0; RF=1
(2) Before CPU responds with acknowledge, device 1 sends interrupt request:	PI=0; PD=0; RF=1	PI=0; PD=0; RF=1
(3) After CPU sends an acknowledge, device 1 has priority:	PI=1; PD=0; RF=1 VAD enable=1	PI=0; PD=0; RF=1 VAD enable=0

# 11-22 Table 11-2

$I_0$	$I_1$	$I_2$	$I_3$	$XY$	$IST$
1	X	X	X	00	1
0	1	X	X	01	1
0	0	1	X	10	1
0	0	0	1	11	1
0	0	0	0	XX	0

Map simplification



$$X = I_0' I_1'$$

$$Y = I_0' I_1 + I_0' I_2'$$

# 11-23

Same as Fig. 11-14. Needs 8 AND gates and an 8x3 decoder.

# 11-24

$I_0$	$I_1$	$I_2$	$I_3$	$I_4$	$I_5$	$I_6$	$I_7$	$XYZ$	$IST$
1	X	X	X	X	X	X	X	000	1
0	1	X	X	X	X	X	X	001	1
0	0	1	X	X	X	X	X	010	1
0	0	0	1	X	X	X	X	011	1
0	0	0	0	1	X	X	X	100	1
0	0	0	0	0	1	X	X	101	1
0	0	0	0	0	0	1	X	110	1
0	0	0	0	0	0	0	1	111	1
0	0	0	0	0	0	0	0	XXX	0

(b)

Binary

hexadecimal

10100000  
10100100  
10101000  
10101100  
10110000  
10110100  
10111000  
10111100

A0  
A4  
A8  
AC  
B0  
B4  
B8  
BC

# 11-25

$$76 = (01001100)_2$$

Replace the six 0's by 010011, xy

# 11-26

Set the mask bit belonging to the interrupt source so it can interrupt again.

At the beginning of the service routine, check the value of the return address in the stack. If it is an address within the source service program, then the same source has interrupted again while being serviced.

# 11-21

The service routine checks the flags in sequence to determine which one is set. The first flag that is checked has the highest priority level. The priority level of the other sources corresponds to the order in which the flags are checked.

11-27

When the CPU communicates with the DMA controller, the read and write lines are used as inputs from the CPU to the DMA controller.

When the DMA controller communicates with memory, the read and write lines are used as outputs from the DMA to memory.

11-28

- (a) CPU initiates DMA by transferring:
- 256 to the word count register.
  - 1230 to the DMA address register.
  - Bits to the control register to specify a write operation.

(b)

1. I/O device sends a "DMA request".
2. DMA sends BR (bus request) to CPU.
3. CPU responds with a BG (bus grant).
4. Contents of DMA address register are placed in address bus.
5. DMA sends "DMA acknowledge" to I/O device and enables the write control line to memory.
6. Data word is placed on data bus by I/O device.
7. Increment DMA address register by 1 and decrement DMA word count register by 1.
8. Repeat steps 4-7 for each data word transferred.

