# 第 6 章  时序逻辑电路

## Sequential  Logic Circuits

§6.1 概述 Introduction

§6.2 同步时序电路分析 Sequential  Logic Circuits Analysis

§6.3 同步时序电路设计 Synchronous Sequential Circuit Design

§6.4 计数器 Counter

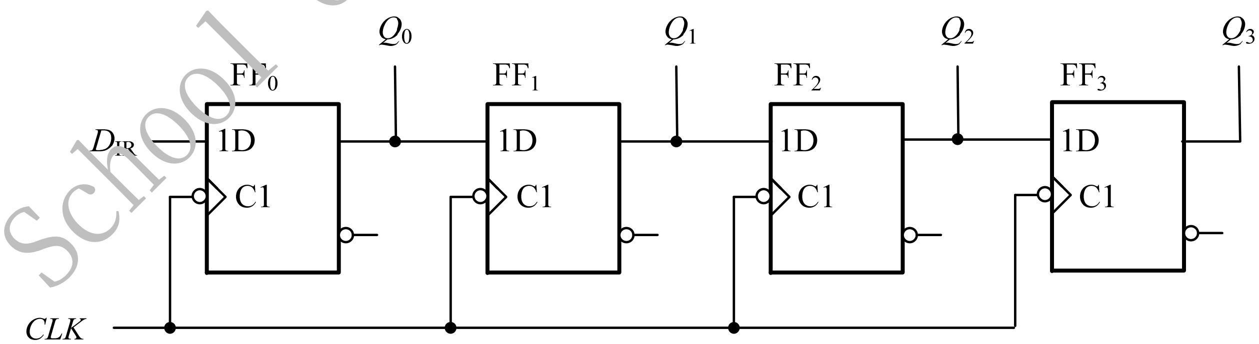
§6.5 寄存器 Register

§6.6 序列信号发生器 Series Signal Generator

# § 6.1 概述 Introduction

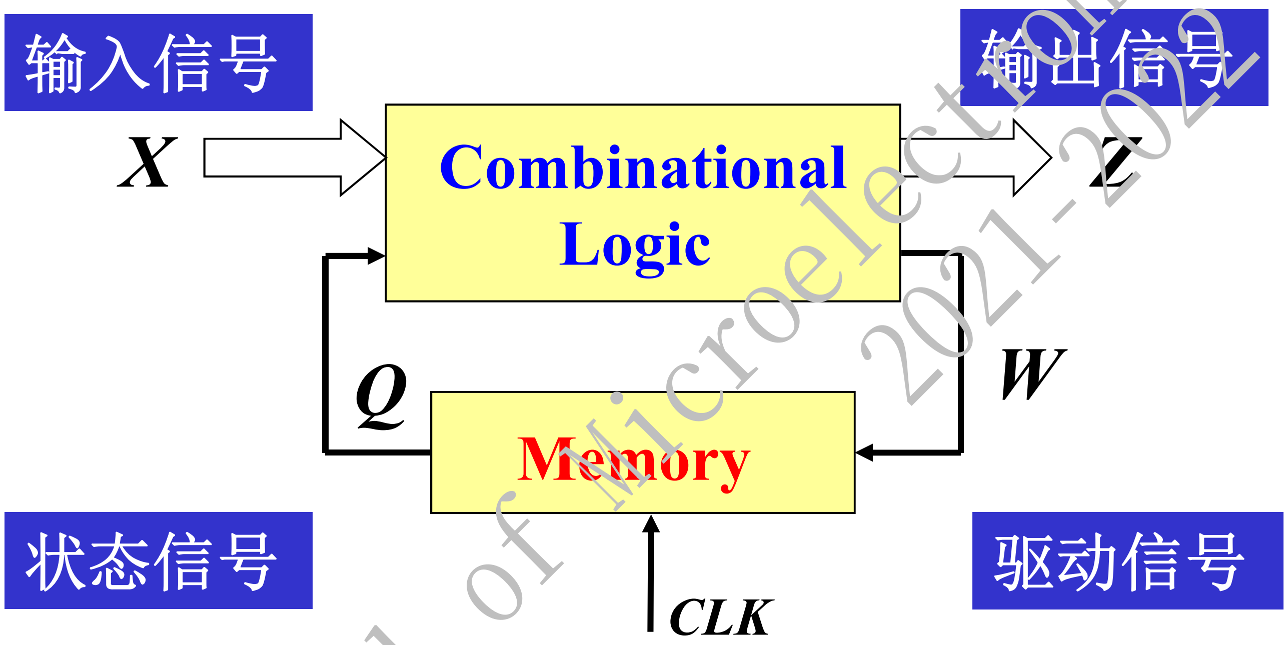
时序电路
- 输出
  - 输入
  - 以前状态 记忆
- 基本单元：FF（逻辑门 + 反馈线）

逻辑电路
- 同步 所有的触发器在*CLK* 同一边沿触发
- 异步 没有统一的时钟脉冲



# 时序电路结构

组合电路 + 存储电路（记忆元件）

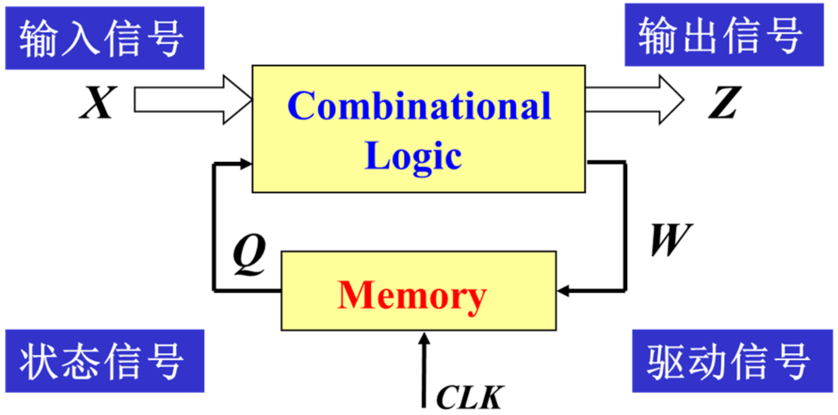



*X*：外输入

*Z*：外输出

*W*: 控制输入 — *J, K, D, T*

*Q*: 触发器输出（状态）




外输入 $X$　控制输入 $W$

外输出 $Z$　状态 $Q$

关系:

