6.3 同步时序逻辑电路的设计

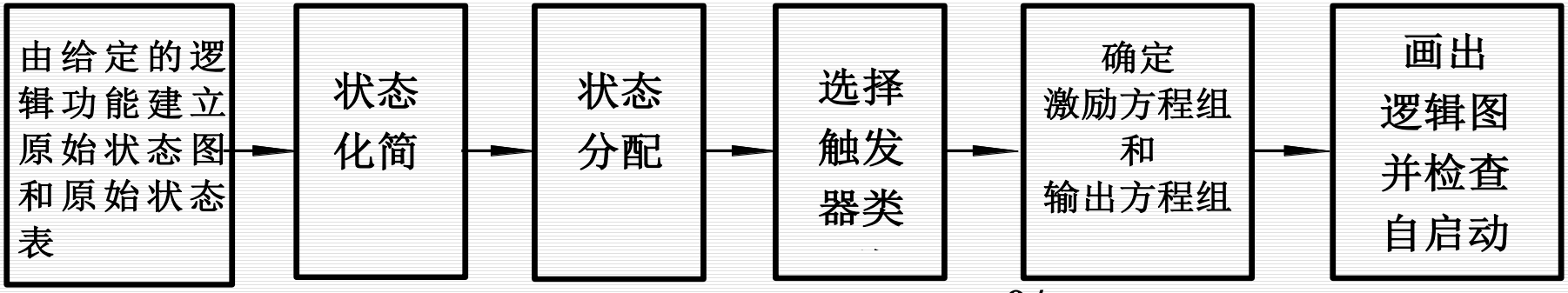
6.3.1 设计同步时序逻辑电路的一般步骤

6.3.2 同步时序逻辑电路设计举例

6.3.1 设计同步时序逻辑电路的一般步骤

同步时序逻辑电路的设计是分析的逆过程,其任务是根据实际问题的要求，设计出能实现给定逻辑功能的电路。

同步时序电路的设计过程



(1)根据给定的逻辑功能建立原始状态图和原始状态表

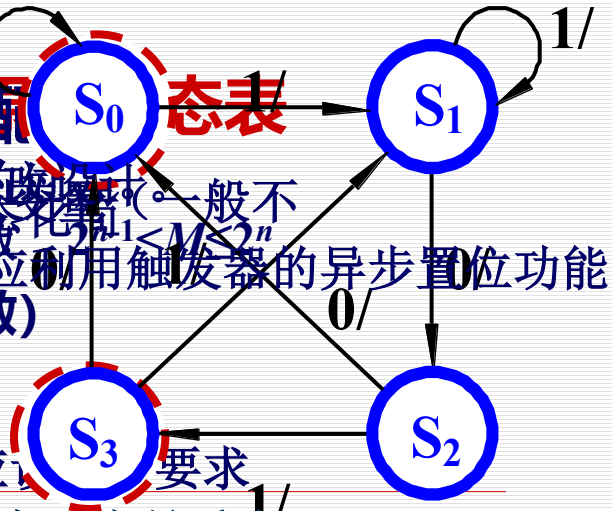
①明确电路的输入条件和相应的输出要求，确定输入变量和输出变量(一般不含时钟脉冲)和输出变量的个数，并用字母表示。

②找出所有可能的状态和状态转换之间的关系，并用相应的状态图表示出来。

③根据原始状态图建立原始状态表。

要求得到的原始状态图和原始状态表能够全面正确地反应设计要求

如何准确做出电路状态图、状态表是时序逻辑电路设计难点，也是重点

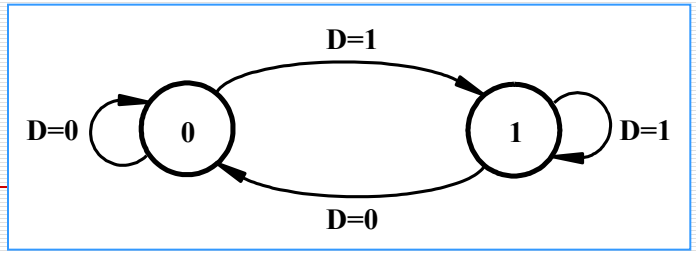


例1 用*D* 触发器设计一个8421 BCD码同步十进制加计数器。

8421码同步十进制加计数器的状态表

计数脉冲*CP*的顺序	现 态				次 态			
	Q_3^n	Q_2^n	Q_1^n	Q_0^n	Q_3^{n+1}	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}
0	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0
2	0	0	1	0	0	0	1	1
3	0	0	1	1	0	1	0	0
4	0	1	0	0	0	1	0	1
5	0	1	0	1	0	1	1	0
6	0	1	1	0	0	1	1	1
7	0	1	1	1	1	0	0	0
8	1	0	0	0	1	0	0	1
9	1	0	0	1	0	0	0	0

(2) 确定激励方程组



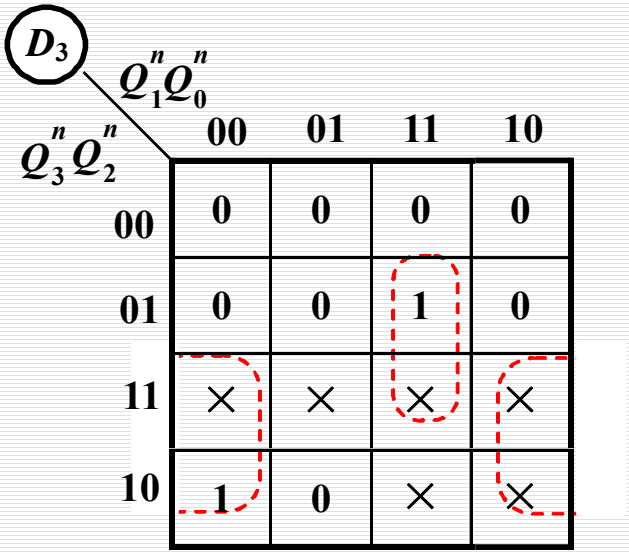
计数脉冲CP的顺序	现态				次态				激励信号			
	Q_3^n	Q_2^n	Q_1^n	Q_0^n	Q_3^{n+1}	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}	D_3	D_2	D_1	D_0
0	0	0	0	0	0	0	0	1	0	0	0	1
1	0	0	0	1	0	0	1	0	0	0	1	0
2	0	0	1	0	0	0	1	1	0	0	1	1
3	0	0	1	1	0	1	0	0	0	1	0	0
4	0	1	0	0	0	1	0	1	0	1	0	1
5	0	1	0	1	0	1	1	0	0	1	1	0
6	0	1	1	0	0	1	1	1	0	1	1	1
7	0	1	1	1	1	0	0	0	1	0	0	0
8	1	0	0	0	1	0	0	1	1	0	0	1
9	1	0	0	1	0	0	0	0	0	0	0	0

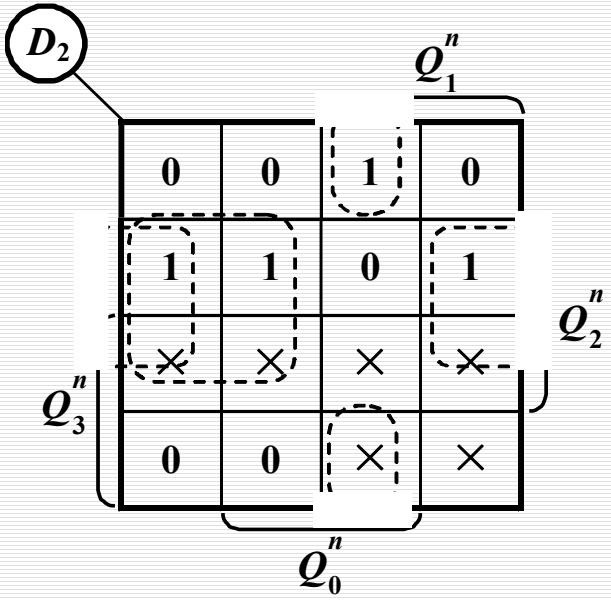
D_3、D_2、D_1、D_0、是触发器初态还是次态的函数?

D_3、D_2、D_1、D_0是触发器初态的函数

计数脉冲CP的顺序	现态				次态				激励信号			
	Q_3^n	Q_2^n	Q_1^n	Q_0^n	Q_3^{n+1}	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}	D_3	D_2	D_1	D_0
0	0	0	0	0	0	0	0	1	0	0	0	1
1	0	0	0	1	0	0	1	0	0	0	1	0
2	0	0	1	0	0	0	1	1	0	0	1	1
3	0	0	1	1	0	1	0	0	0	1	0	0
4	0	1	0	0	0	1	0	1	0	1	0	1
5	0	1	0	1	0	1	1	0	0	1	1	0
6	0	1	1	0	0	1	1	1	0	1	1	1
7	0	1	1	1	1	0	0	0	1	0	0	0
8	1	0	0	0	1	0	0	1	1	0	0	1
9	1	0	0	1	0	0	0	0	0	0	0	0

画出各触发器激励信号的卡诺图





$$D_3 = Q_3^n\overline{Q_0^n} + Q_2^nQ_1^nQ_0^n$$

$$D_2 = Q_2^n\overline{Q_1^n} + Q_2^n\overline{Q_0^n} + Q_2^nQ_1^nQ_0^n$$

计数脉冲CP的顺序	现态				次态				激励信号			
	Q_3^n	Q_2^n	Q_1^n	Q_0^n	Q_3^{n+1}	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}	D_3	D_2	D_1	D_0
0	0	0	0	0	0	0	0	1	0	0	0	1
1	0	0	0	1	0	0	1	0	0	0	1	0
2	0	0	1	0	0	0	1	1	0	0	1	1
3	0	0	1	1	0	1	0	0	0	1	0	0
4	0	1	0	0	0	1	0	1	0	1	0	1
5	0	1	0	1	0	1	1	0	0	1	1	0
6	0	1	1	0	0	1	1	1	0	1	1	1
7	0	1	1	1	1	0	0	0	1	0	0	0
8	1	0	0	0	1	0	0	1	1	0	0	1
9	1	0	0	1	0	0	0	0	0	0	0	0

