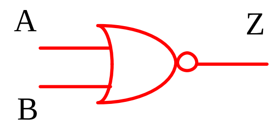
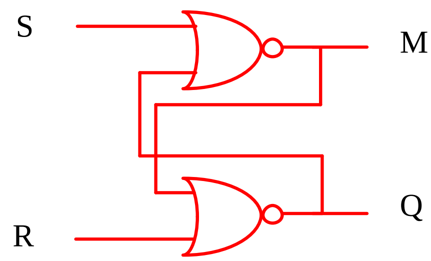
<u>NOR gate property:</u>

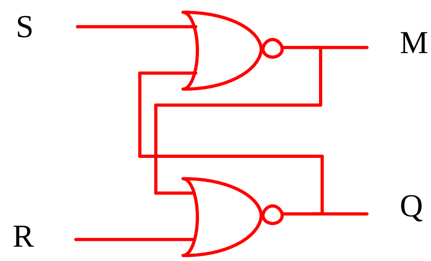
A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0



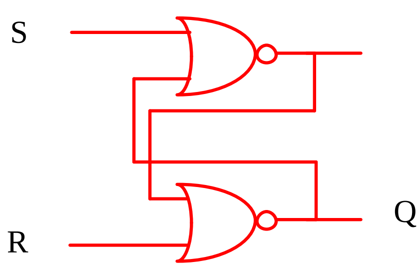
<u>Cross coupled NOR gates:</u>

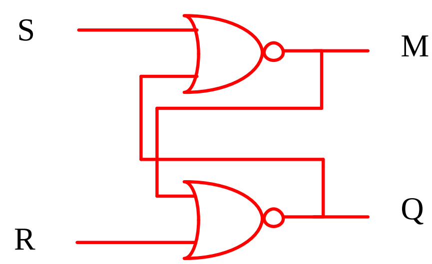
S	R	Q	M
0	0		
0	1		
1	0		
1	1		

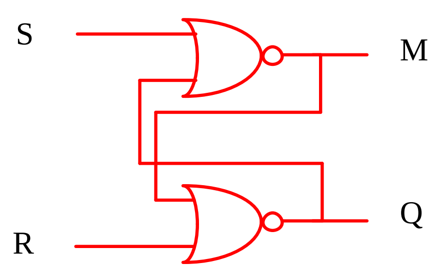


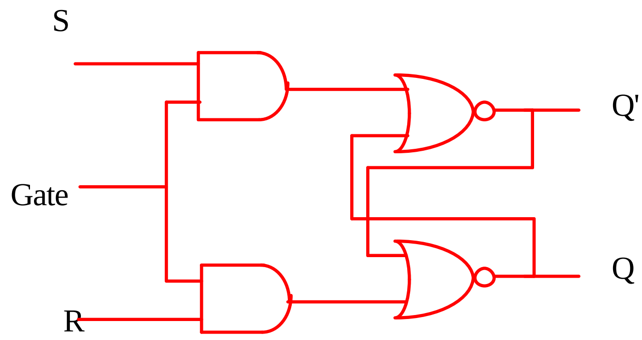


S	R	Q
0	0	
0	1	
1	0	
1	1	

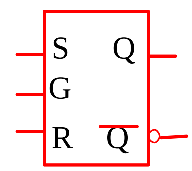




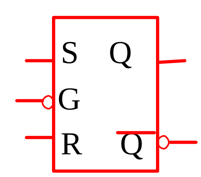




Gate	S	R	Q



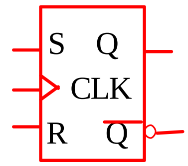
S	R	Q(t+1)



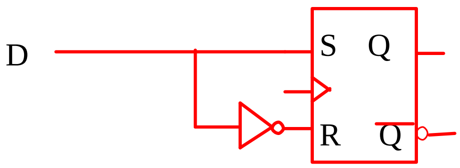
Flip flops:

1. S-R flip-flop

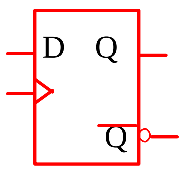
S	R	Q(t+1)



2. D flip-flop



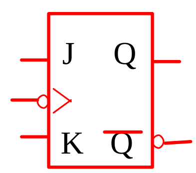
D	S R	Q(t+1)



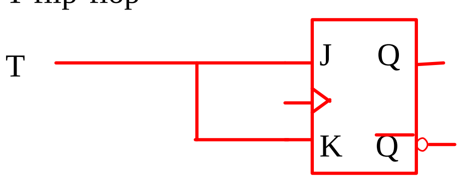
D	Q(t+1)

3. J K flip-flop

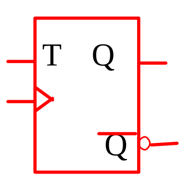
J	K	Q(t+1)



4. T flip-flop

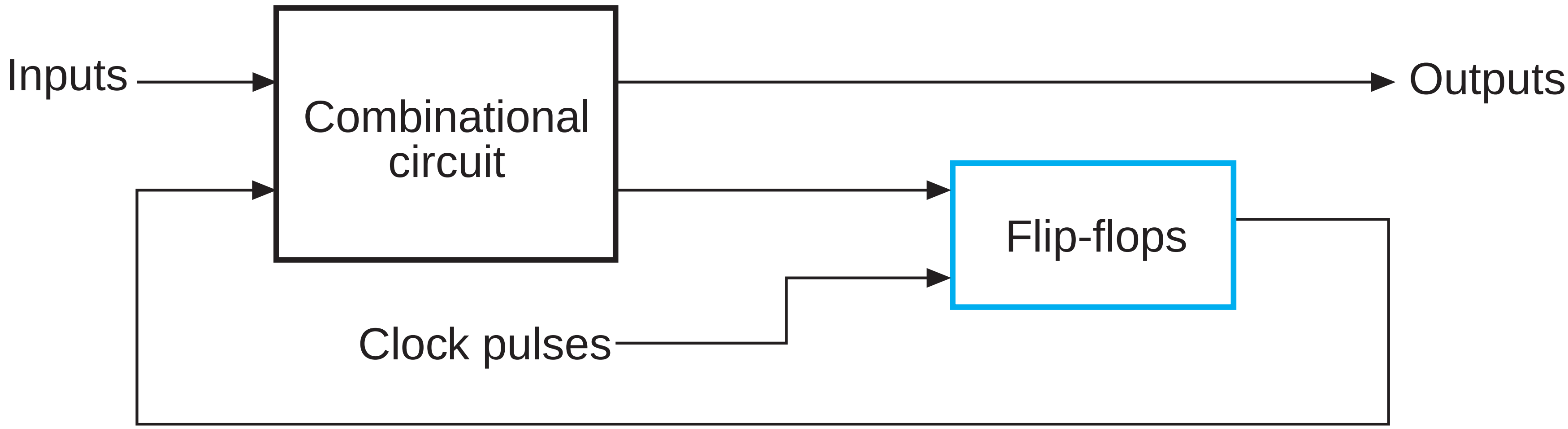


T	J K	Q(t+1)