输出方程　$Z = F(X, Q)$

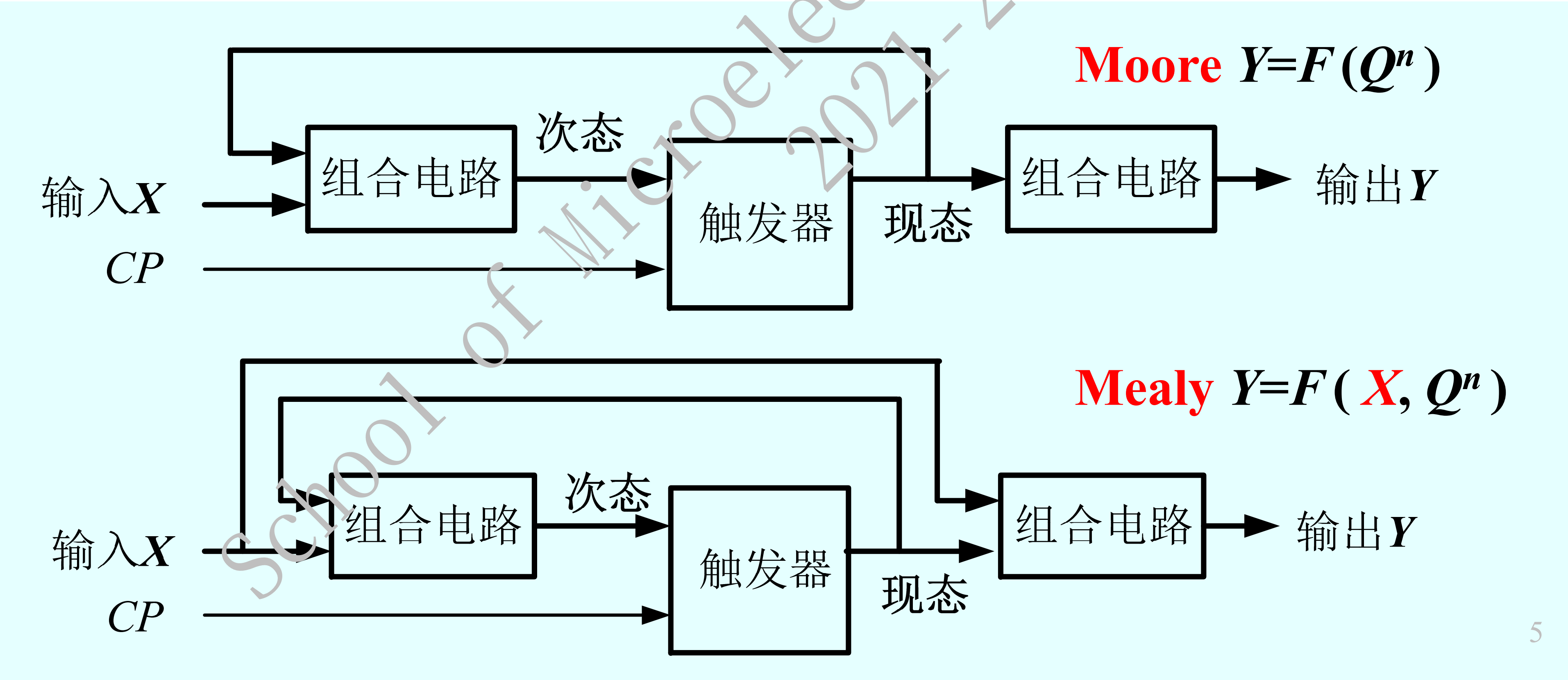
驱动方程　$W = H(X, Q)$

特征方程　$Q^{n+1} = G(W, Q^{n})$

# 按照电路中输出变量是否和输入变量直接相关

**时序电路**

- **莫尔型** (Moore) **输出** $Z \sim Q^n$
- **米里型** (Mealy) **输出** $Z$ $\begin{cases} Q^n \\ X \end{cases}$



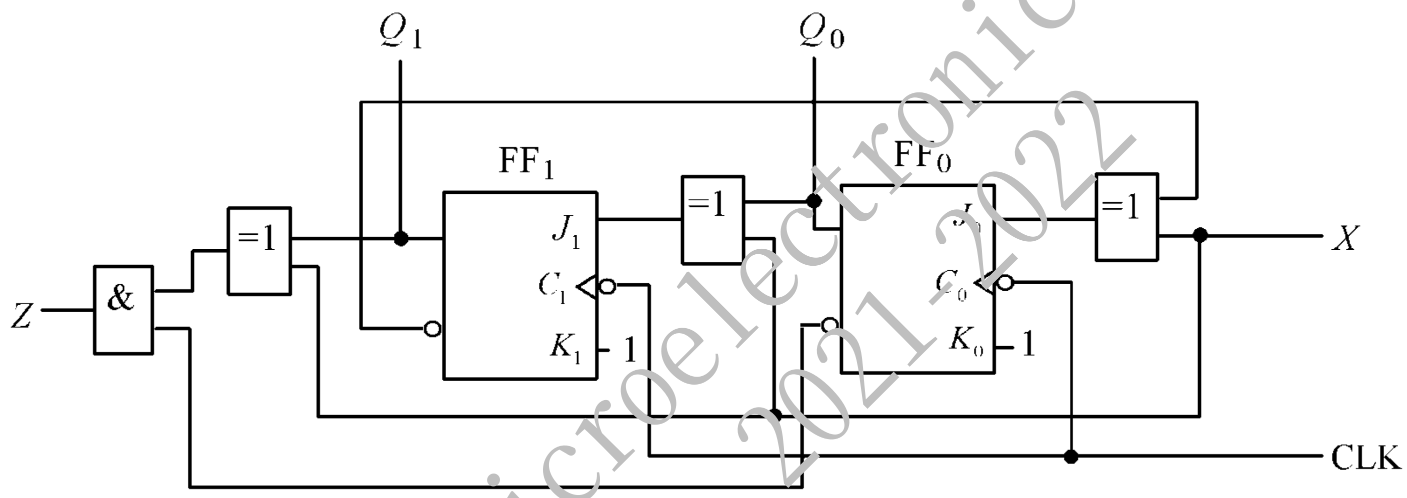
# §6.2 同步时序电路分析
## Sequential Logic Circuits Analysis