D_1

Q_3^n \ $Q_1^n Q_0^n$	00	01	11	10
Q_2^n = 0	0	1	1	0
Q_2^n = 1	0	1	1	0
×	×	×	×	×
0	0	×	×	×

$$D_1 = Q_1^n \overline{Q_0^n} + \overline{Q_3^n} Q_1^n Q_0^n$$

D_0

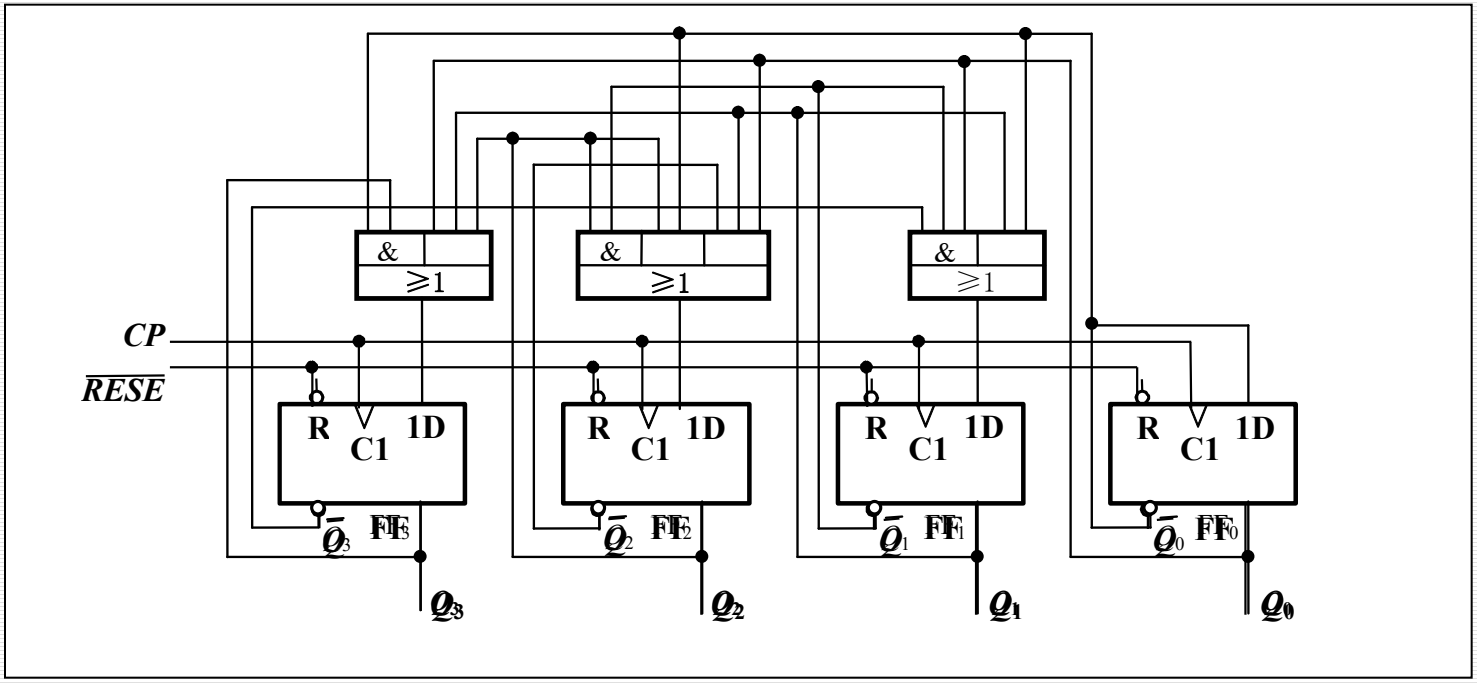
Q_3^n \ $Q_1^n Q_0^n$	00	01	11	10
Q_2^n = 0	1	1	0	0
Q_2^n = 1	1	1	0	0
×	×	×	×	×
1	0	×	×	×

$$D_0 = \overline{Q_0^n}$$

(3) 画出逻辑图，并检查自启动能力

$$D_3 = Q_3^n \overline{Q_0^n} + Q_2^n Q_1^n Q_0^n \qquad D_2 = Q_2^n \overline{Q_1^n} + Q_2^n \overline{Q_0^n} + \overline{Q_2^n} Q_1^n Q_0^n$$

$$D_1 = Q_1^n \overline{Q_0^n} + \overline{Q_3^n}\,\overline{Q_1^n} Q_0^n \qquad D_0 = \overline{Q_0^n}$$



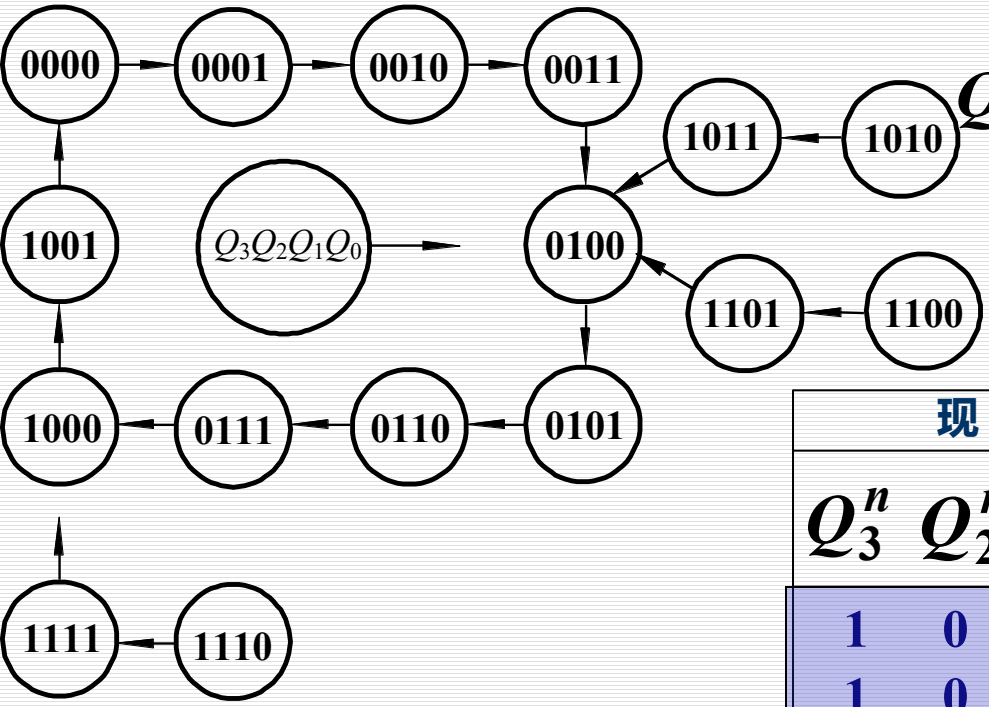
画出完全状态图

$$Q_0^{n+1} = D_0 = \overline{Q_0^n}$$

$$Q_1^{n+1} = D_1 = Q_1^n \overline{Q_0^n} + \overline{Q_3^n}\,\overline{Q_1^n} Q_0^n$$

$$Q_2^{n+1} = D_2 = Q_2^n \overline{Q_1^n} + Q_2^n \overline{Q_0^n} + \overline{Q_2^n} Q_1^n Q_0^n$$

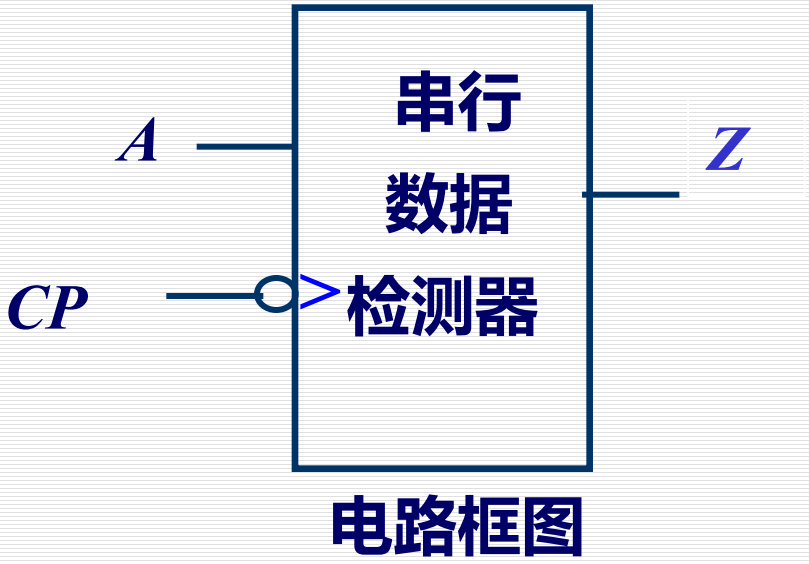
$$Q_3^{n+1} = D_3 = Q_3^n \overline{Q_0^n} + Q_2^n Q_1^n Q_0^n$$



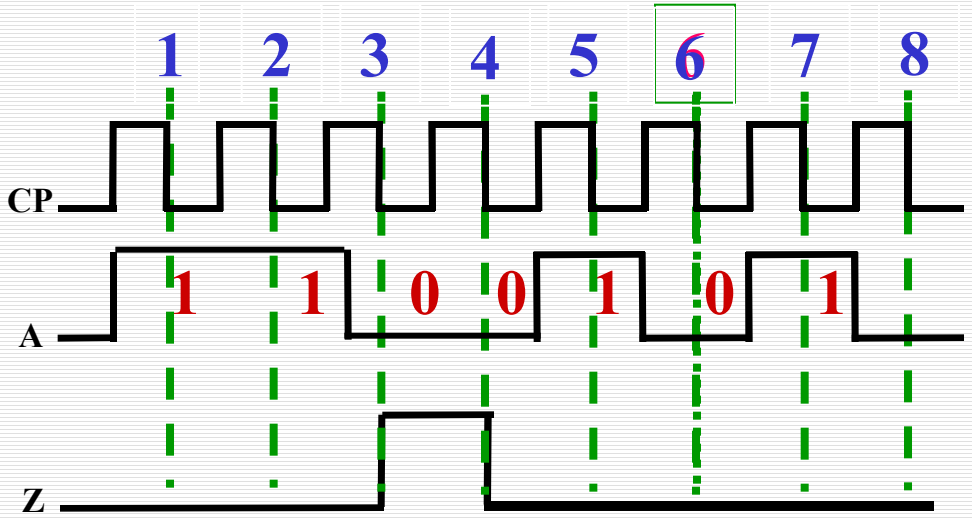
现 态				次 态			
Q_3^n	Q_2^n	Q_1^n	Q_0^n	Q_3^{n+1}	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}
1	0	1	0	1	0	1	1
1	0	1	1	0	1	0	0
1	1	0	0	1	1	0	1
1	1	0	1	0	1	0	0
1	1	1	0	1	1	1	1
1	1	1	1	1	0	0	0

电路具有自启动能力

例2：设计一个串行数据检测器。电路的输入信号X是与时钟脉冲同步的串行数据，其时序关系如下图所示。输出信号为Z；要求电路在X信号输入出现110序列时，输出信号Z为1，否则为0。



电路框图



1、逻辑抽象建立原始状态图或状态表.