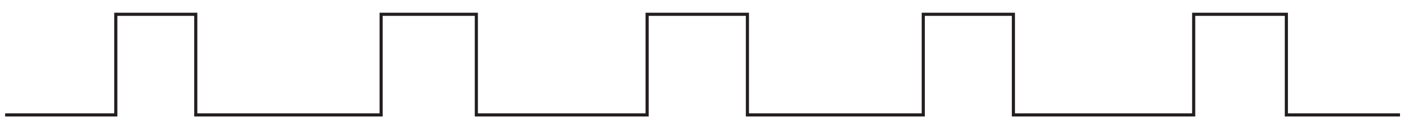


T	Q(t+1)

Figure 4-3 Synchronous Clocked Sequential Circuit



(a) Block diagram



(b) Timing diagram of clock pulses

Table 4-1 Flip-Flop Characteristic Table

(a) *JK* Flip-Flop

J	K	*Q* (*t* 1 1)	Operation
0	0	$Q(t)$	No change
0	1	0	Reset
1	0	1	Set
1	1	$\overline{Q}(t)$	Complement

(b) *SR* Flip-Flop

S	R	*Q* (*t* 1 1)	Operation
0	0	$Q(t)$	No change
0	1	0	Reset
1	0	1	Set
1	1	?	Undefined

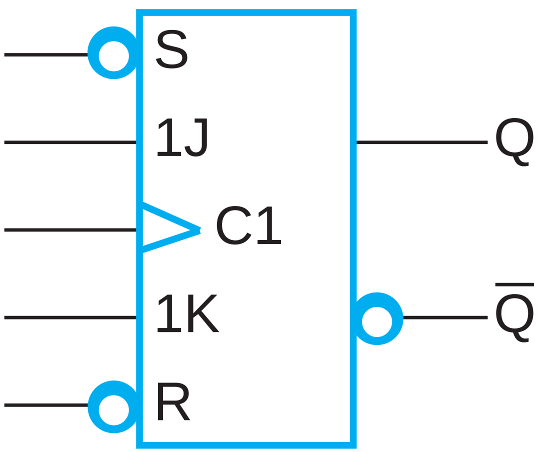
(c) *D* Flip-Flop

D	*Q* (*t* 1 1)	Operation
0	0	Reset
1	1	Set

(d) *T* Flip-Flop

T	*Q* (*t* 1 1)	Operation
0	$Q(t)$	No change
1	$\overline{Q}(t)$	Complement

Figure 4-16 *JK* Flip-Flop with Direct Set and Reset



(a) Graphic symbols

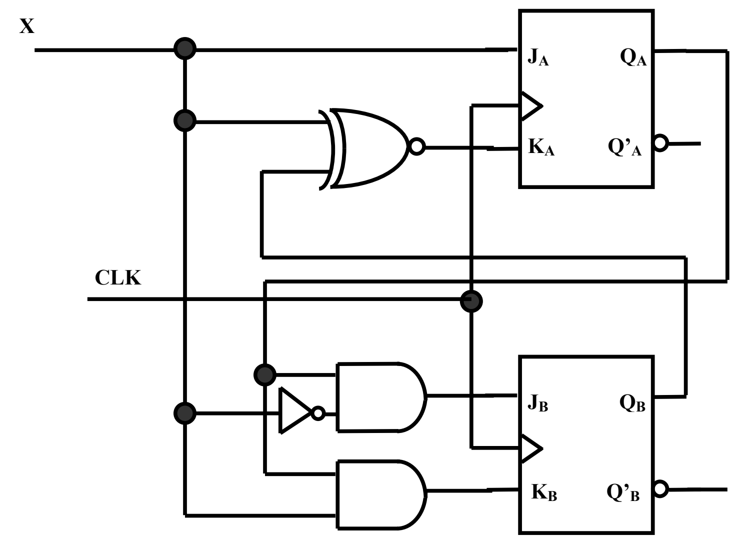
S	R	C	J	K	Q	$\overline{Q}$
0	1	X	X	X	1	0
1	0	X	X	X	0	1
0	0	X	X	X	Undefined	
1	1	↑	0	0	No change	
1	1	↑	0	1	0	1
1	1	↑	1	0	1	0
1	1	↑	1	1	Complement	

(b) Function table

Analysis Procedure:

1. **Obtain flip-flop input equations**
2. **Write down characteristic table of each type of flip-flop in use**
3. **Develop state table**
4. **Obtain state diagram**

❑ **Example #1:**



Step 1: Flip-flop input equations and output equation

$J_A = X$
$K_A = \overline{Q_B \oplus X} = Q_B \odot X$
$J_B = Q_A X'$
$K_B = Q_A X$

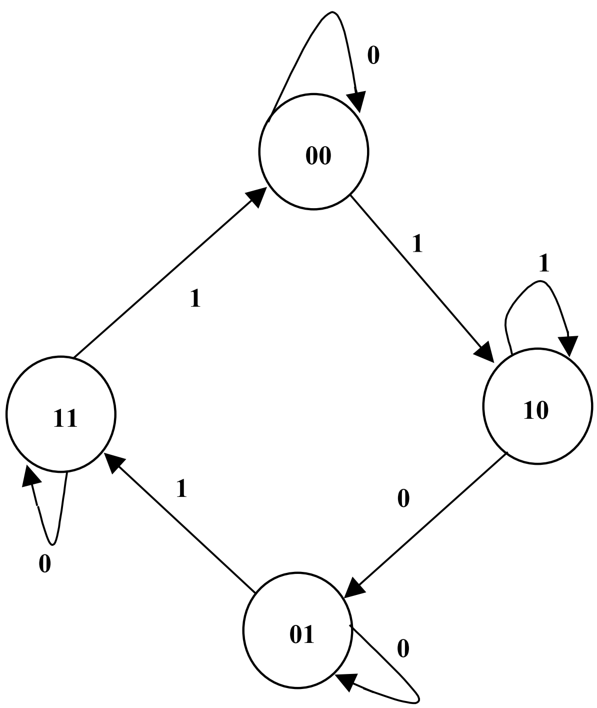
Step 2: Characteristic Table

J K	Q(t+1)
0 0	Q(t)
0 1	0
1 0	1
1 1	Q'(t)