**分析: 已知电路, 描述电路原理及功能**

### 时序电路的分析步骤

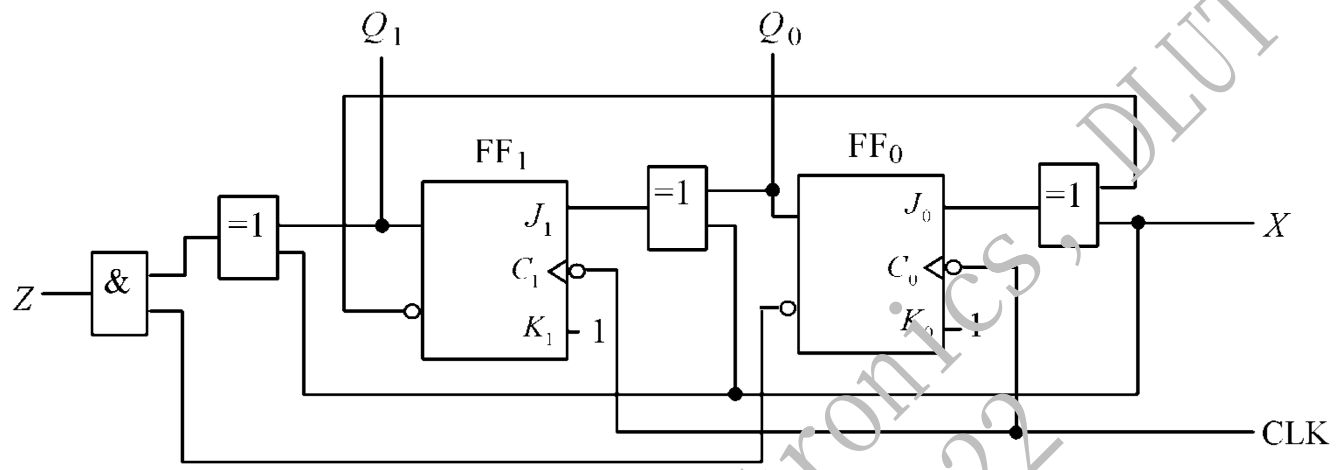
电路图 →(1) 驱动方程、输出方程 →(2) 特征方程 →(3) 逻辑运算 →(4) 状态图、状态表或时序图 →(5) 判断电路逻辑功能

# 例1: 分析下图时序逻辑电路




1) 输入 $X$ 控制输入 $J_0$, $K_0$, $J_1$, $K_1$

输出 $Z$ 状态 $Q_1$ (MSB), $Q_0$




## 2) 方程

**输出方程**

$$Z = (X \oplus Q_1^n) \cdot \overline{Q_0^n}$$

**驱动方程**

$$\begin{cases} J_0 = X \oplus \overline{Q_1^n} \\ K_0 = 1 \end{cases} \qquad \begin{cases} J_1 = X \oplus Q_0^n \\ K_1 = 1 \end{cases}$$

**特征方程**

$$\begin{cases} Q_0^{n+1} = J_0 \overline{Q_0^n} + \overline{K_0} Q_0^n = (X \oplus \overline{Q_1^n}) \cdot \overline{Q_0^n} \\ Q_1^{n+1} = J_1 \overline{Q_1^n} + \overline{K_1} Q_1^n = (X \oplus Q_0^n) \cdot \overline{Q_1^n} \end{cases}$$