1）确定输入、输出变量及电路的状态数:

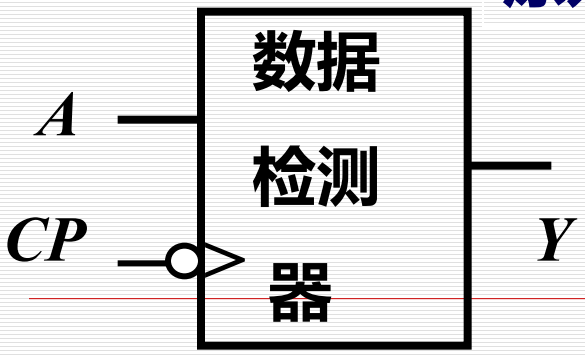
输入变量：A　输出变量：*Y*　状态数：4个

2）定义输入 输出逻辑状态和每个电路状态的含义；

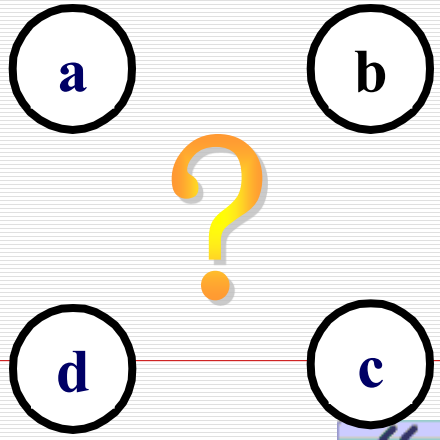
a —— 初始状态;　b—— A输入1后;

c —— A输入11后;　d —— A输入110后。

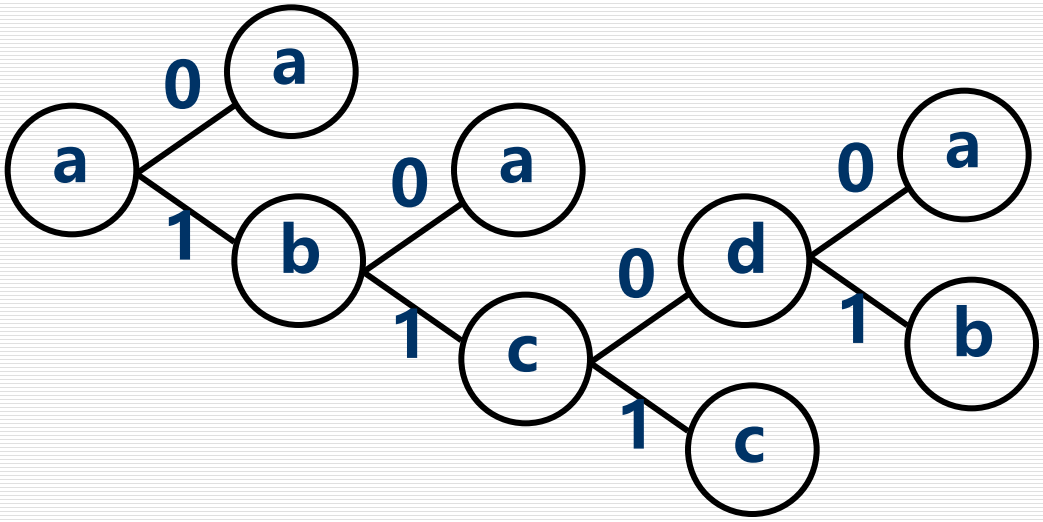
3）按题意画出状态转换图或列出电路的状态表。

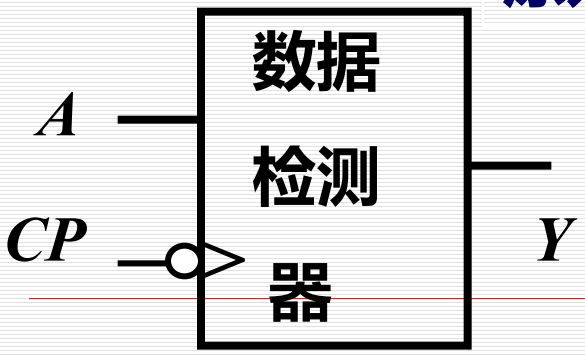


原始状态图

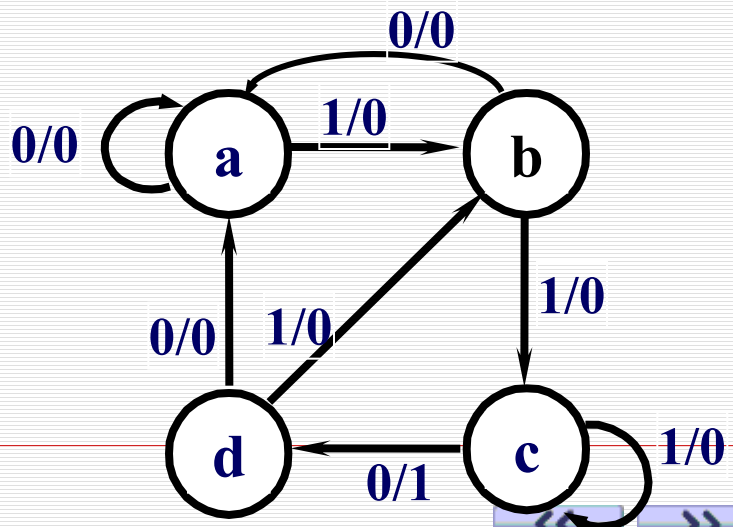


1、逻辑抽象建立原始状态图或状态表.

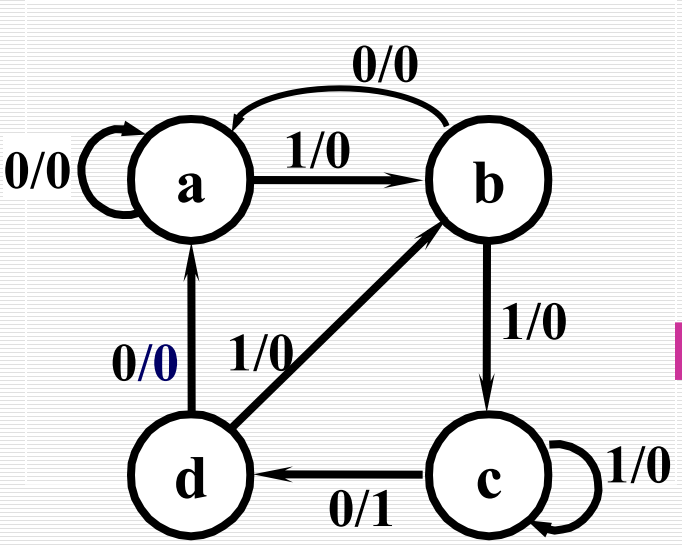




原始状态图

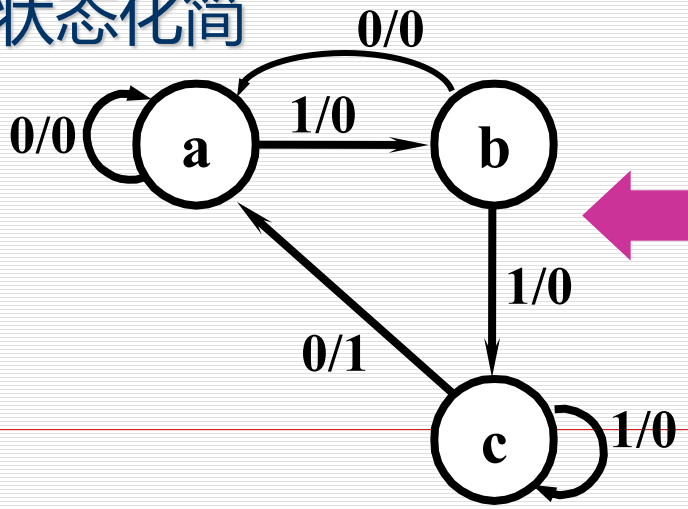


列出原始状态表



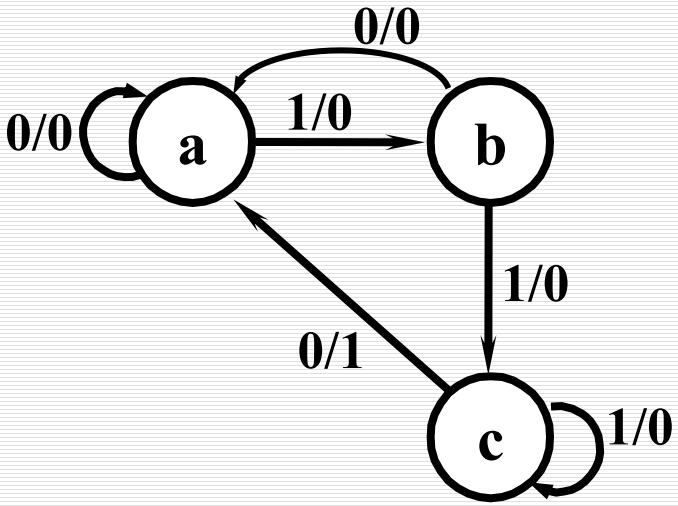
现态	次态/输出	
	A=0	A=1
a	a / 0	b / 0
b	a / 0	c / 0
c	d/ 1	c/ 0
d	a/ 0	b/ 0