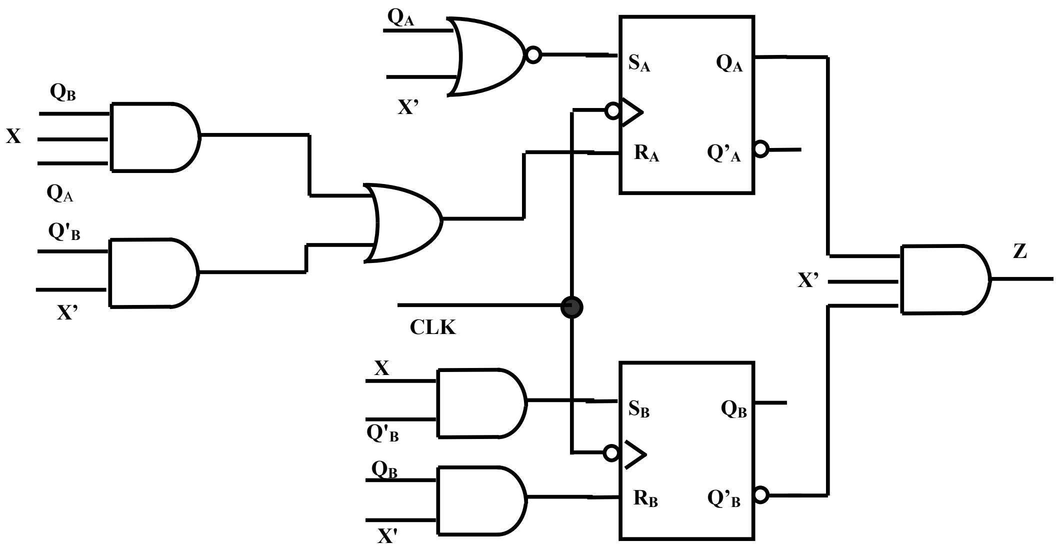
Step 3: State Table

PS Q_A Q_B X	J_A	K_A	J_B	K_B	NS Q_A Q_B
000	0	1	0	0	0 0
001	1	0	0	0	1 0
010	0	0	0	0	0 1
011	1	1	0	0	1 1
100	0	1	1	0	0 1
101	1	0	0	1	1 0
110	0	0	1	0	1 1
111	1	1	0	1	0 0

Step 4: State Diagram



❑ **Example #2:**



Step 1: Flip-flop input equations and output equation

$S_A = (Q_A + X')' = Q'_A X$
$R_A = Q_A Q_B X + Q'_B X'$
$S_B = Q'_B X$
$R_B = Q_B X'$
$Z = Q_A Q'_B X'$

Step 2: Characteristic Table

S R	Q(t+1)
0 0	Q(t)
0 1	0
1 0	1
1 1	-

Step 3: State Table

PS $Q_A\,Q_B\,X$	S_A	R_A	S_B	R_B	NS $Q_A\ Q_B$	Z
000	0	1	0	0	0 0	0
001	1	0	1	0	1 1	0
010	0	0	0	1	0 0	0
011	1	0	0	0	1 1	0
100	0	1	0	0	0 0	1
101	0	0	1	0	1 1	0
110	0	0	0	1	1 0	0
111	0	1	0	0	0 1	0

Step 4: State Diagram

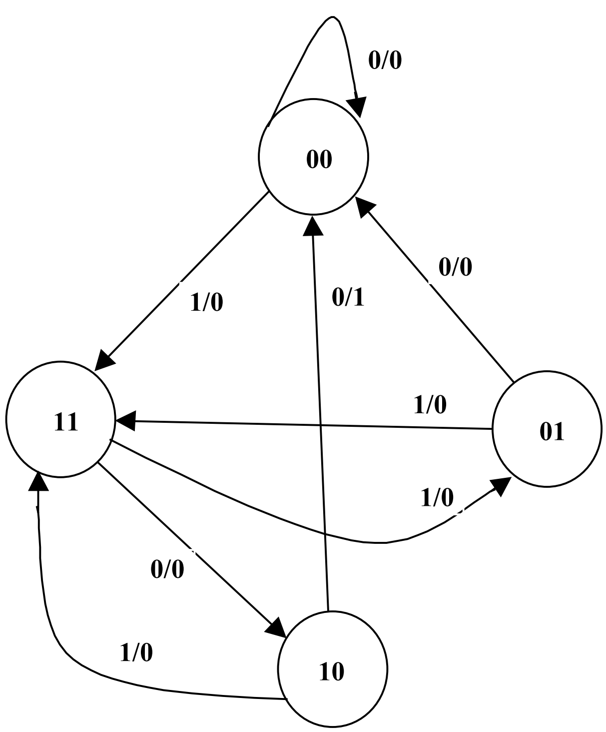
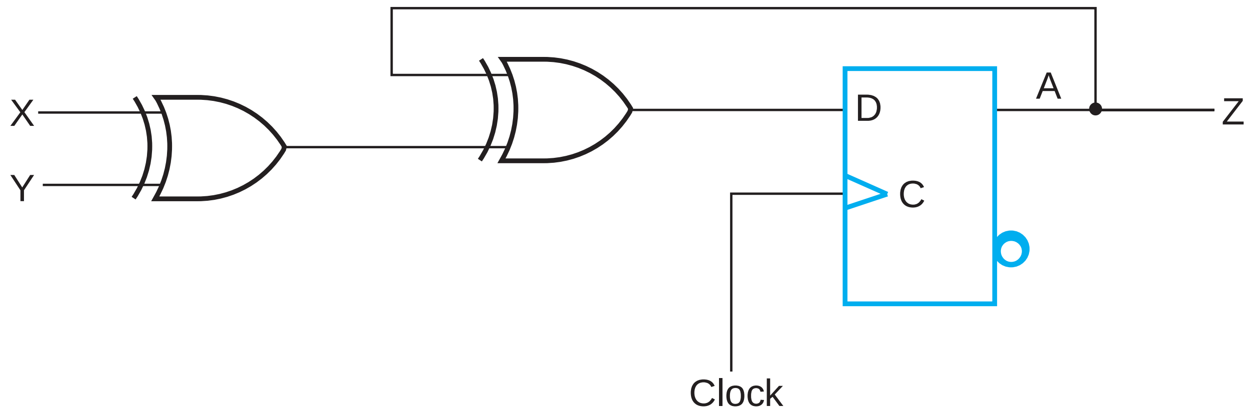