## 3) 状态表和状态图

**已知：输入 $X$，$Q^n$**

**求：输出 $Z$，$Q^{n+1}$**

$$Q_1^{n+1} = (X \oplus Q_0^n) \cdot \overline{Q_1^n}$$

$$Q_0^{n+1} = (X \oplus \overline{Q_1^n}) \overline{Q_0^n}$$

$$Z = (X \oplus Q_1^n) \cdot \overline{Q_0^n}$$

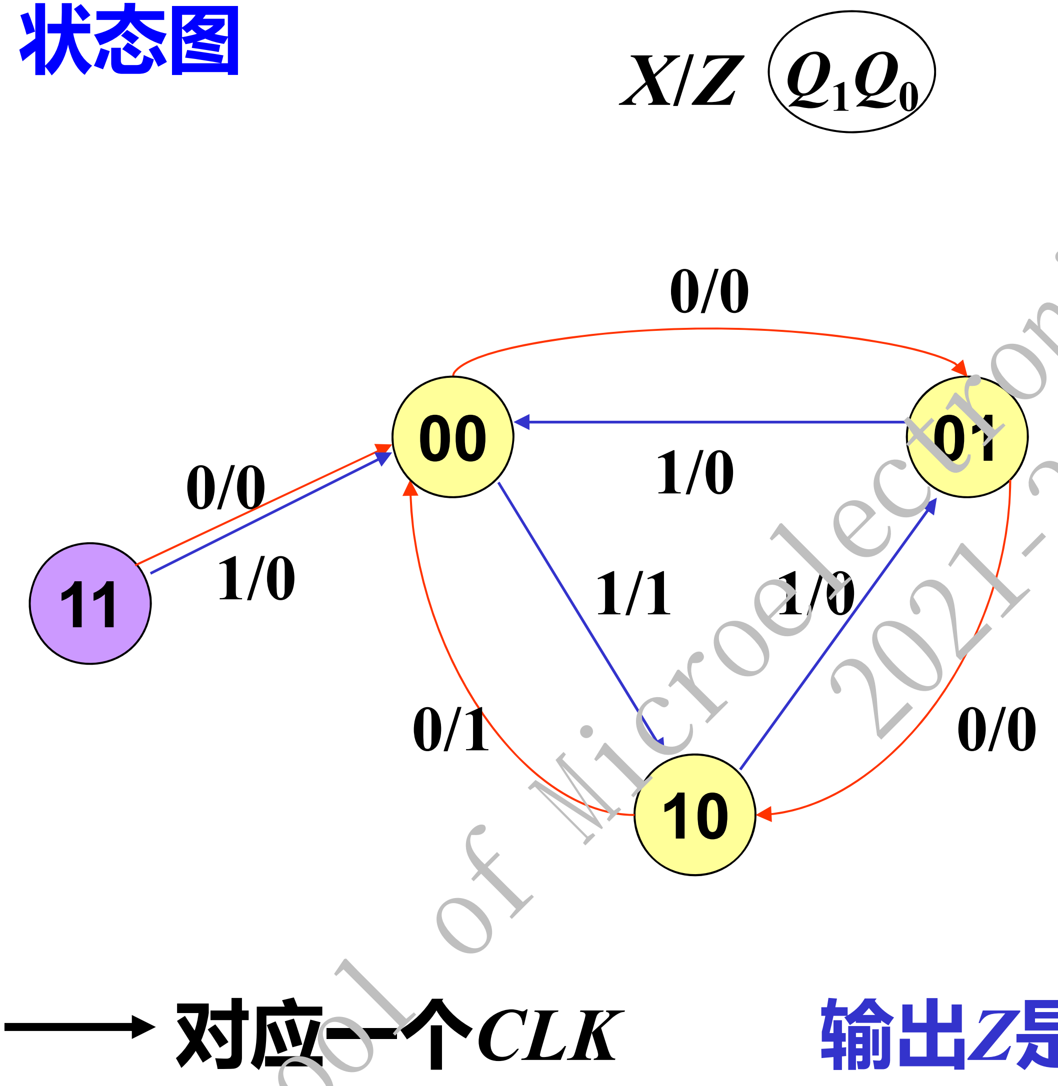
### 状态表

| | $X$ | $Q_1^n$ | $Q_0^n$ | $Q_1^{n+1}$ | $Q_0^{n+1}$ | $Z$ |
|---|---|---|---|---|---|---|
| $X$=0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 0 | 0 | 1 | 1 | 0 | 0 |
| | 0 | 1 | 0 | 0 | 0 | 1 |
| | 0 | 1 | 1 | 0 | 0 | 0 |
| $X$=1 | 1 | 0 | 0 | 1 | 0 | 1 |
| | 1 | 0 | 1 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 1 | 0 |
| | 1 | 1 | 1 | 0 | 0 | 0 |

$X$=0
$$\begin{cases} Q_1^{n+1} = Q_0^n \cdot \overline{Q}_1^n \\ Q_0^{n+1} = \overline{Q_1^n} \cdot \overline{Q_0^n} = \overline{Q_1^n + Q_0^n} \\ Z = Q_1^n \cdot \overline{Q_0^n} \end{cases}$$

$X$=1
$$\begin{cases} Q_1^{n+1} = \overline{Q_0^n} \cdot \overline{Q_1^n} \\ Q_0^{n+1} = Q_1^n \cdot \overline{Q_0^n} \\ Z = \overline{Q_1^n} \cdot \overline{Q_0^n} \end{cases}$$

## 状态图




## 状态表

| $X$ , $Q_1^n$ $Q_0^n$ | $Q_1^{n+1}$ | $Q_0^{n+1}$ | $Z$ |
|---|---|---|---|
| 0 0 0 | 0 | 1 | 0 |
| 0 0 1 | 1 | 0 | 0 |
| 0 1 0 | 0 | 0 | 1 |
| 0 1 1 | 0 | 0 | 0 |
| 1 0 0 | 1 | 0 | 1 |
| 1 0 1 | 0 | 0 | 0 |
| 1 1 0 | 0 | 1 | 0 |
| 1 1 1 | 0 | 0 | 0 |