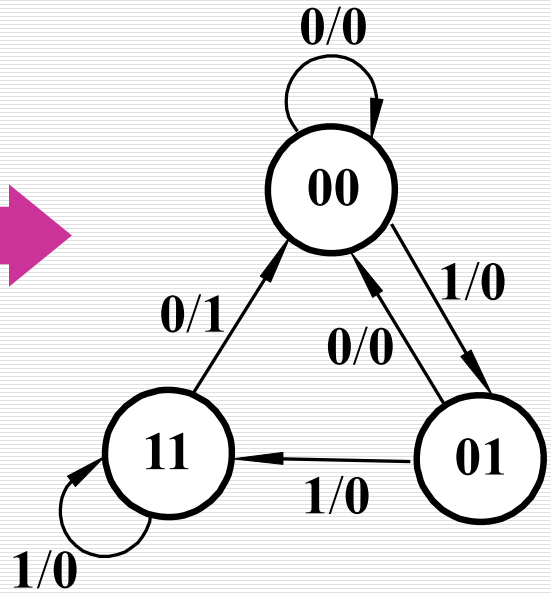
2. 状态化简



现态	次态 / 输出	
	A=0	A=1
a	a/ 0	b /0
b	a / 0	c/0
c	a/1	c /0

3、状态分配　　令 $a=00$，$b=01$，$c=11$，





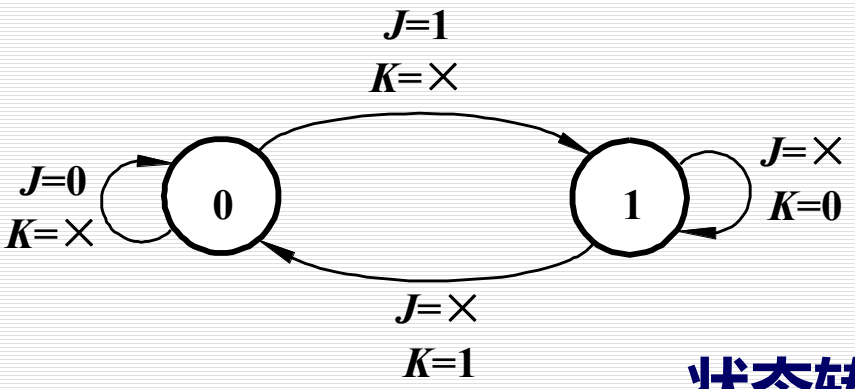
4、选择触发器的类型

触发器个数: 两个。

类型：采用功能较强的*JK* 触发器。

现态 Q_1Q_0	$Q_1^{n+1}Q_0^{n+1}$ / Y	
	A=0	A=1
00	00 / 0	01 /0
01	00 / 0	11 /0
11	00 / 1	11 /0

5. 求激励方程和输出方程（难点！！）



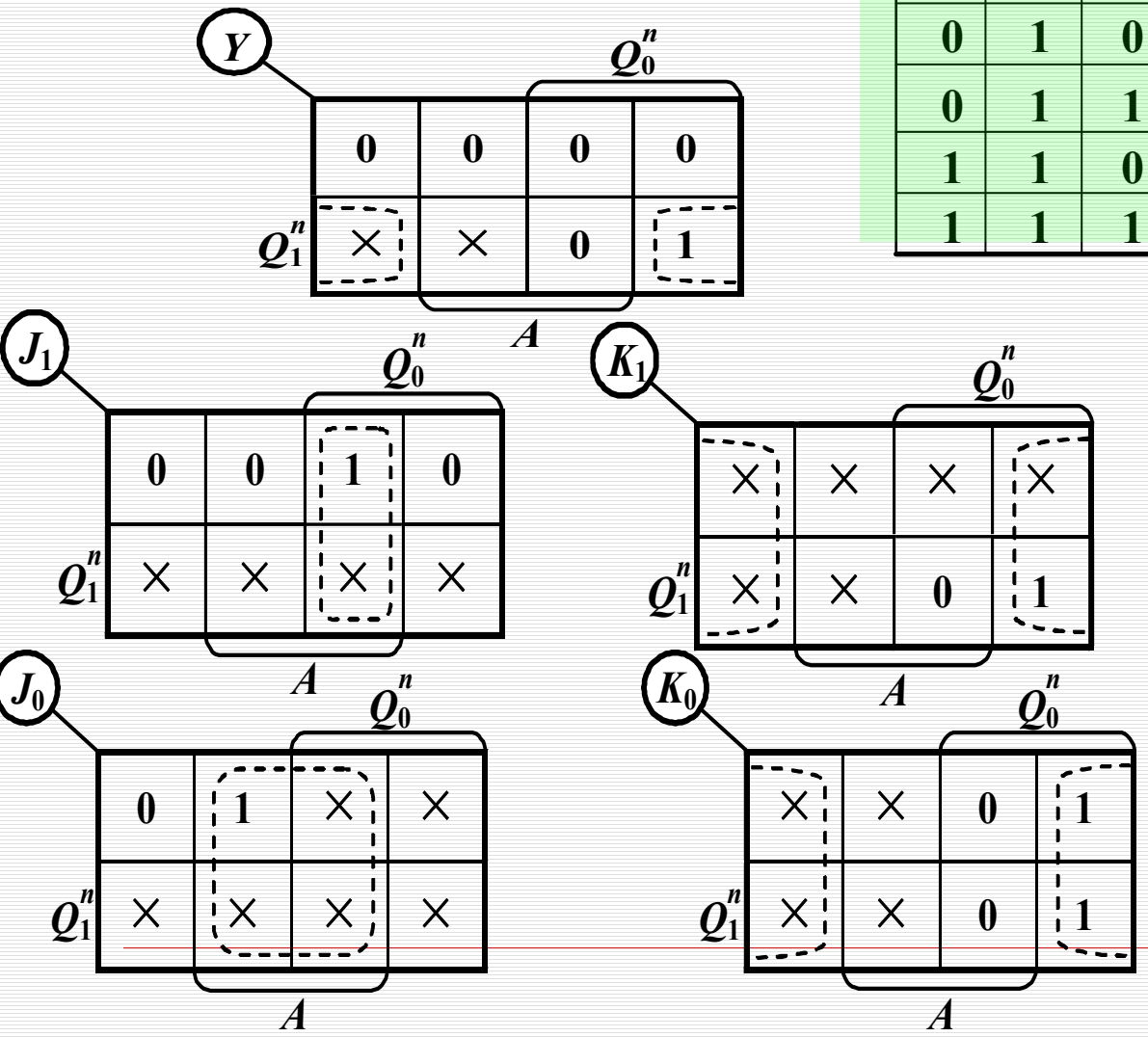
现态 Q_1Q_0	$Q_1^{n+1}Q_0^{n+1}$ / Y	
	A=0	A=1
00	00 / 0	01 /0
01	00 / 0	11 /0
11	00 / 1	11 /0

状态转换真值表及激励信号

Q_1^n	Q_0^n	A	Q_1^{n+1}	Q_0^{n+1}	Y	激励信号			
						J_1	K_1	J_0	K_0
0	0	0	0	0	0	0	×	0	×
0	0	1	0	1	0	0	×	1	×
0	1	0	0	0	0	0	×	×	1
0	1	1	1	1	0	1	×	×	0
1	1	0	0	0	1	×	1	×	1
1	1	1	1	1	0	×	0	×	0

（J_1、K_1、J_0、K_0、Y为A和触发器初态的函数）

Q_1^n	Q_0^n	A	Q_1^{n+1}	Q_0^{n+1}	Y	激励信号			
						J_1	K_1	J_0	K_0
0	0	0	0	0	0	0	×	0	×
0	0	1	0	1	0	0	×	1	×
0	1	0	0	0	0	0	×	×	1
0	1	1	1	1	0	1	×	×	0
1	1	0	0	0	1	×	1	×	1
1	1	1	1	1	0	×	0	×	0