Figure 4-19 Logic Diagram and State Table for $D_A = A \oplus X \oplus Y$

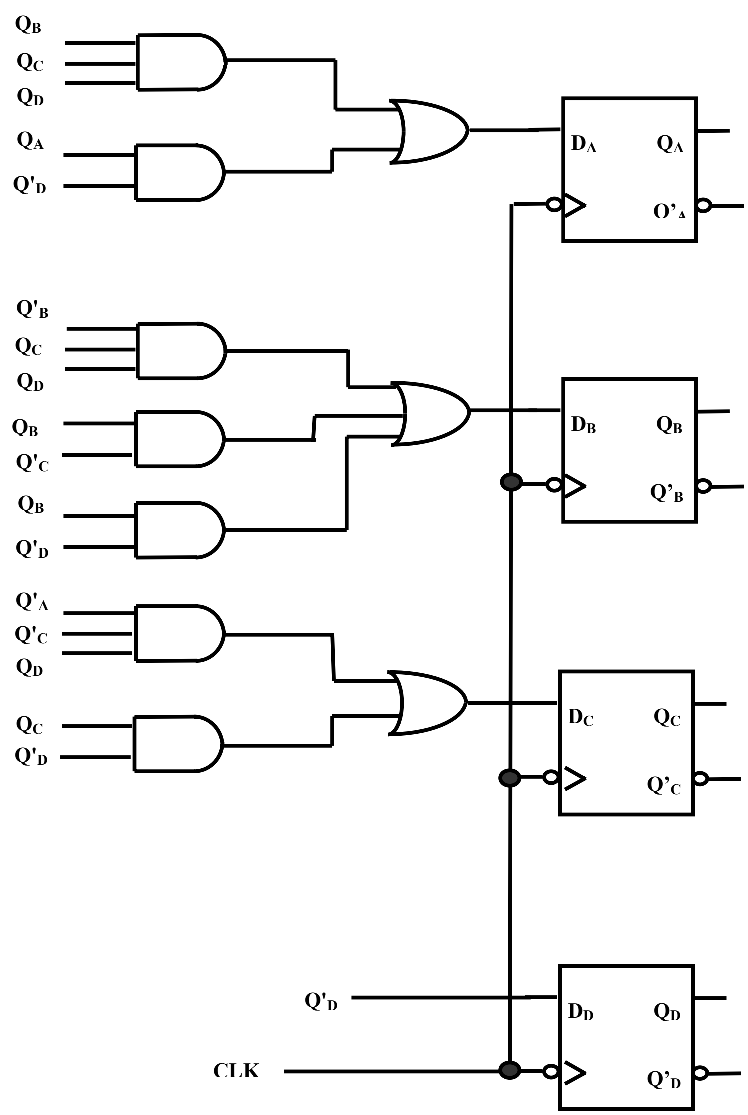


(a)

Present state	Inputs		Next state	Output
A	X	Y	A	Z
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	0
1	0	0	1	1
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

(b) State table

❑ Example #3:



Step 1: Flip-flop input equations

$D_A = Q_B Q_C Q_D + Q_A Q_D'$

$D_B = Q_B' Q_C Q_D + Q_B Q_C' + Q_B Q_D'$

$D_C = Q_A' Q_C' Q_D + Q_C Q_D'$

$D_D = Q_D'$

Step 2: Characteristic Table

D	Q(t+1)
0	0
1	1

Step 3: State Table

PS $Q_AQ_BQ_CQ_D$	D_A	D_B	D_C	D_D	NS $Q_AQ_BQ_CQ_D$
0 0 0 0	0	0	0	1	0 0 0 1
0 0 0 1	0	0	1	0	0 0 1 0
0 0 1 0	0	0	1	1	0 0 1 1
0 0 1 1	0	1	0	0	0 1 0 0
0 1 0 0	0	1	0	1	0 1 0 1
0 1 0 1	0	1	1	0	0 1 1 0
0 1 1 0	0	1	1	1	0 1 1 1
0 1 1 1	1	0	0	0	1 0 0 0
1 0 0 0	1	0	0	1	1 0 0 1
1 0 0 1	0	0	0	0	0 0 0 0
1 0 1 0	1	0	1	1	1 0 1 1
1 0 1 1	0	1	0	0	0 1 0 0
1 1 0 0	1	1	0	1	1 1 0 1
1 1 0 1	0	1	0	0	0 1 0 0
1 1 1 0	1	1	1	1	1 1 1 1
1 1 1 1	1	0	0	0	1 0 0 0