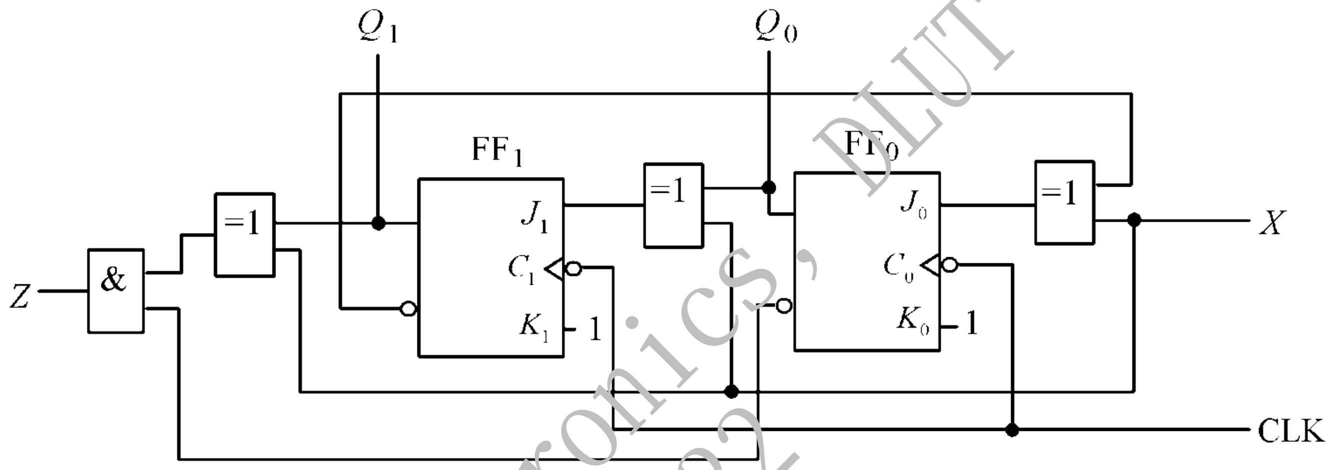
**输出$Z$是原状态下的输出**

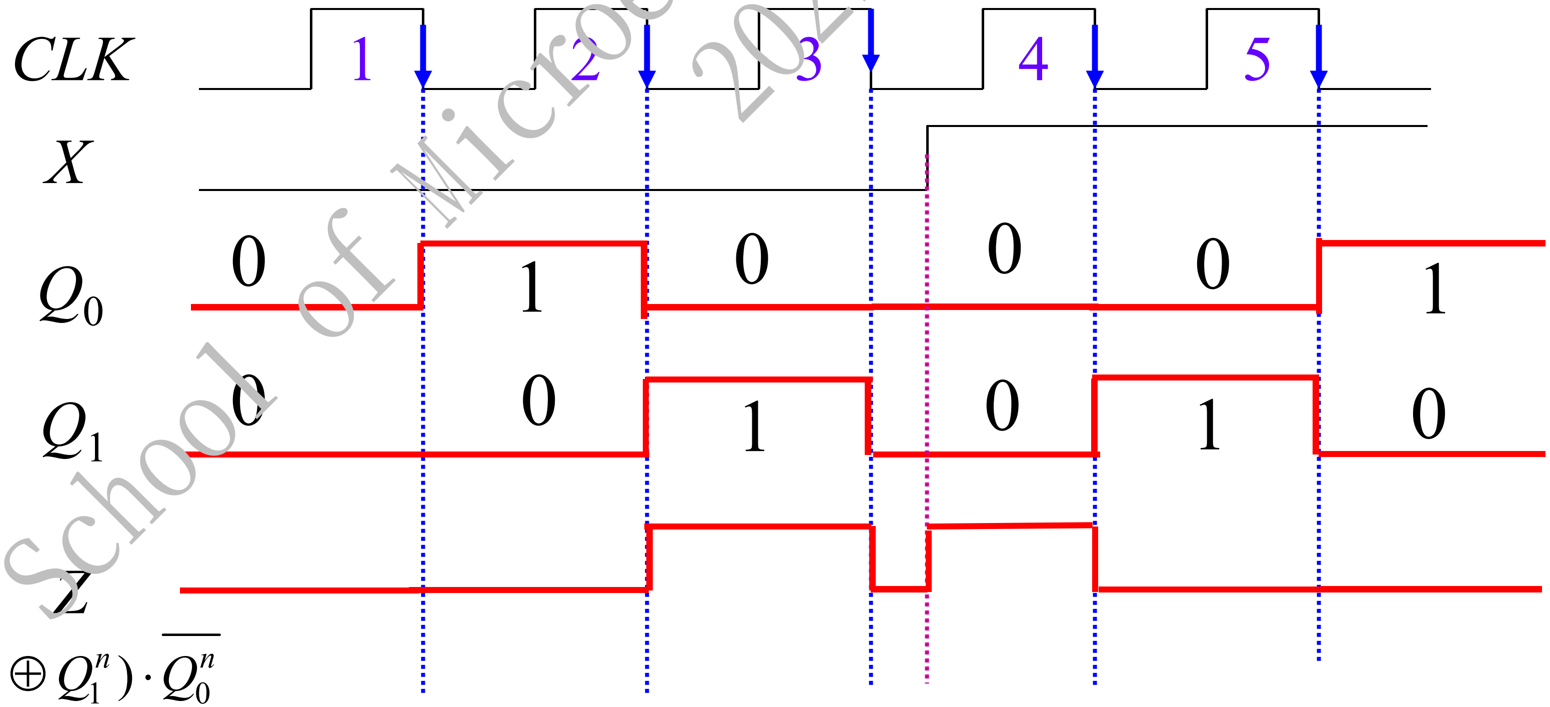
**每条转换线对应真值表的一行**

# 4) 画波形图

**状态表**

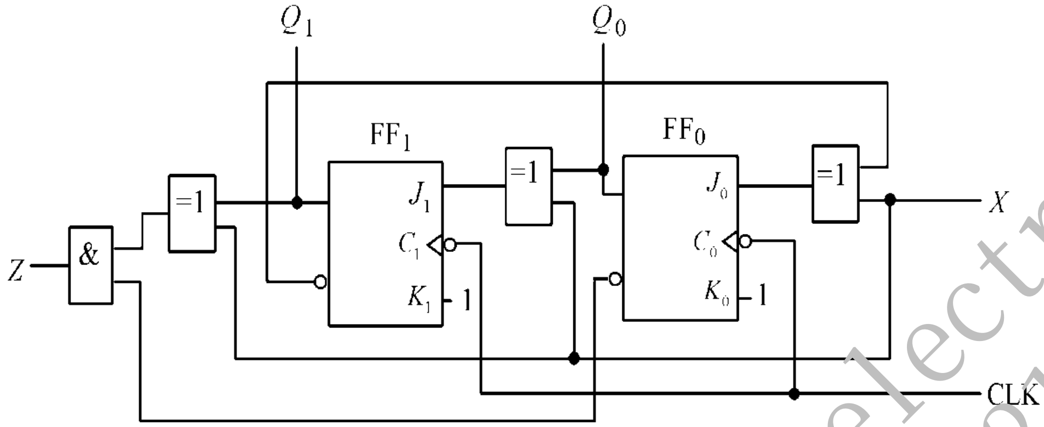
| $X$ | $Q_1^n$ | $Q_0^n$ | $Q_1^{n+1}$ | $Q_0^{n+1}$ | $Z$ |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 1 |
| 0 | 1 | 1 | 0 | 0 | 0 |
| 1 | 0 | 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 | 0 | 0 |