11-29

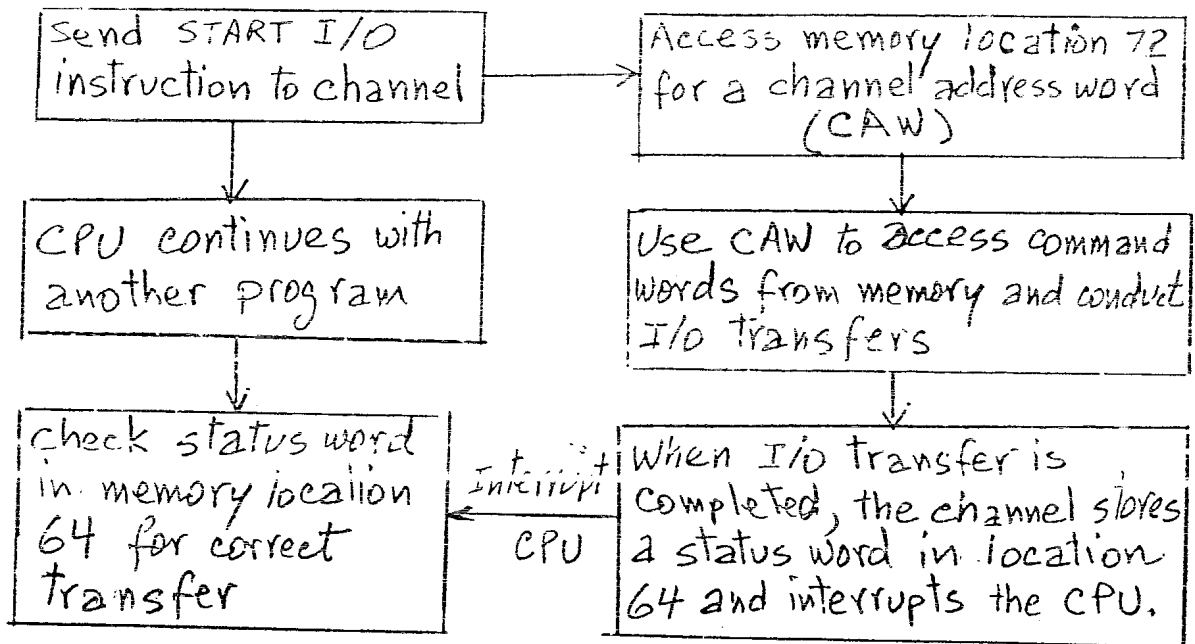
CPU refers to memory on the average once (or more) every  $1 \mu\text{sec}$ , ( $1/10^6$ ). Characters arrive one every  $1/2400 = 416.6 \mu\text{sec}$ . Two characters of 8 bits each are packed into a 16-bit word every  $2 \times 416.6 = 833.3 \mu\text{sec}$ . The CPU is slowed down by no more than  $(1/833.3) \times 100 = 0.12\%$ .

11-30

The CPU can wait to fetch instructions and data from memory without any damage occurring except loss of time. DMA usually transfers data from a device that cannot be stopped since information continues to flow so loss of data may occur.

### 11-31 CPU operations

### I/O channel operations



11-32 There are 26 letters and 10 numerals.

$$26 \times 26 + 26 \times 10 = 936 \text{ possible addresses.}$$

11-33

The processor transmits the address of the terminal followed by ENQ (enquiry) code 0000 0101. The terminal responds with either ACK (acknowledge) or NAK (negative acknowledge) or the terminal does not respond during a timeout period. If the processor receives an ACK, it sends a block of text.

11-34

DLE	STX	DLE	DLE	ETX	DLE	DLE	ETX	DLE	ETX
↑		↑			↑			↑	
delete		delete			delete			delete	
	STX		DLE	ETX		DLE	ETX		ETX

32-bit text = 0001 0000 1000 0011 0001 0000 1000 0011

11-35

32 bits between two flags; 48 bits including the flags.

11-36

Information to be sent (1023): 0 1111111111  
After zero insertion, information transmitted: 0 11111 0 11111 0  
Information received after 0's deletion: 0 11111 11111

12-1 (a)  $\frac{2048}{128} = 16$  chips

## CHAPTER 12

- (b)  $\frac{2048}{128} = 2^{11}$  11 lines to address 2048 bytes  
 $\frac{128}{128} = 2^7$  7 lines to address each chip  
 4 lines to decoder for selecting 16 chips

(c) 4x16 decoder

12-2

- (a) 8 chips are needed with address lines connected in parallel.  
 (b)  $16 \times 8 = 128$  chips. Use 14 address lines ( $16K = 2^{14}$ )  
 10 lines specify the chip address.  
 4 lines are decoded into 16 chip-select inputs.

12-3

10 pins for inputs, 4 for chip-select, 8 for outputs, 2 for power.  
 Total of 24 pins.

12-4

$4096/128 = 32$  RAM chips ;  $4096/512 = 8$  ROM chips.  
 $4096 = 2^{12}$  — There 12 common address lines + 1 line to select between RAM and ROM.