Step 4: State Diagram

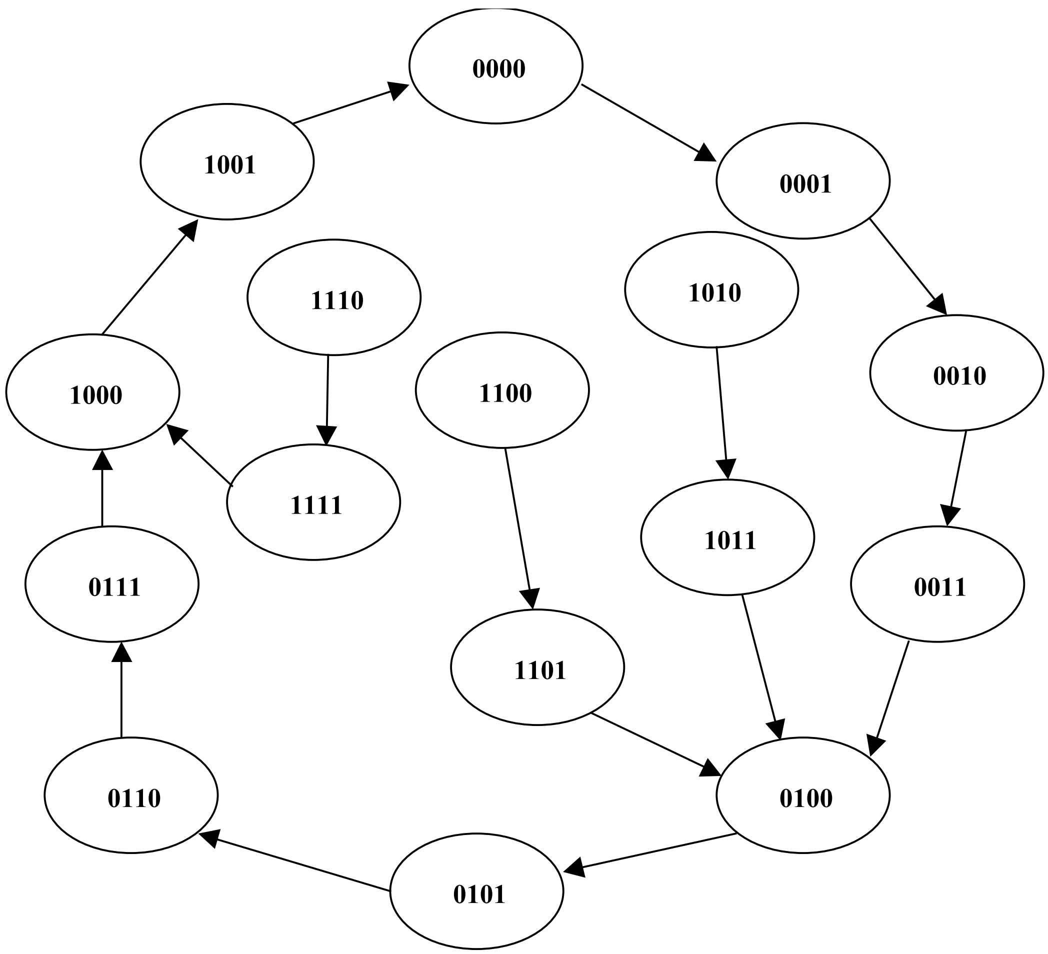


Table 4-10 Flip-Flop Excitation Table

(a) *JK* Flip-Flop

$Q(t)$	$Q(t+1)$	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0

(b) *SR* Flip-Flop

$Q(t)$	$Q(t+1)$	S	R
0	0	0	X
0	1	1	0
1	0	0	1
1	1	X	0

(c) *D* Flip-Flop

$Q(t)$	$Q(t+1)$	D
0	0	0
0	1	1
1	0	0
1	1	1

(d) *T* Flip-Flop

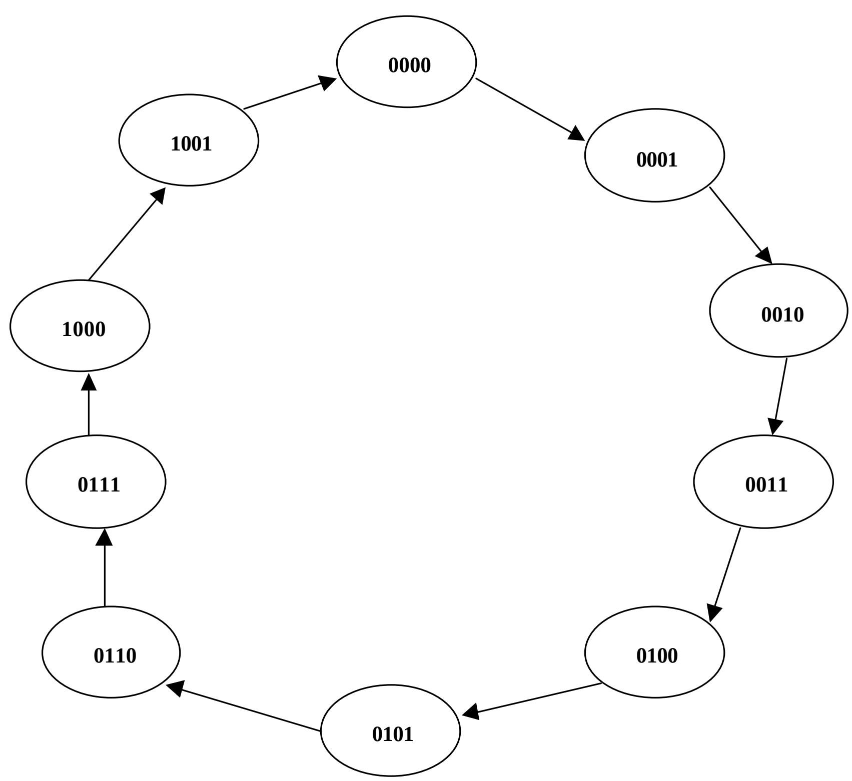
$Q(t)$	$Q(t+1)$	T
0	0	0
0	1	1
1	0	1
1	1	0

- ## DESIGN PROCEDURE

1. Word description.
2. State diagram.
3. Assign binary values.
4. Decide on type of flip flops.
5. Excitation table for the flip flop.
6. State table.
7. Generate simplified logic equations for flip flop inputs and system outputs.
8. Draw logic diagram.

- **Example #1: Using D flip-flops, design a 0 to 9 synchronous counter.**

  - **State diagram**



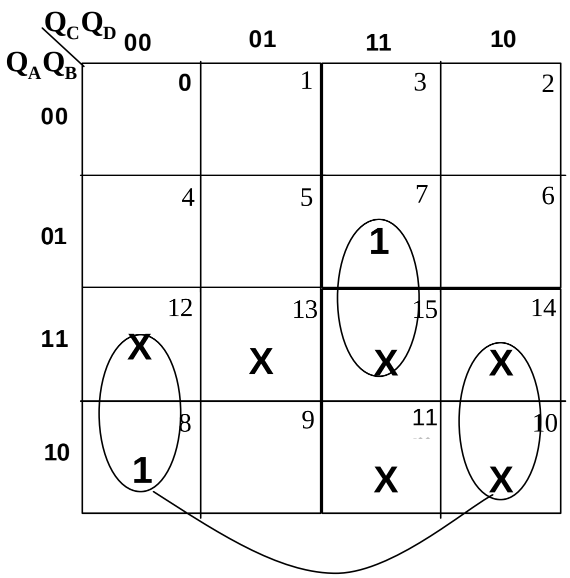
- **D Flip-Flop Excitation Table**

Q(t)	Q(t+1)	D
0	0	0
0	1	1
1	0	0
1	1	1

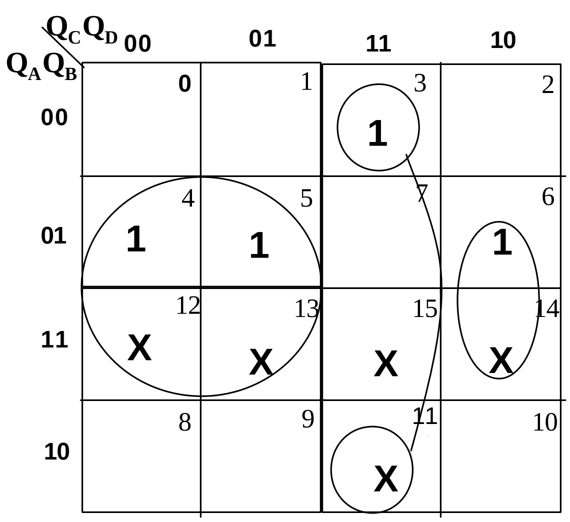
- **State Table**

PRESENT STATE	NEXT STATE				
$Q_AQ_BQ_CQ_D$	$Q_AQ_BQ_CQ_D$	D_A	D_B	D_C	D_D
0000	0001	0	0	0	1
0001	0010	0	0	1	0
0010	0011	0	0	1	1
0011	0100	0	1	0	0
0100	0101	0	1	0	1
0101	0110	0	1	1	0
0110	0111	0	1	1	1
0111	1000	1	0	0	0
1000	1001	1	0	0	1
1001	0000	0	0	0	0
1010	XXXX	X	X	X	X
1011	XXXX	X	X	X	X
1100	XXXX	X	X	X	X
1101	XXXX	X	X	X	X
1110	XXXX	X	X	X	X
1111	XXXX	X	X	X	X