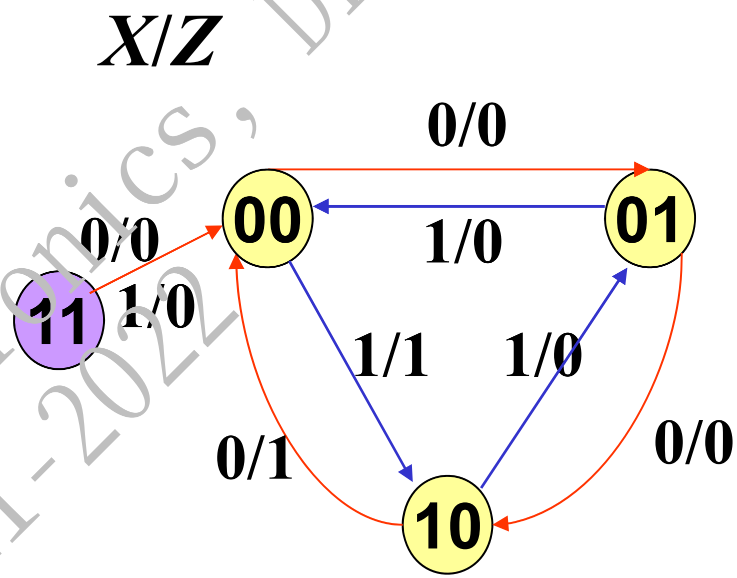



$$= (X \oplus Q_1^n) \cdot \overline{Q_0^n}$$

## 5) 电路功能



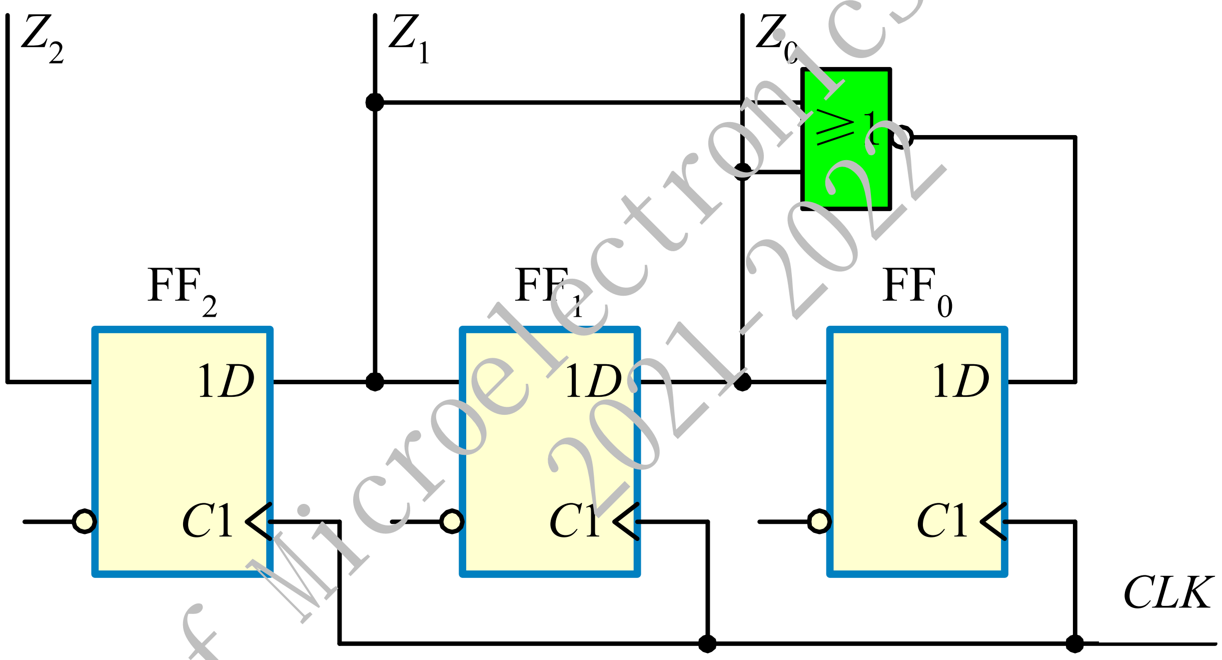




**$X$=0, M-3 加法计数：$Z = 1$，进位输出；**

**$X$=1, M-3 减法计数：$Z = 1$，借位输出。**

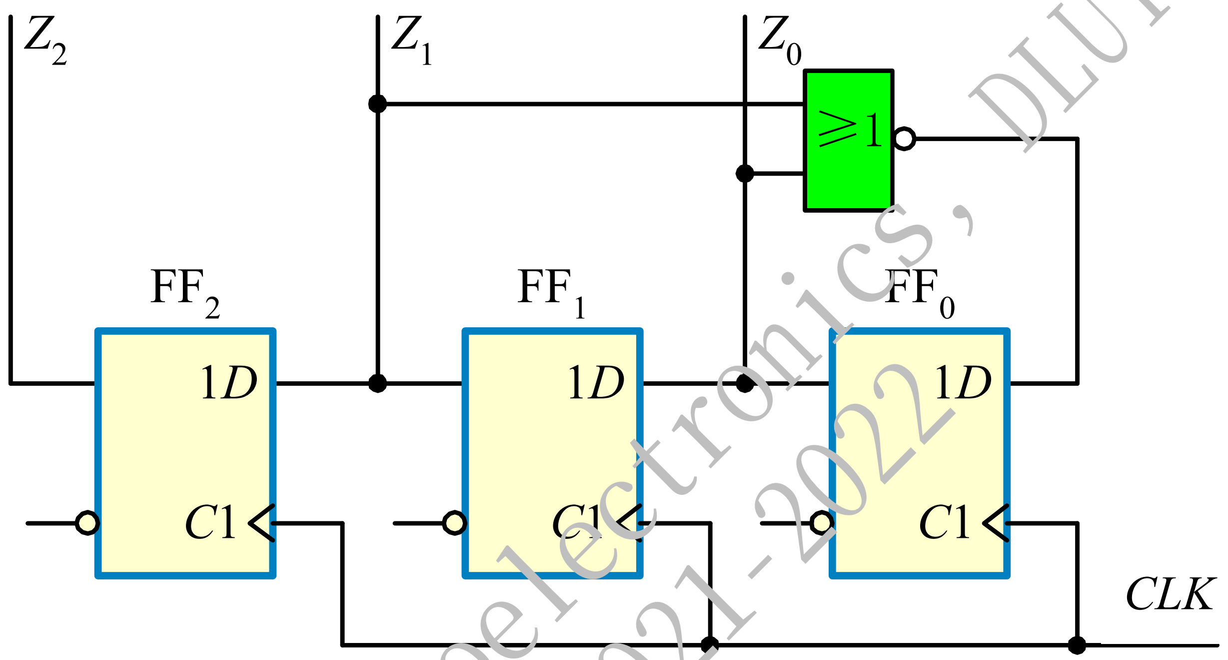
**状态图主循环：模 3 加减双向计数器**

# 例2: 分析下图时序逻辑电路




1) 输入 无 控制输入 $D_0, D_1, D_2$

输出 $Z_2, Z_1, Z_0$ 状态 $Q_2, Q_1, Q_0$