Component	Address	16 15 14 13	12 11 10 9	8 7 6 5	4 3 2 1
RAM	0000-0FFF	0 0 0 0	$\xleftrightarrow[5 \times 32]{\text{decoder}}$	x x x x	x x x x
ROM	1000-1FFF	0 0 0 1	$\xleftrightarrow[3 \times 8]{\text{decoder}}$	x x x x	x x x x

to CS2  $\uparrow$  decoder

12-5

RAM  $2048/256 = 8$  chips ;  $2048 = 2^{11}$  ;  $256 = 2^8$   
 ROM  $4096/1024 = 4$  chips ;  $4096 = 2^{12}$  ;  $1024 = 2^{10}$   
 Interface  $4 \times 4 = 16$  registers ;  $16 = 2^4$

Component	Address	16 15 14 13	12 11 10 9	8 7 6 5	4 3 2 1
RAM	0000-07FF	0 0 0 0	$\xleftrightarrow[3 \times 8]{\text{decoder}}$	x x x x	x x x x
ROM	4000-4FFF	0 1 0 0	$\xleftrightarrow[2 \times 4]{\text{decoder}}$	x x x x	x x x x
Interface	8000-800F	1 0 0 0	0 0 0 0	0 0 0 0	x x x x

12-6

The processor selects the external register with an address 8000 hexadecimal. Each bank of 32K bytes are selected by addresses 0000-7FFF. The processor loads an 8-bit number into the register with a single 1 and 7 0's. Each output of the register selects one of the 8 banks of 32K bytes through a chip-select input. A memory bank can be changed by changing the number in the register.



12-7 Average time =  $T_s$  + time for half revolution +  
+ time to read a sector.

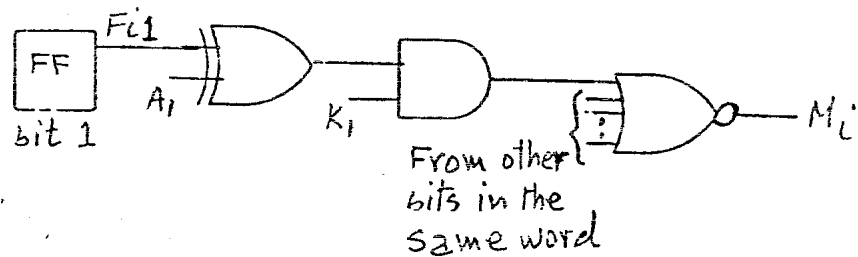
$$T_2 = T_s + \frac{1}{2R} + \frac{N_s}{N_t} \times \frac{1}{R}$$

12-8 An eight-track tape reads 8 bits (one character)  
at the same time. Transfer rate =  $1600 \times 120 = 192,000$   
characters/s

12-9

From Sec. 12-4:  $M_i = \prod_{j=1}^n [(A_j \oplus F_{ij})' + K_j']$

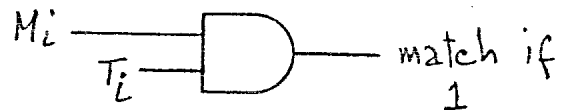
$$M_i' = \sum_{j=1}^n (A_j \oplus F_{ij}) K_j$$