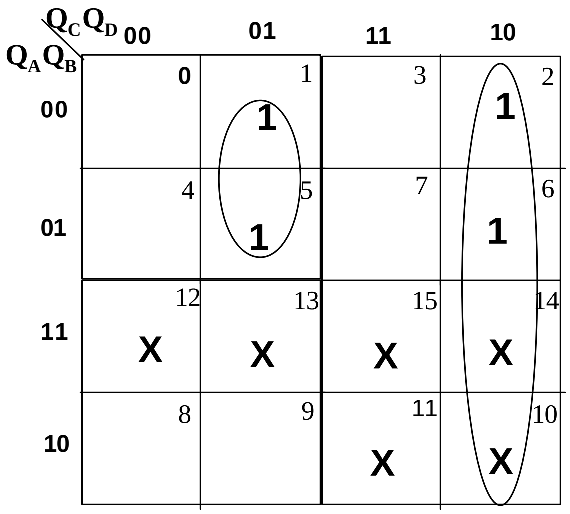
- **Karnaugh Map**



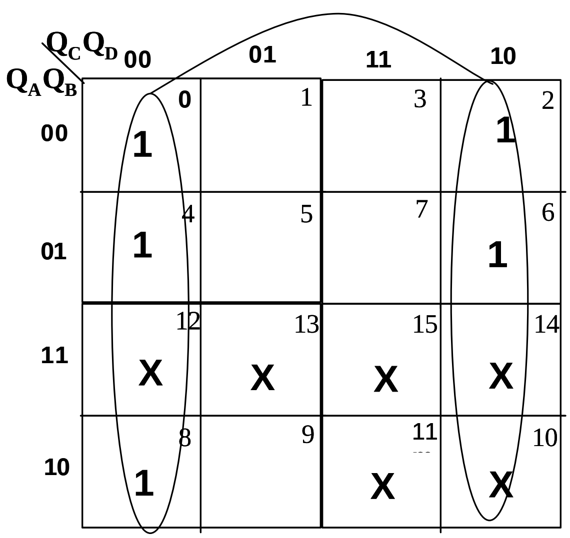
- $D_A = Q_B Q_C Q_D + Q_A Q_D'$



- $D_B = Q_B' Q_C Q_D + Q_B Q_C' + Q_B Q_D'$

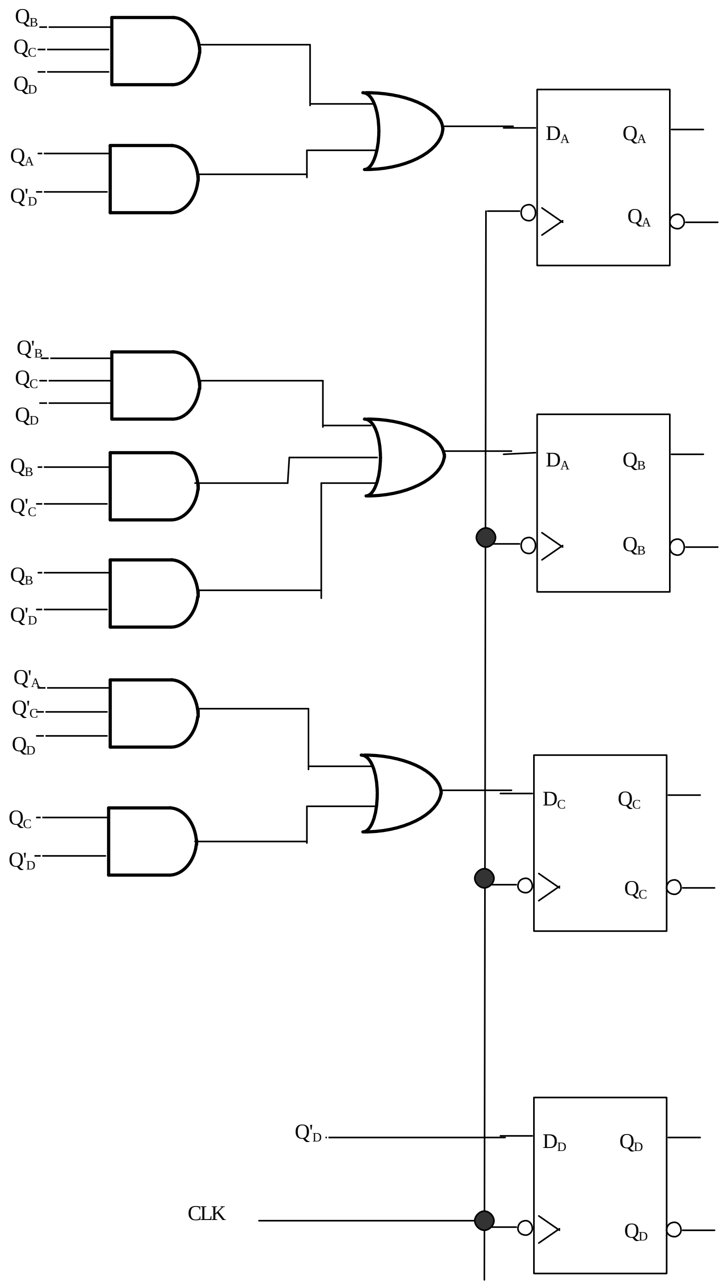


- $D_C = Q_A'Q_C'Q_D + Q_C Q_D'$



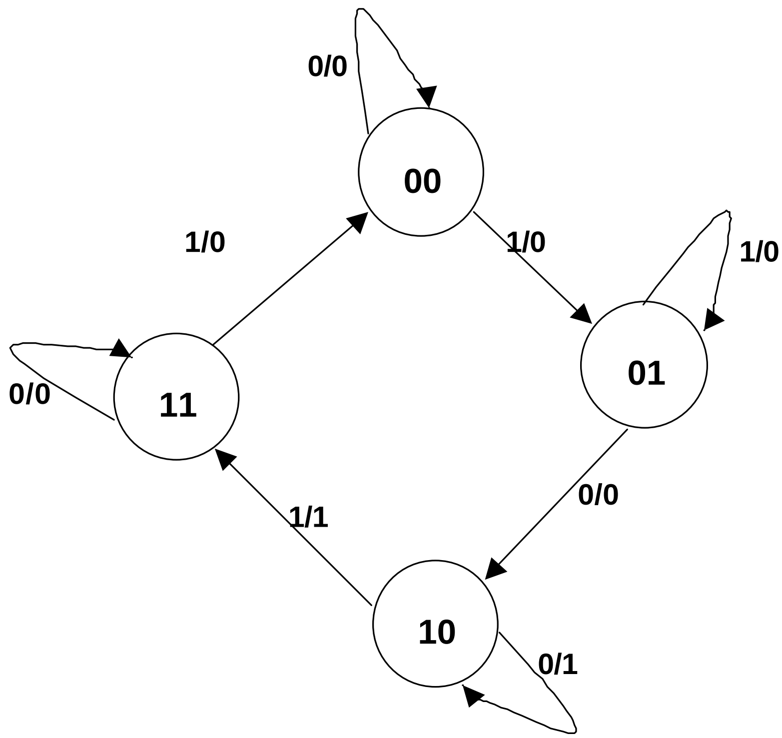
- $D_D = Q_D'$

- **Circuit**


Q_B
Q_C
Q_D
Q_A
Q'_D
D_A
Q_A
Q_A
Q'_B
Q_C
Q_D
Q_B
Q'_C
Q_B
Q'_D
D_A
Q_B
Q_B
Q'_A
Q'_C
Q_D
Q_C
Q'_D
D_C
Q_C
Q_C
Q'_D
D_D
Q_D
CLK
Q_D

❑ **Example #2:**

1. State diagram



2. Use JK flip flops

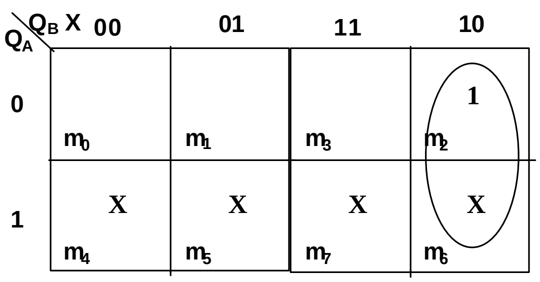
3. Flip flop Excitation Table

PRESENT STATE Q(t)	NEXT STATE Q(t+1)	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0

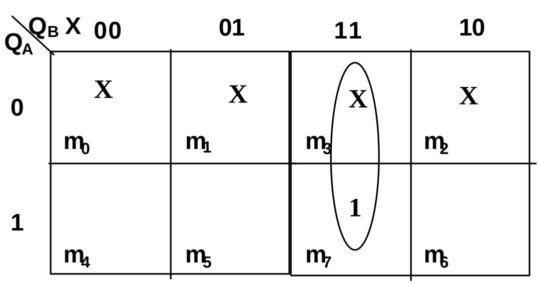
4. State Table

PRESENT STATE	INPUT	NEXT STATE	FLIP-FLOP INPUTS				OUTPUT
Q_A Q_B	X	Q_AQ_B	J_A	K_A	J_B	K_B	Z
00	0	00	0	X	0	X	0
00	1	01	0	X	1	X	0
01	0	10	1	X	X	1	0
01	1	01	0	X	X	0	0
10	0	10	X	0	0	X	1
10	1	11	X	0	1	X	1
11	0	11	X	0	X	0	0
11	1	00	X	1	X	1	0