## 2) 方程

**输出方程** $Z_2 = Q_2^n, Z_1 = Q_1^n, Z_0 = Q_0^n$

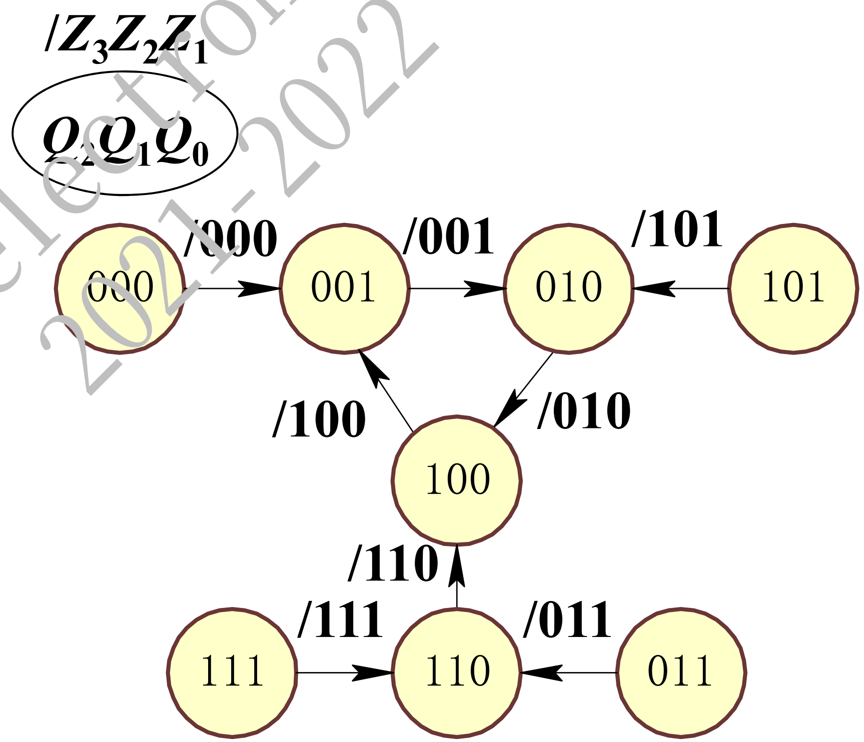
**驱动方程** $D_2 = Q_1^n, D_1 = Q_0^n, D_0 = \overline{Q_1^n + Q_0^n}$

**特征方程** $Q_2^{n+1} = D_2 = Q_1^n, Q_1^{n+1} = D_1 = Q_0^n, Q_0^{n+1} = D_0 = \overline{Q_1^n + Q_0^n}$

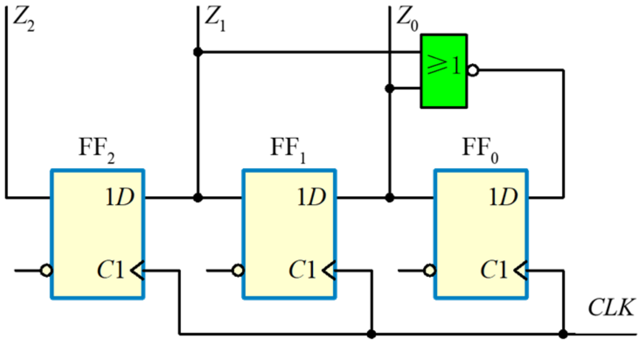
## 3) 状态表和状态图

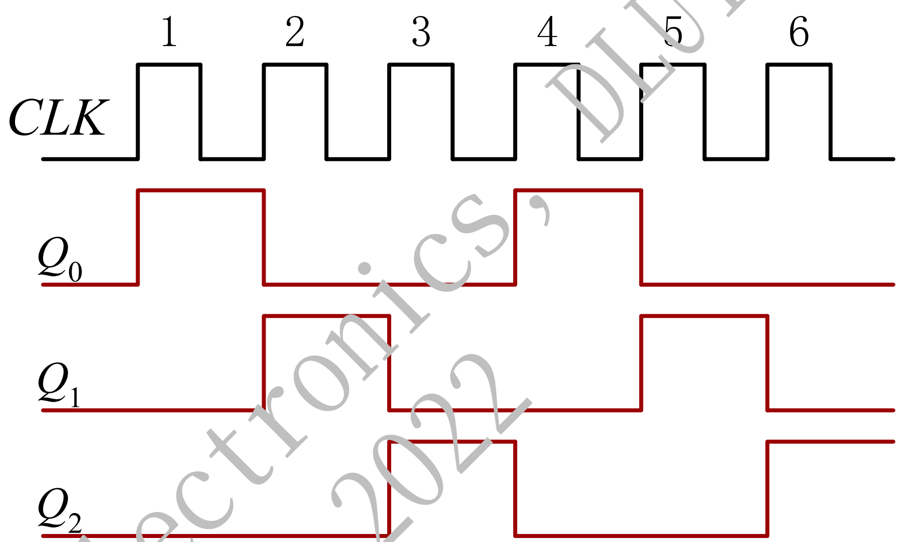
$$Q_2^{n+1} = D_2 = Q_1^n$$
$$Q_1^{n+1} = D_1 = Q_0^n$$
$$Q_0^{n+1} = D_0 = \overline{Q_1^n + Q_0^n}$$