12-10

A match occurs if  $T_i = 1$

$$\text{match} = M_i T_i$$

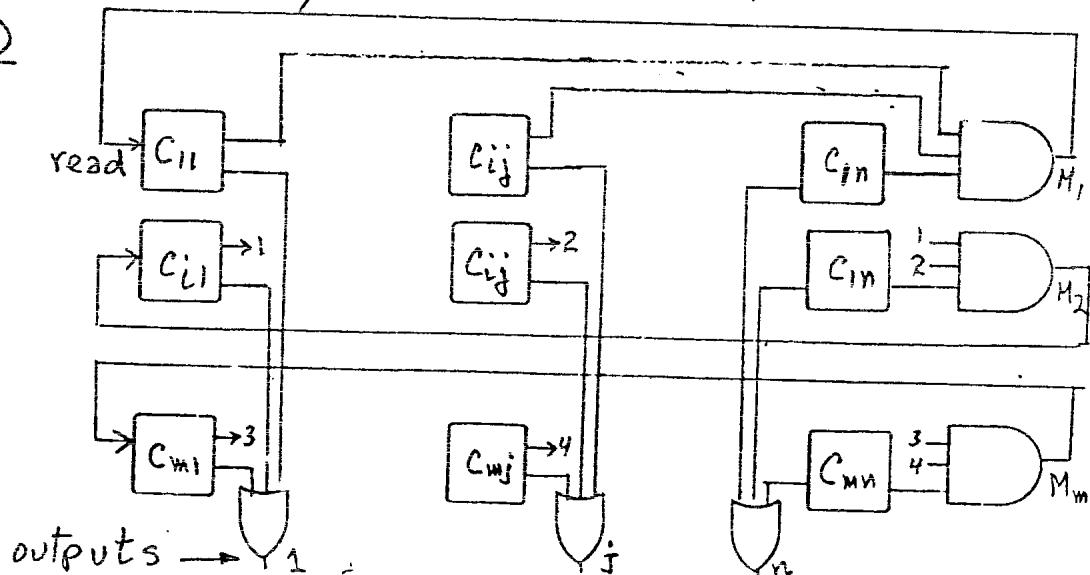


12-11

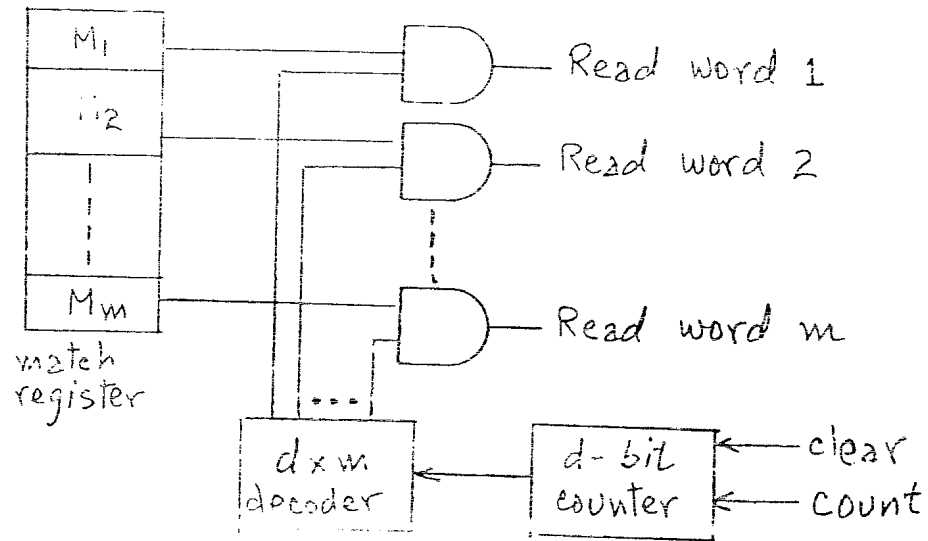
$$M_i = \left( \prod_{j=1}^n A_j F_{ij} + A_j' F_{ij}' + K_j' \right) \cdot (K_1 + K_2 + K_3 + \dots + K_n)$$

At least one key bit  $K_i$  must be equal to 1

12-12(c)



12-13



A  $d$ -bit counter drives a  $d$ -to- $m$  line decoder where  $2^d = m$  ( $m$  = No. of words in memory). For each count, the  $M_i$  bit is checked and if 1, the corresponding read signal for word  $i$  is activated.