卡诺图化简得

输出方程

$$Y = Q_1 \overline{A}$$

激励方程

$$J_1 = Q_0 A \qquad K_1 = \overline{A}$$

$$J_0 = A \qquad K_0 = \overline{A}$$

6. 根据激励方程和输出方程画出逻辑图,并检查自启动能力

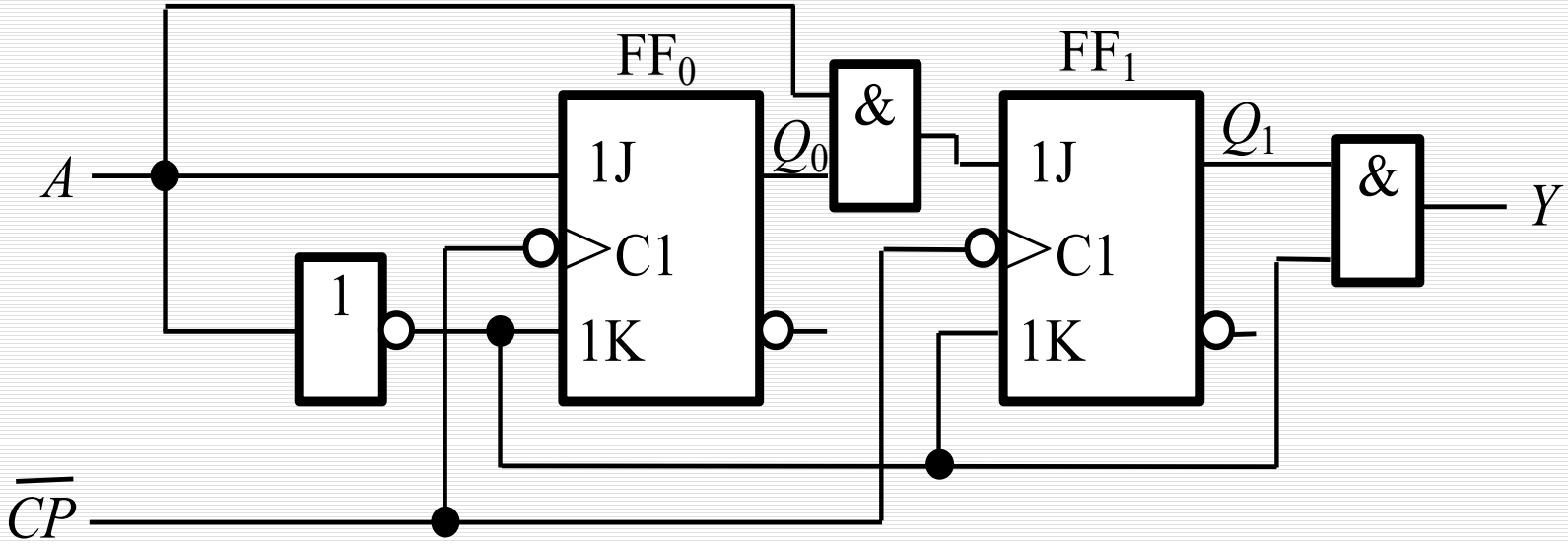
激励方程

$$J_1 = Q_0 A \qquad K_1 = \overline{A}$$

$$J_0 = A \qquad K_0 = \overline{A}$$

输出方程

$$Y = Q_1 \overline{A}$$



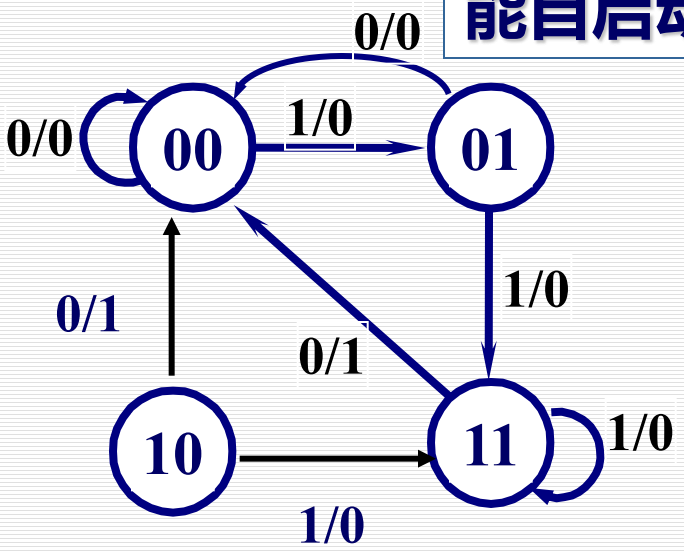
检查自启动能力和输出

$J_1 = Q_0 A \qquad K_1 = \overline{A}$

$J_0 = A \qquad K_0 = \overline{A}$

$Y = Q_1 \overline{A}$

能自启动



当 $Q_1 Q_0$= 10时

A=0 $Y = 1$

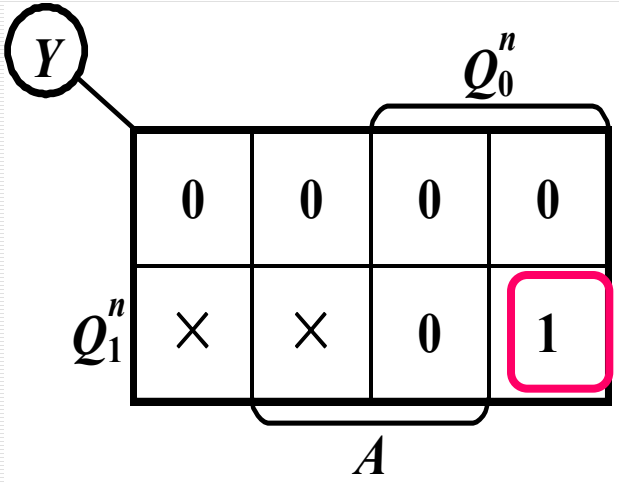
$J_1 = 0 \quad K_1 = 1 \quad Q_1^{n+1} = 0$

$J_0 = 0 \quad K_0 = 1 \quad Q_0^{n+1} = 0$

A=1 $Y = 0$

$J_1 = 0 \quad K_1 = 0 \quad Q_1^{n+1} = 1$

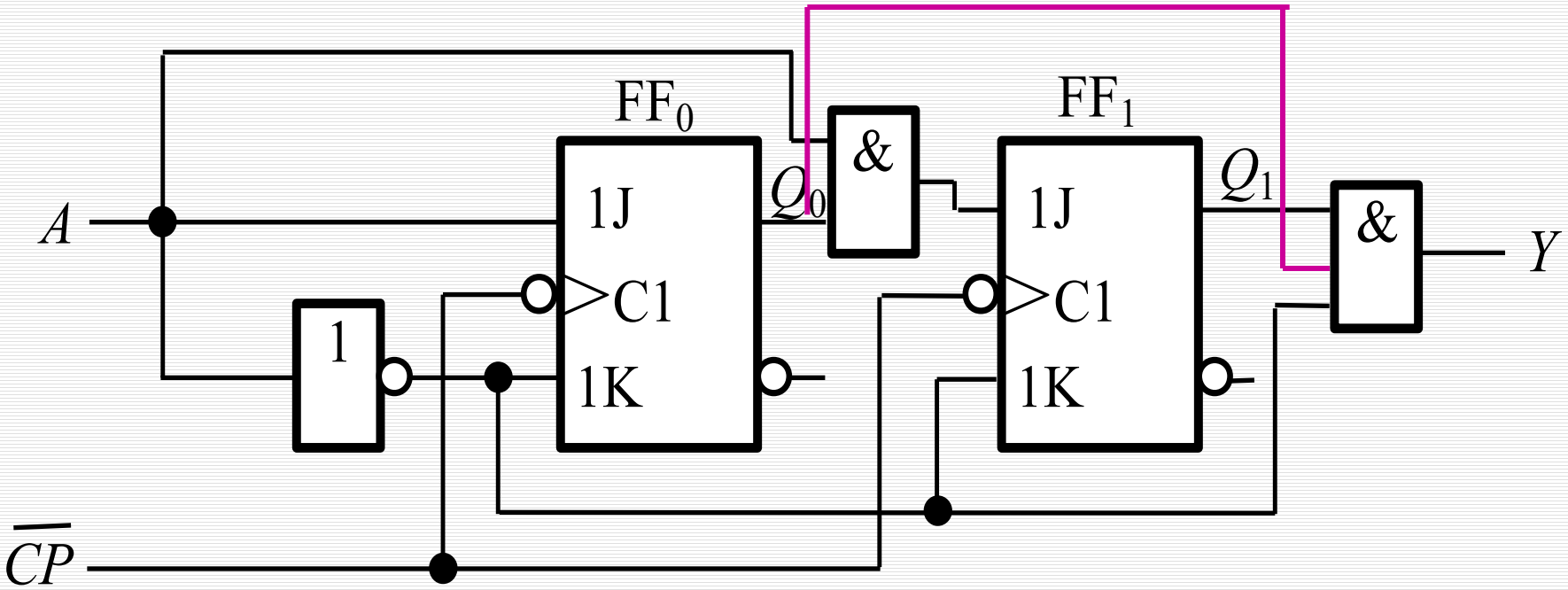
$J_0 = 1 \quad K_0 = 0 \quad Q_0^{n+1} = 1$



输出方程 $Y = Q_1 \overline{A}$ ➡ $Y = Q_1 Q_0 \overline{A}$

修改电路

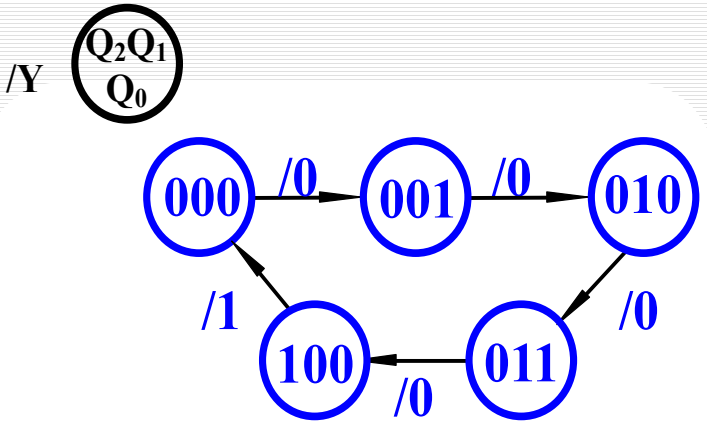
输出方程 $Y = Q_1 \overline{A}$ ➡ $Y = Q_1 Q_0 \overline{A}$

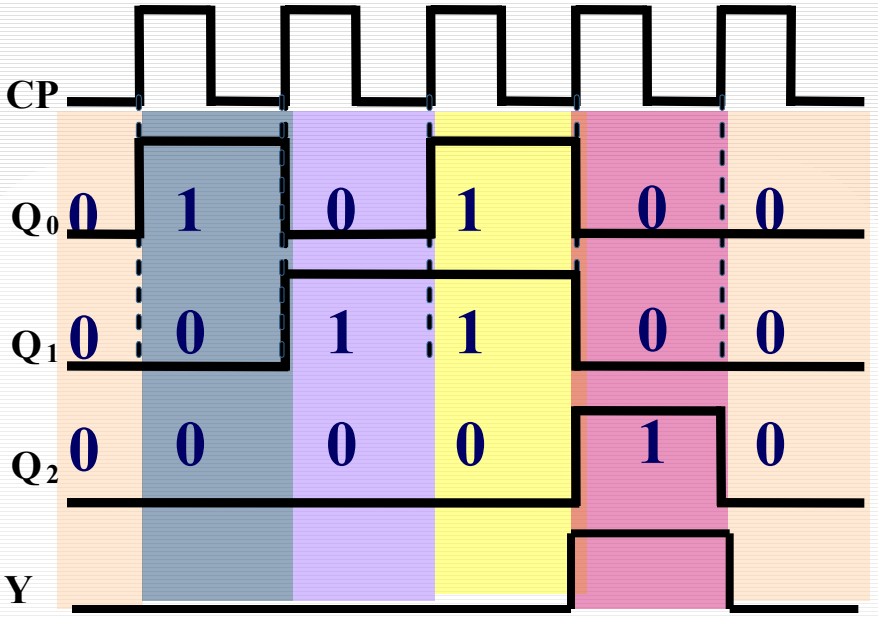


例3:试设计一个同步时序电路，要求电路中触发器Q_0、Q_1、Q_2及输出Y端的信号与CP时钟信号波形满足下图所示的时序关系。

解：据题意可直接由波形图

1、画出电路状态图。





2、 确定触发器的类型和个数

触发器个数： 3个

触发器类型： 上升沿触发的JK边沿触发器。

3、求出电路的激励方程和输出方程；

Q_2^n	Q_1^n	Q_0^n	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}	Y
0	0	0	0	0	1	0
0	0	1	0	1	0	0
0	1	0	0	1	1	0
0	1	1	1	0	0	0
1	0	0	0	0	0	1