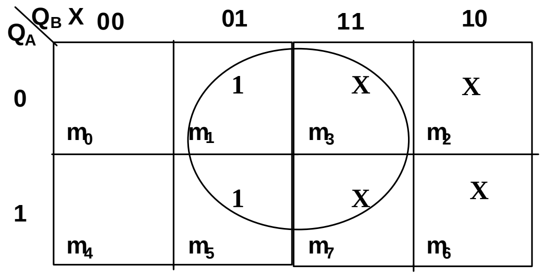
5. Karnaugh Map



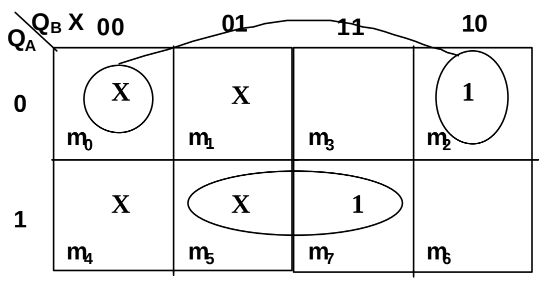
· $J_A = Q_B\ X'$



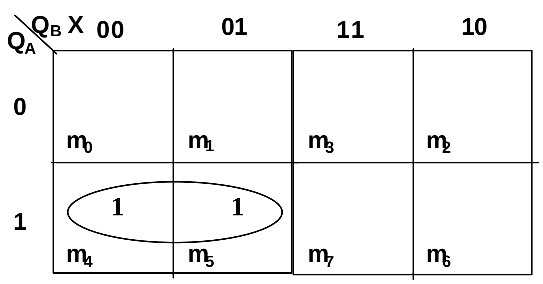
· $K_A = Q_B\ X$



· $J_B = X$

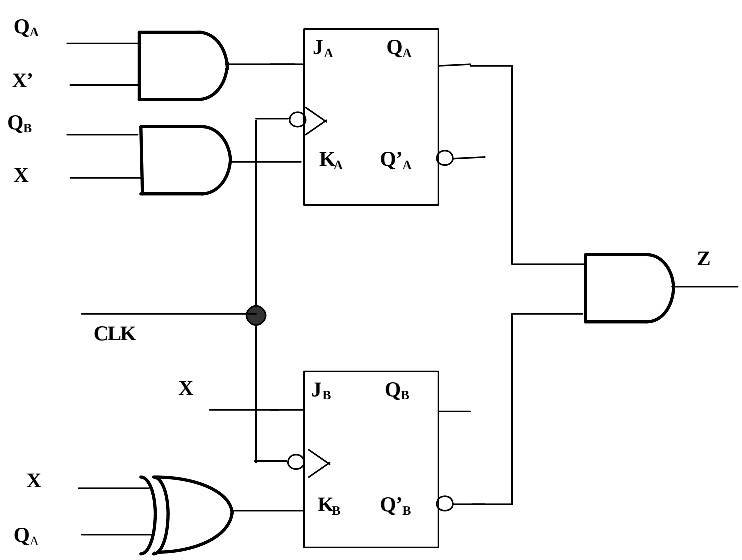


· $K_B = Q_A X' + Q'_A X = Q_A \oplus X$



· $Z = Q_A Q'_B$

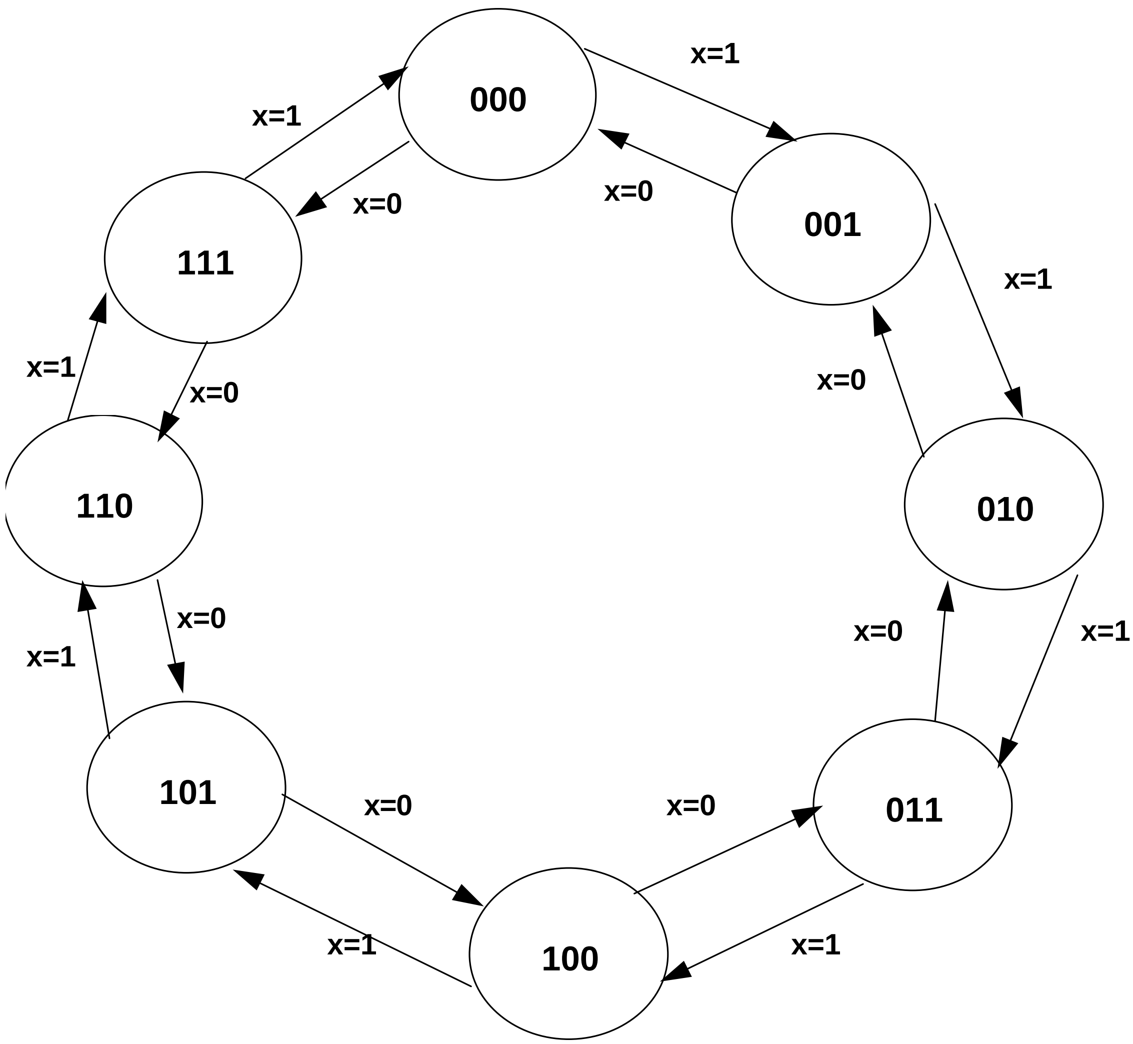
6. Schematic



- **Example #3:**

  Using JK flip-flops, design an up/down synchronous counter as specified below. The counter counts up if input X is 1 and it counts down when X is 0.

  - **State Diagram**



- **Use JK flip flops**

- **Flip flop Excitation Table**

PRESENT STATE	NEXT STATE		
Q(t)	Q(t+1)	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0

- **State Table**

PRESENT STATE	INPUT	NEXT STATE						
$Q_AQ_BQ_C$	X	$Q_AQ_BQ_C$	J_A	K_A	J_B	K_B	J_C	K_C
000	0	111	1	X	1	X	1	X
000	1	001	0	X	0	X	1	X
001	0	000	0	X	0	X	X	1
001	1	010	0	X	1	X	X	1
010	0	001	0	X	X	1	1	X
010	1	011	0	X	X	0	1	X
011	0	010	0	X	X	0	X	1
011	1	100	1	X	X	1	X	1