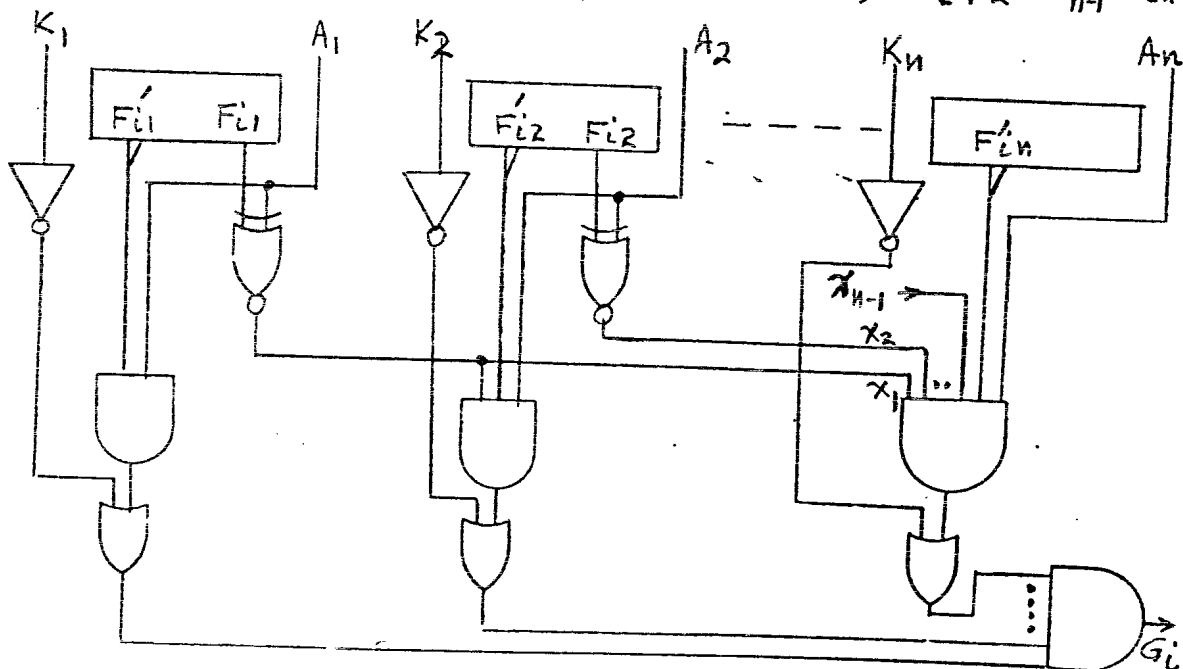
12-14

Let  $x_j = A_j F_{ij} + A'_j F'_{ij}$  (argument bit = memory word bit)

Output indicator  $G_i = 1$  if:

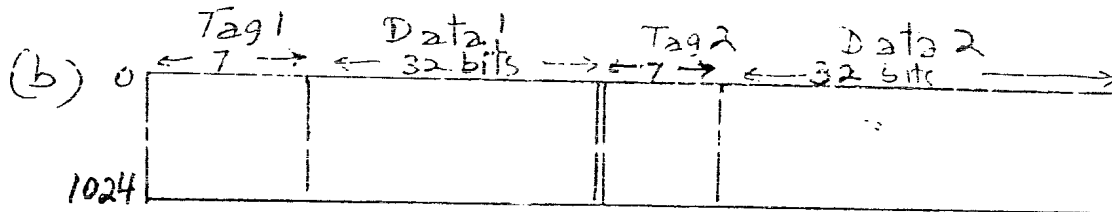
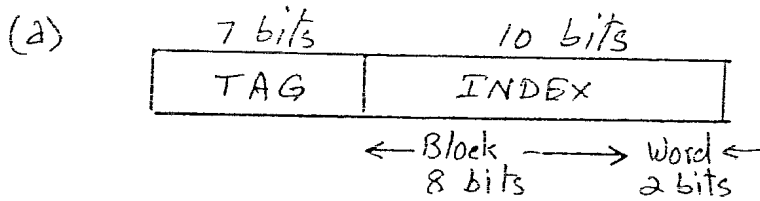
$A_1 F'_{i1} = 1$  and  $K_1 = 1$  (First bit in  $A = 1$  while  $F_{i1} = 0$ )  
 or if  $x_1 A_2 F'_{i2} = 1$  and  $K_2 = 1$  (First pair of bits are equal and second bit in  $A = 1$  while  $F_{i2} = 0$ )  
 ... etc.

$$G_i = (A_1 F'_{i1} + K'_1)(x_1 A_2 F'_{i2} + K'_2)(x_1 x_2 A_3 F'_{i3} + K'_3) \dots (x_1 x_2 \dots x_{n-1} A_n F'_{in} + K'_n)$$



12-15

$128K = 2^{17}$ ; For a set size of 2, the index address has 10 bits to accommodate  $\frac{2048}{2} = 1024$  words of cache.