| $Q_2^n$ | $Q_1^n$ | $Q_0^n$ | $Q_2^{n+1}$ | $Q_1^{n+1}$ | $Q_0^{n+1}$ |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 1 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 0 |



## 4) 画波形图



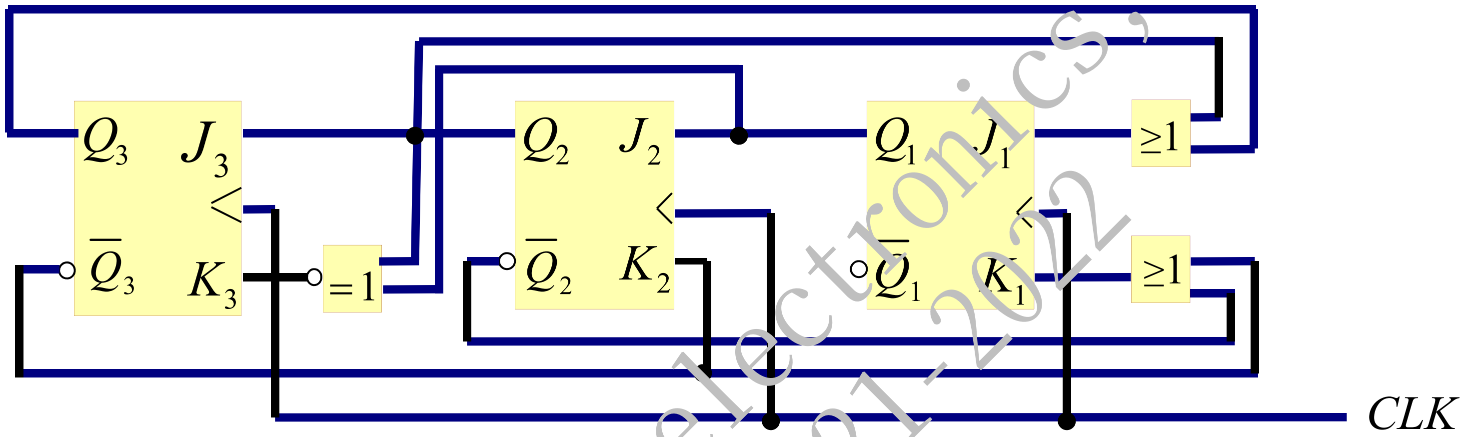




| $Q_2^n$ | $Q_1^n$ | $Q_0^n$ | $Q_2^{n+1}$ | $Q_1^{n+1}$ | $Q_0^{n+1}$ |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 1 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 0 |

## 5) 电路功能

- 在*CLK*作用下，把宽度为*T*的脉冲以三次分配给$Q_0$,$Q_1$和$Q_2$各端，因此该电路是一个脉冲分配器
- 每经过三个时钟周期循环一次

# 例 3. 分析下图时序电路




**无外输入，无外输出**

$$\begin{cases} J_3 = Q_2^n \\ K_3 = \overline{Q_2^n \oplus Q_1^n} \end{cases} \quad \begin{cases} J_2 = Q_1^n \\ K_2 = \overline{Q}_3^n \end{cases} \quad \begin{cases} J_1 = Q_2^n + Q_3^n \\ K_1 = \overline{Q}_2^n + \overline{Q}_3^n = \overline{Q_2^n Q_3^n} \end{cases}$$

$$Q_3^{n+1} = J_3\overline{Q_3^n} + \overline{K}_3 Q_3^n = Q_2^n\overline{Q_3^n} + (Q_2^n \oplus Q_1^n)Q_3^n$$

$$Q_2^{n+1} = J_2\overline{Q_2^n} + \overline{K}_2 Q_2^n = Q_1^n\overline{Q_2^n} + Q_3^n Q_2^n$$

$$Q_1^{n+1} = J_1\overline{Q_1^n} + \overline{K}_1 Q_1^n = (Q_2^n + Q_3^n)\overline{Q_1^n} + Q_2^n Q_3^n Q_1^n$$

| $Q_3^n$ | $Q_2^n$ | $Q_1^n$ | $Q_3^{n+1}$ | $Q_2^{n+1}$ | $Q_1^{n+1}$ |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 1 | 0 |
| 1 | 1 | 0 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 | 1 |

$$Q_3^{n+1}\begin{cases} Q_2^n & Q_3^n = 0, \\ Q_2^n \oplus Q_1^n & Q_3^n = 1, \end{cases}$$

$$Q_2^{n+1}\begin{cases} Q_1^n & Q_2^n = 0, \\ Q_3^n & Q_2^n = 1, \end{cases}$$

$$Q_1^{n+1}\begin{cases} Q_2^n + Q_3^n & Q_1^n = 0, \\ Q_2^n Q_3^n & Q_1^n = 1, \end{cases}$$

| $Q_3^n$ | $Q_2^n$ | $Q_1^n$ | $Q_3^{n+1}$ | $Q_2^{n+1}$ | $Q_1^{n+1}$ |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 1 | 0 |
| 1 | 1 | 0 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 | 1 |

000 **孤立状态**

**自启动**