100	0	011	X	1	1	X	1	X
100	1	101	X	0	0	X	1	X
101	0	100	X	0	0	X	X	1
101	1	110	X	0	1	X	X	1
110	0	101	X	0	X	1	1	X
110	1	111	X	0	X	0	1	X
111	0	110	X	0	X	0	X	1
111	1	000	X	1	X	1	X	1

· **Karnaugh Map**

$Q_A Q_B$ \ $Q_C X$	00	01	11	10
00	1 m_0	m_1	m_3	m_2
01	m_4	m_5	1 m_7	m_6
11	X m_{12}	X m_{13}	X m_{15}	X m_{14}
10	X m_8	X m_9	X m_{11}	X m_{10}

· $J_A = Q'_B\ Q'_C\ X' + Q_B\ Q_C\ X$

$Q_A Q_B$ \ $Q_C X$	00	01	11	10
00	X m_0	X m_1	X m_3	X m_2
01	X m_4	X m_5	X m_7	X m_6
11	m_{12}	m_{13}	1 m_{15}	m_{14}
10	1 m_8	m_9	m_{11}	m_{10}

· $K_A = Q'_B\ Q'_C\ X' + Q_B\ Q_C\ X$

$Q_A Q_B$ \ $Q_C X$	00	01	11	10
00	1 m_0	m_1	1 m_3	m_2
01	X m_4	X m_5	X m_7	X m_6
11	X m_{12}	X m_{13}	X m_{15}	X m_{14}
10	1 m_8	m_9	1 m_{11}	m_{10}

- $J_B = Q'_C\ X' + Q_C X = Q_C \odot X$

$Q_A Q_B$ \ $Q_C X$	00	01	11	10
00	X m_0	X m_1	X m_3	X m_2
01	1 m_4	m_5	1 m_7	m_6
11	1 m_{12}	m_{13}	1 m_{15}	m_{14}
10	X m_8	X m_9	X m_{11}	X m_{10}

- $K_B = Q'_C\ X' + Q_C X = Q_C \odot X$
- $J_C = 1$
- $K_C = 1$

- **Schematic**