Size of cache memory is  $1024 \times 2(7+32)$   
 $= 1024 \times 78$

12-16

(a)  $0.9 \times \underbrace{100}_{\text{cache access}} + 0.1 \times \underbrace{11000}_{\text{cache+memory access}} = 90 + 110 = 200 \text{ nsec.}$

(b)  $0.2 \times \underbrace{1000}_{\text{write access}} + 0.8 \times \underbrace{200}_{\text{read access from (a)}} = 200 + 160 = 360 \text{ nsec.}$

(c) Hit ratio =  $0.8 \times 0.9 = 0.72$

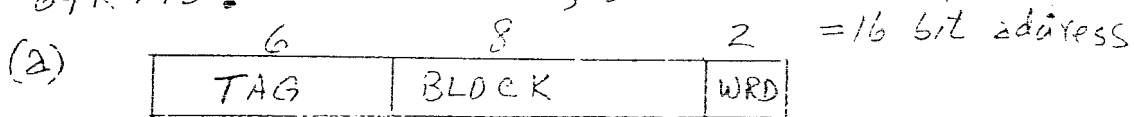
12-17

Sequence: A B C D B E D A C E C E

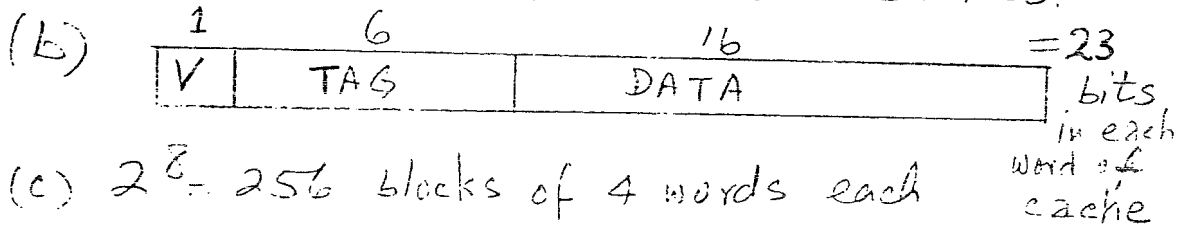
	LRU $\rightarrow$
Count value =	<u>3 2 1 0</u>
Initial words =	A B C D
B is a hit	A C D B
E is a miss	C D B E
D is a hit	C B E D
A is a miss	B E D A
C is a miss	E D A C
E is a hit	D A C E
C is a hit	D A E C
E is a hit	D A C E

12-18

64K x 16 : 16 bit address; 16-bit data.



INDEX = 10 bit cache address.



(c)  $2^8 = 256$  blocks of 4 words each

12-19

(a) Address space = 24 bits  $2^{24} = 16$  M words

(b) Memory space = 16 bits  $2^{16} = 64$  K words

(c)  $\frac{16 \text{ M}}{2 \text{ K}} = 8 \text{ K pages}$   $\frac{64 \text{ K}}{2 \text{ K}} = 32 \text{ blocks}$

12-20

The pages that are not in main memory are:

Page	Address	address that will cause fault
2	2K	2048 - 3071
3	3K	3072 - 4095
5	5K	5120 - 6143
7 ...	7K	7168 - 8191

12-21

4 2 0 1 2 6 14 0 10 2 3 5 7

Page reference	(a) Pages in main memory	Contents of FIFO	(b) Pages in memory	LRU	Most recently used
Initial	0 1 2 4	4 2 0 1	0 1 2 4	4 2 0 1	
2	0 1 2 4	4 2 0 1	0 1 2 4	4 0 1 2	
6	0 1 2 6	2 0 1 6	0 1 2 6	0 1 2 6	
1	0 1 2 6	2 0 1 6	0 1 2 6	0 2 6 1	
4	0 1 4 6	0 1 6 4	1 2 4 6	2 6 1 4	
0	0 1 4 6	0 1 6 4	0 1 4 6	6 1 4 0	
1	0 1 4 6	0 1 6 4	0 1 4 6	6 4 0 1	
0	0 1 4 6	0 1 6 4	0 1 4 6	6 4 1 0	
2	1 2 4 6	1 6 4 2	0 1 2 4	4 1 0 2	
3	2 3 4 6	6 4 2 3	0 1 2 3	1 0 2 3	
5	2 3 4 5	4 2 3 5	0 2 3 5	0 2 3 5	
7	2 3 5 7	2 3 5 7	2 3 5 7	2 3 5 7	

12-22

600AF and F00AF

12-23

Logical address: 

7 bits	5 bits	12 bits	= 24 bits
Segment	Page	Word	

Physical address: 

12 bits	12 bits
Block	Word

12-24

Segment 36 =  $(0100100)_2$  (7-bit binary)

Page 15 =  $(01111)_2$  (5-bit binary)

Word 2000 =  $(011111010000)_2$  (12-bit binary)

Logical address = 0100100 0111 011111010000  
(24-bit binary)

## CHAPTER 13

13-1

Tightly coupled multiprocessors require that all processors in the system have access to a common global memory. In loosely coupled multiprocessors, the memory is distributed and a mechanism is required to provide message-passing between the processors. Tightly coupled systems are easier to program. Since no special steps are required to make shared data available to two or more processors, A loosely coupled system required that sharing of data be implemented by the messages.