J_2	K_2	J_1	K_1	J_0	K_0
0	X	0	X	1	X
0	X	1	X	X	1
0	X	X	0	1	X
1	X	X	1	X	1
X	1	0	X	0	X

J_2 卡诺图

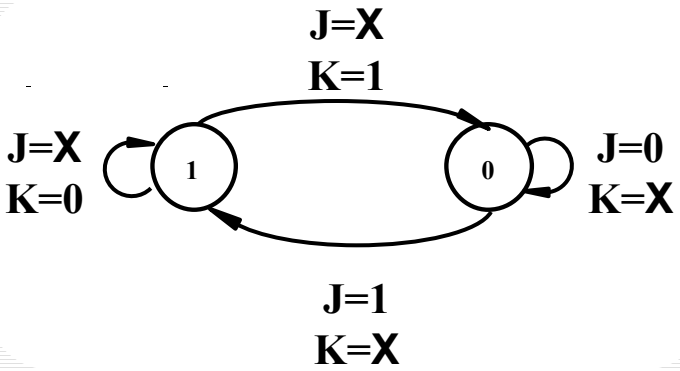
Q_2^n \ $Q_1^n Q_0^n$	00	01	11	10
0	0	0	1	0
1	X	X	X	X

$$J_2 = Q_0^n Q_1^n$$

K_2 卡诺图

Q_2^n \ $Q_1^n Q_0^n$	00	01	11	10
0	X	X	X	X
1	1	X	X	X

$$K_2 = 1$$



$$J_1 = Q_0^n \quad K_1 = Q_0^n$$

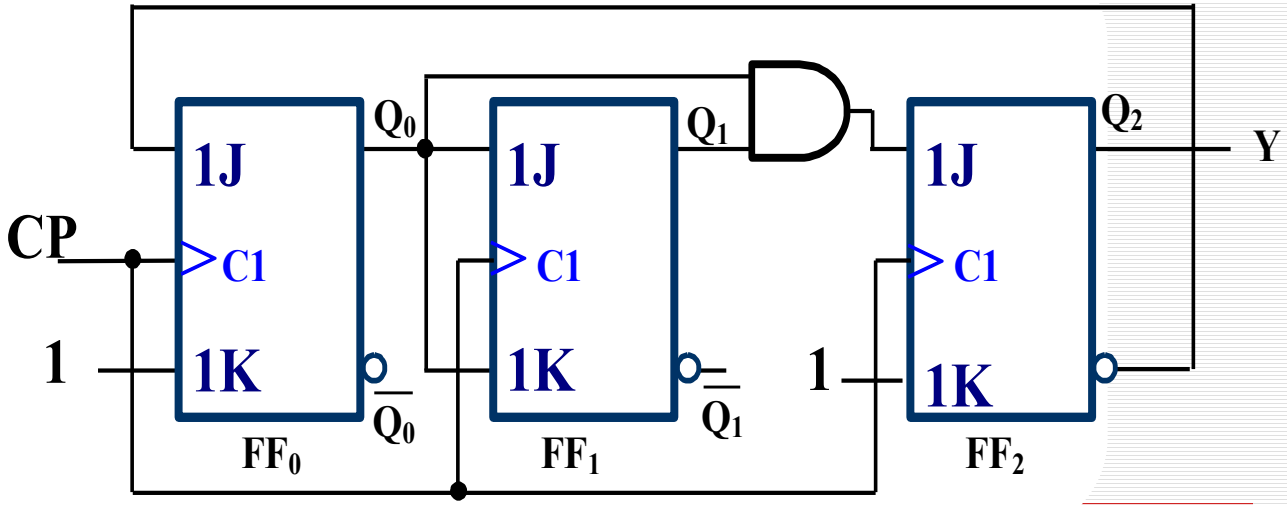
$$J_0 = \overline{Q_2^n} \quad K_0 = 1$$

$$J_2 = Q_0^n Q_1^n \qquad K_2 = 1$$

$$J_1 = Q_0^n \qquad K_1 = Q_0^n \qquad Y = Q_2^n$$

$$J_0 = \overline{Q_2^n} \qquad K_0 = 1$$

(3) 画出逻辑图



(4) 检查自启动能力

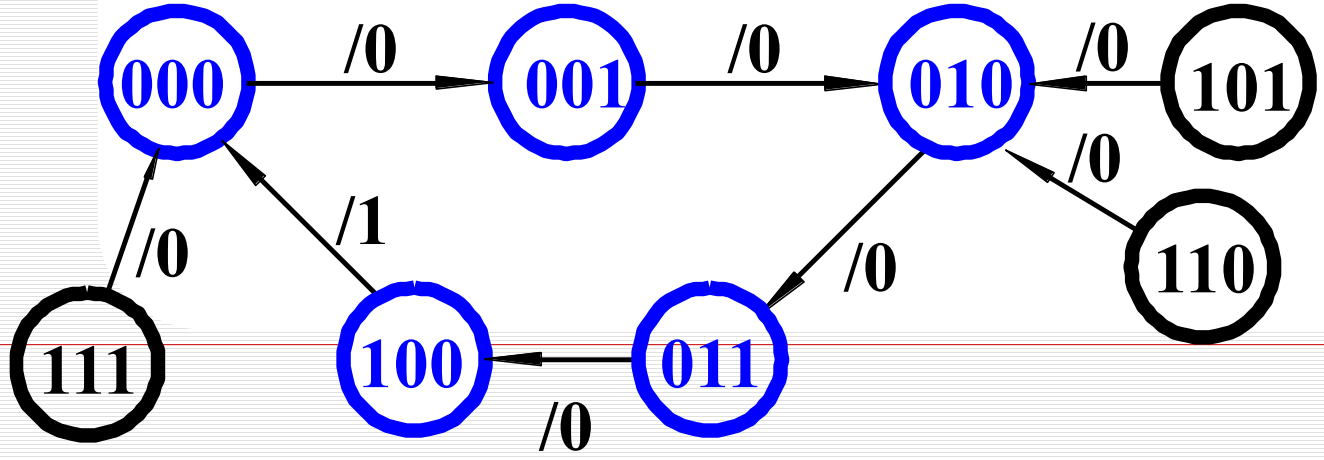
$$Q_0^{n+1} = \overline{Q_2^n} \cdot \overline{Q_0^n}$$

$$Q_1^{n+1} = Q_0^n \overline{Q_1^n} + \overline{Q_0^n} Q_1^n$$

$$Q_2^{n+1} = Q_0^n Q_1^n \overline{Q_2^n}$$

Q_2^n	Q_1^n	Q_0^n	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}	Y
0	0	0	0	0	1	0
0	0	1	0	1	0	0
0	1	0	0	1	1	0
0	1	1	1	0	0	0
1	0	0	0	0	0	1
1	0	1	0	1	0	1
1	1	0	0	1	0	1
1	1	1	0	0	0	1

电路具备自启动能力



Q_2^n	Q_1^n	Q_0^n	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}	Y
0	0	0	0	0	1	0
0	0	1	0	1	0	0
0	1	0	0	1	1	0
0	1	1	1	0	0	0
1	0	0	0	0	0	1