13-2

The address assigned to common memory is never assigned to any of the local memories. The common memory is recognized by its distinct address.

13-3

$P \times M$  switches

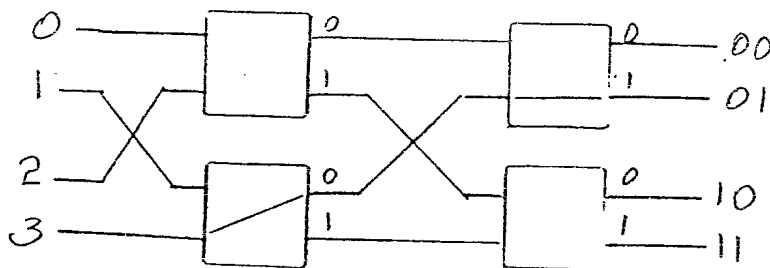
13-4

$\log_2 n$  stages with  $\frac{n}{2}$  switches in each stage.

13-5

Inputs 0, 2, 4, and 6 will be disconnected from outputs 2 and 3.

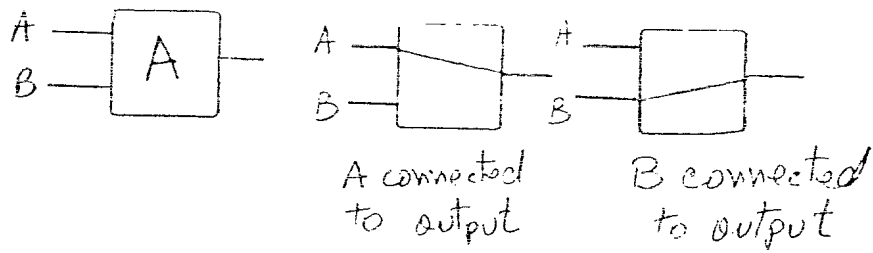
13-6



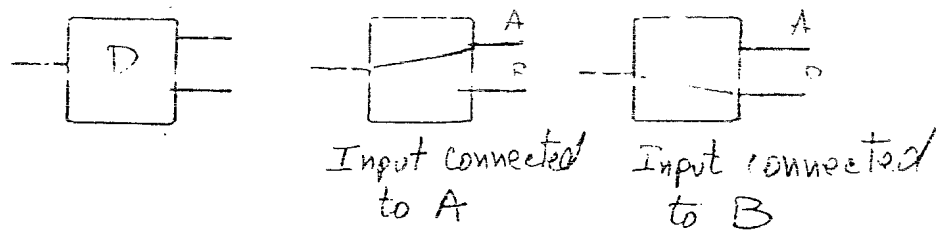
13-7

Arbitration switch:

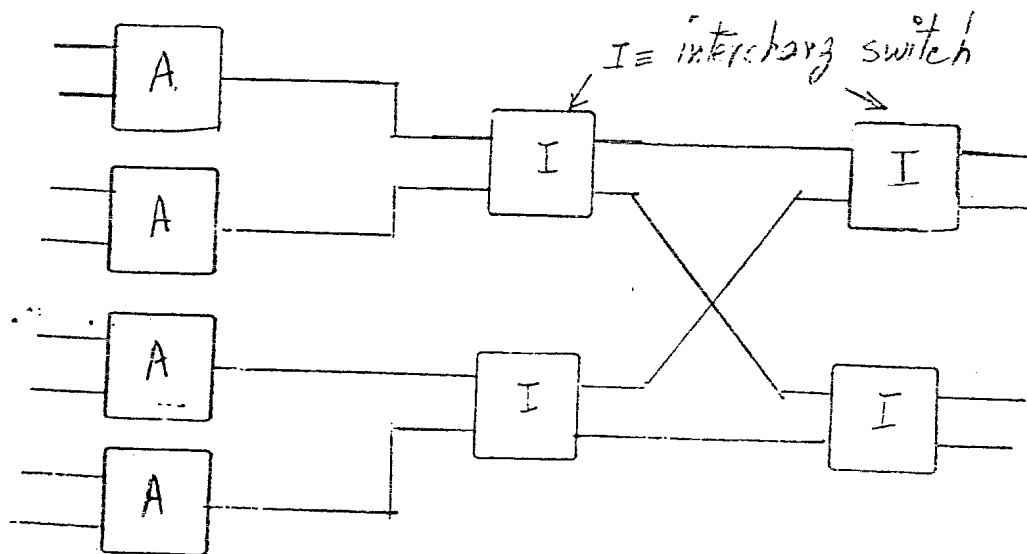
(a)