1	0	1	0	1	0	0
1	1	0	0	1	0	0
1	1	1	0	0	0	0

Y / Q_2^n \ $Q_1^n Q_0^n$	00	01	11	10
0	0	0	0	0
1	1	X	X	X

修改输出方程：

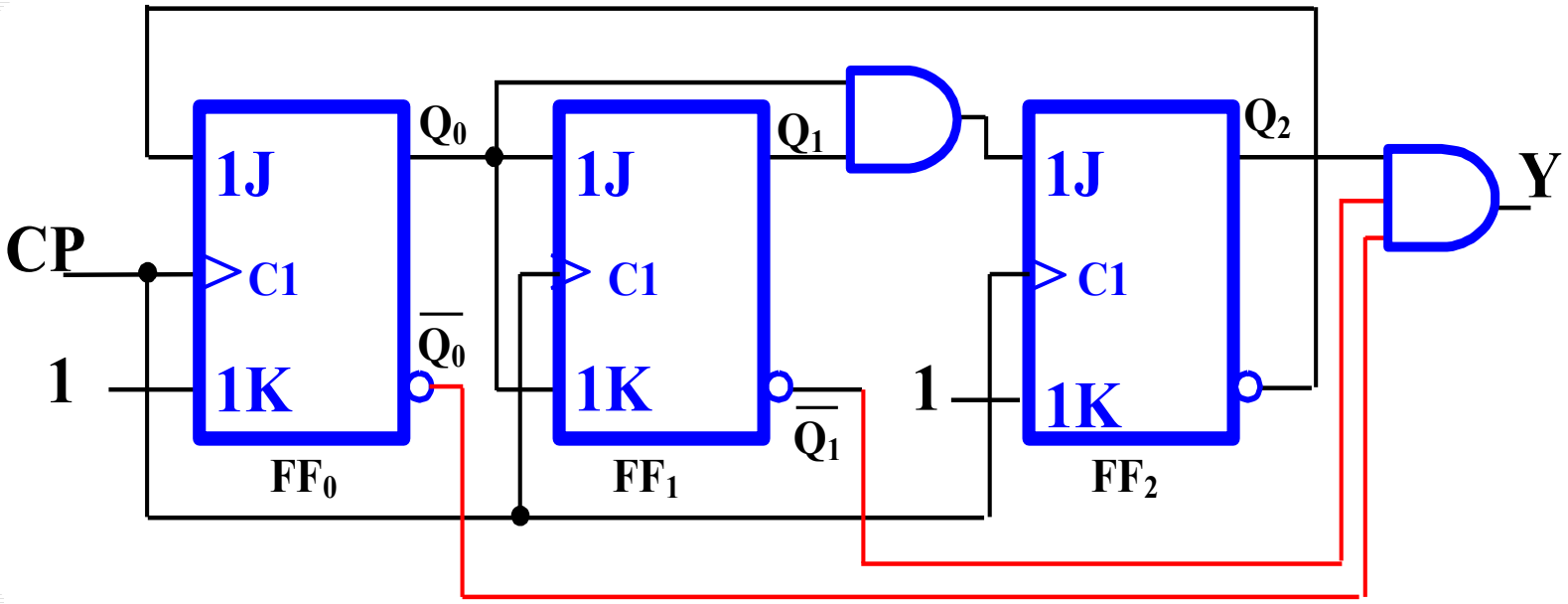
$$Y = Q_2^n$$

$$Y = Q_2^n \cdot \overline{Q_1^n} \cdot \overline{Q_0^n}$$

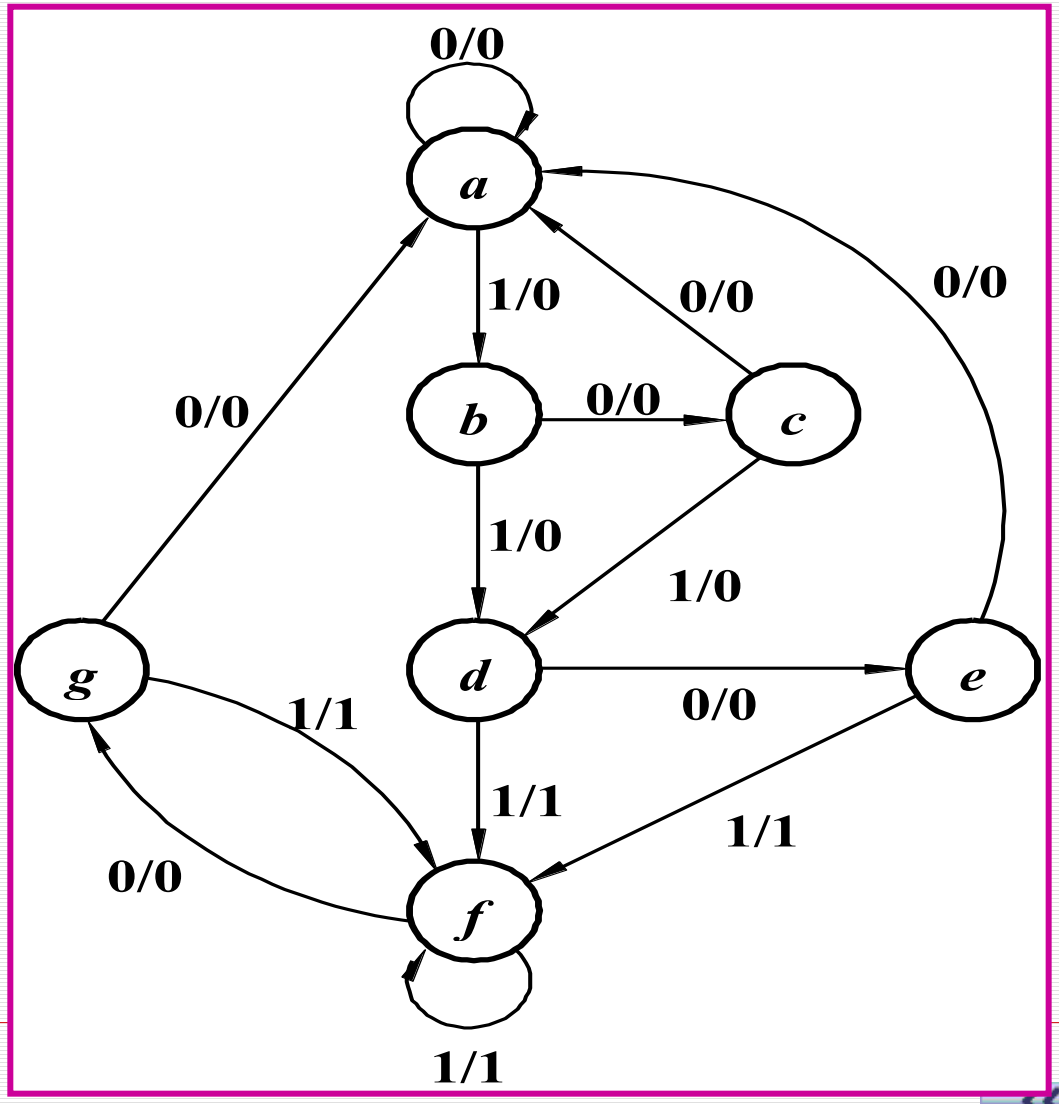
电路的输出有错！

•修改后的逻辑图

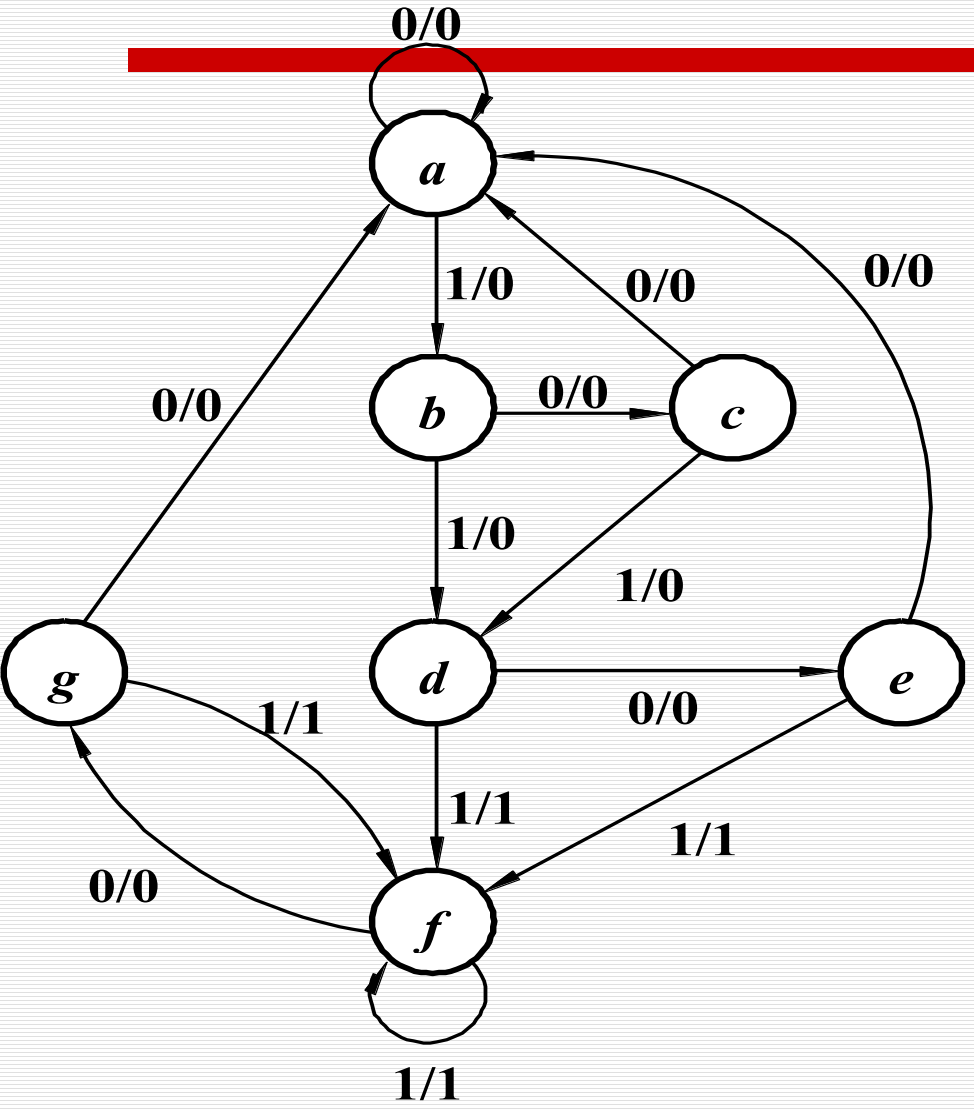
$$Y = Q_2^n \quad \Rightarrow \quad Y = Q_2^n \cdot \overline{Q_1^n} \cdot \overline{Q_0^n}$$



例4 用D触发器设计状态变化满足下状态图的时序逻辑电路



1、列出原始状态表



原始状态表

现态 (Q^n)	次态/输出 (Q^{n+1}/Y)	
	$A=0$	$A=1$
a	a / 0	b / 0
b	c / 0	d / 0
c	a / 0	d / 0
d	e / 0	f / 1
e	a / 0	f / 1
f	g / 0	f / 1
g	a / 0	f / 1

2、状态表化简

现态 (Q^n)	次态/输出 (Q^{n+1}/Y)	
	$A=0$	$A=1$
a	a / 0	b / 0
b	c / 0	d / 0
c	a / 0	d / 0
d	e / 0	f / 1
e	a / 0	f / 1
f	g / 0	f / 1

第一次化简状态表

现态 (Q^n)	次态/输出 (Q^{n+1}/Y)	
	$A=0$	$A=1$
a	a / 0	b / 0
b	c / 0	d / 0
c	a / 0	d / 0
d	e / 0	f / 1
e	a / 0	f / 1
f	e / 0	f / 1

2、状态编码

a=000;b=001;c=010 ;d=011;e=100

最后简化的状态表

现态 (Q^n)	次态/输出 (Q^{n+1}/Y)	
	A=0	A=1
a	a / 0	b / 0
b	c / 0	d / 0
c	a / 0	d / 0
d	e / 0	d / 1
e	a / 0	d / 1

已分配状态的状态表

现态 (Q^n)	次态/输出 (Q^{n+1}/Y)	
	A=0	A=1
000	000 / 0	001 / 0
001	010 / 0	011 / 0
010	000 / 0	011 / 0
011	100 / 0	011 / 1
100	000 / 0	011 / 1

3、求激励方程、输出方程

状态转换真值表

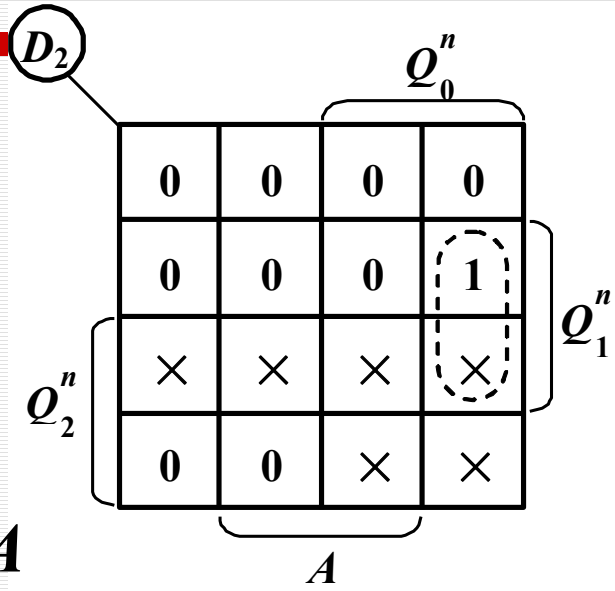
Q_2^n	Q_1^n	Q_0^n	A	$Q_2^{n+1}(D_2)$	$Q_1^{n+1}(D_1)$	$Q_0^{n+1}(D_0)$	Y
0	0	0	0	0	0	0	0
0	0	0	1	0	0	1	0
0	0	1	0	0	1	0	0
0	0	1	1	0	1	1	0
0	1	0	0	0	0	0	0
0	1	0	1	0	1	1	0
0	1	1	0	1	0	0	0
0	1	1	1	0	1	1	1
1	0	0	0	0	0	0	0
1	0	0	1	0	1	1	1

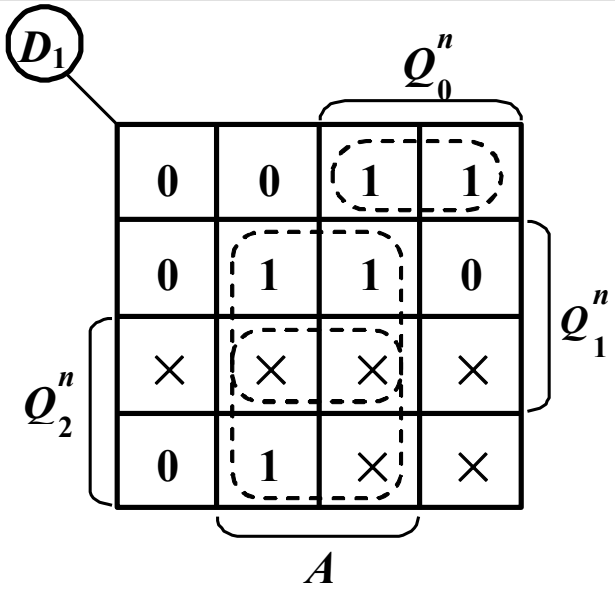
$$D_2 = Q_2^{n+1} = Q_1^n Q_0^n \overline{A}$$

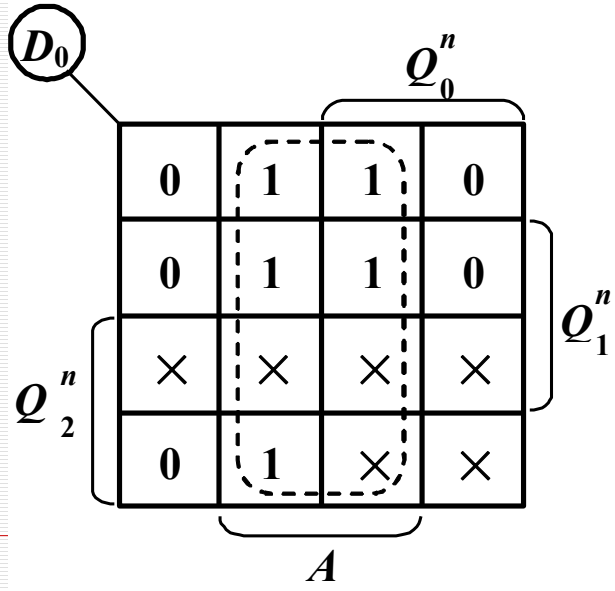
$$D_1 = Q_0^n \overline{Q_1^n} + Q_1^n A + Q_2^n A$$

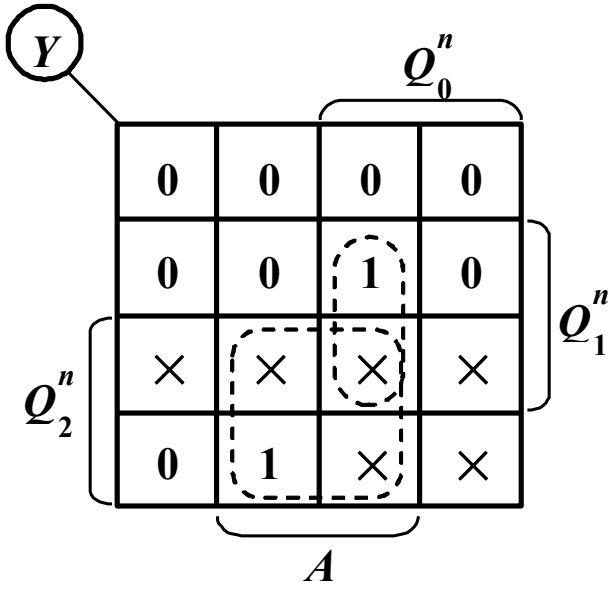
$$D_0 = Q_0^{n+1} = A$$

$$Y = Q_1^n Q_0^n A + Q_2^n A$$

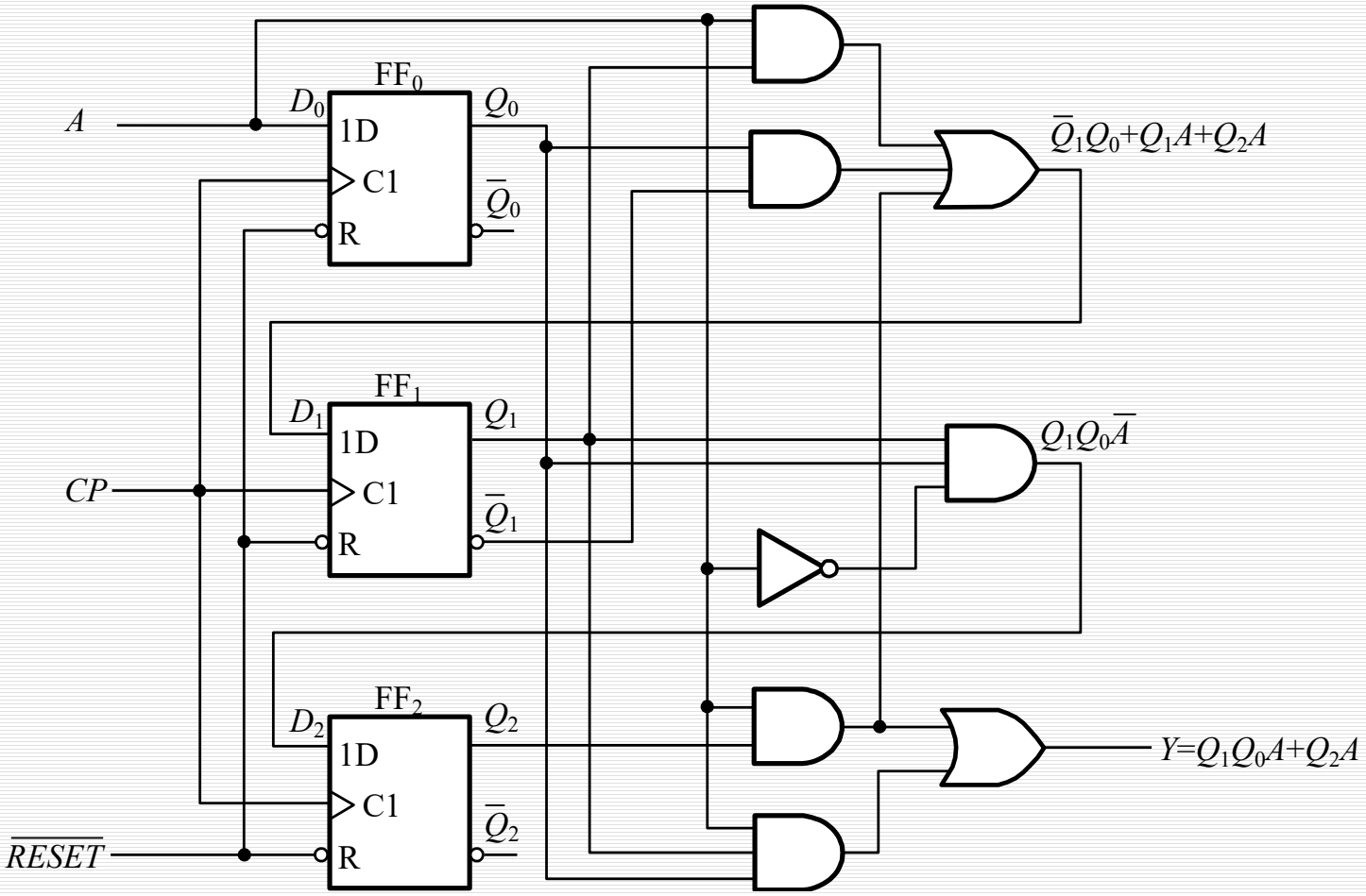








画出逻辑电路


A
CP
$\overline{RESET}$
FF0
FF1
FF2
D0
D1
D2
1D
C1
R
Q0
$\overline{Q}_0$
Q1
$\overline{Q}_1$
Q2
$\overline{Q}_2$
$\overline{Q}_1Q_0+Q_1A+Q_2A$
$Q_1Q_0\overline{A}$
$Y=Q_1Q_0A+Q_2A$

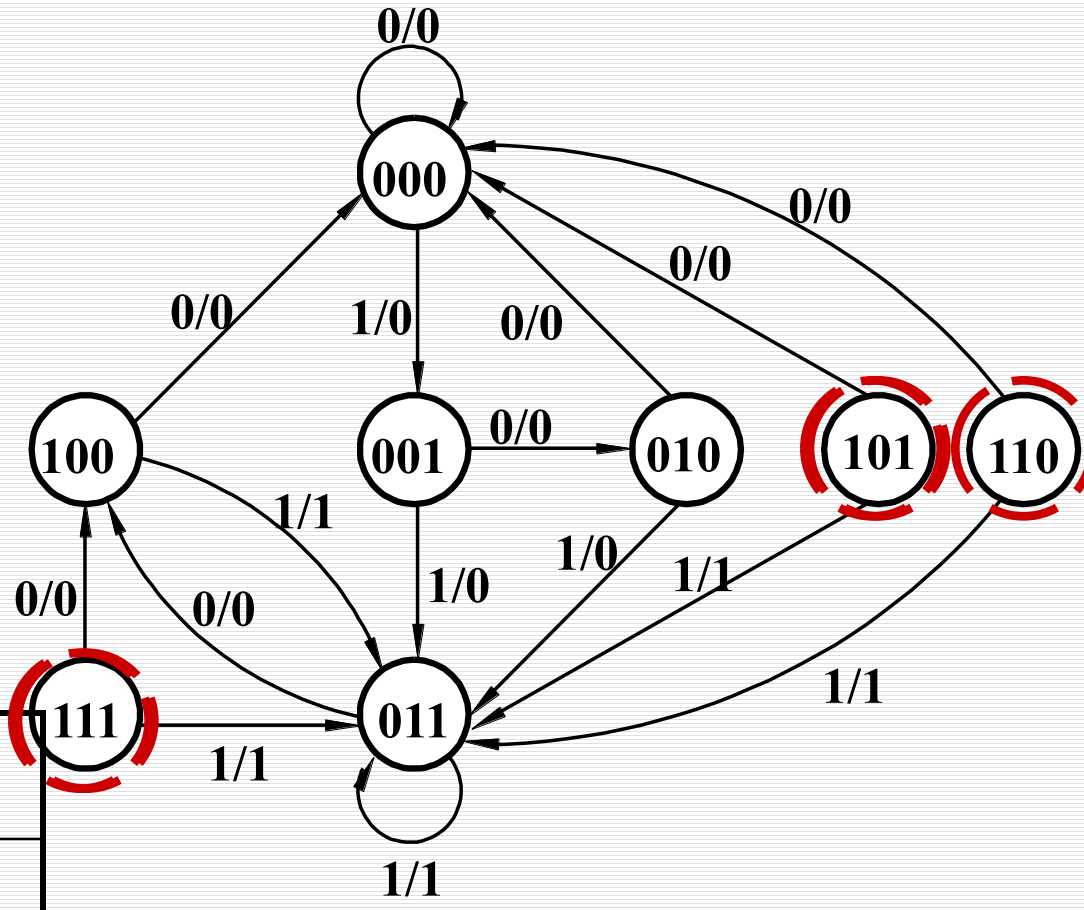
画出完整的状态图，检查所设计的计数器能否自启动.

$$D_2 = Q_2^{n+1} = Q_1^n Q_0^n \overline{A}$$

$$D_1 = Q_0^n \overline{Q_1^n} + Q_1^n A + Q_2^n A$$

$$D_0 = Q_0^{n+1} = A$$

$$Y = Q_1^n Q_0^n + Q_2^n A$$



101	010/0	011/1
110	000/0	011/1
111	100/0	011/1