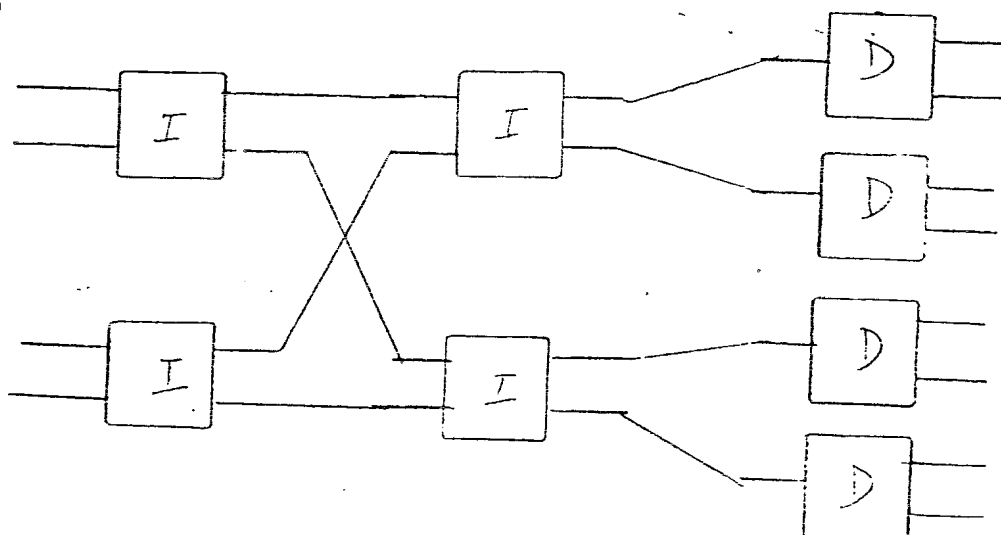
Distribution switch:



(b)



(c)







13-10

Encoder input

Encoder output

Decoder input

Decoder output

$$\begin{array}{cccc} 1 & 2 & 3 & 4 \\ 1 & 1 & 1 & 1 \\ \hline 0 & 1 & 1 & 0 \end{array}$$

01 (I<sub>1</sub> has highest priority)

01  
0100 Arbitrator 2 (I<sub>2</sub>) is acknowledged

13-11

As explained in the text, connect output PO from arbitrator 4 into input PI of arbitrator 1. Once the line is disabled, the arbitrator that releases the bus has the lowest priority.

13-12

Memory access needed to send data from one processor to another must be synchronized with test-and-set instructions. Most of the time would be taken up by unsuccessful test by the receiver. One way to speed the transfer would be to send an interrupt request to the receiving processor.

13-13

(a) Mutual exclusion implies that each processor claims exclusive control of the resources allocated to it.

(b) Critical section is a program sequence that must be completely executed without interruptions by other processors.

(Continued in next page)

### 13-13 (Continued)

- (c) Hardware lock is a hardware signal to ensure that a memory read is followed by a memory write without interruption from another processor.
- (d) Semaphore is a variable that indicates the number of processes attempting to use the critical section.
- (e) Test and set instruction causes a read-modify-write memory operation so that the memory location cannot be accessed and modified by another processor.

### 11-14

Cache coherence is defined as the situation in which all cache copies of shared variables in a multiprocessor system have the same value at all times. A snoop cache controller is a monitoring action that detects a write operation into any cache. The cache coherence problem can be resolved by either updating or invalidating all other cache values of the written information.