# DIGITAL ELECTRONICS

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# Lecture of Module 5

**Sequential Circuits**

**(Counter)**

# Overview

- **Introduction**
- **Synchronous counter**
- **Asynchronous counter**
- **Up counter**
- **Down counter**
- **Decade counter**
- **Ring counter**
- **Johnson counter**

# Introduction

- Counter essentially a register that goes through predetermined sequence of states upon the application of input pulses.
- A counter is a device which can count any particular event on the basis of how many times the particular event(s) is occurred.
- In a digital logic system or computers, this counter can count and store the number of time any particular event or process have occurred, depending on a clock signal.
- Most common type of counter is sequential digital logic circuit with a single clock input and multiple outputs.

- The outputs represent binary or binary coded decimal numbers.
- Each clock pulse either increase the number or decrease the number.
- **Modulus** or **MOD** of a counter is the total number of states through which a counter can progress.
- Two types of counters:
  - Synchronous (parallel) counter
  - Asynchronous (ripple) counter

## Synchronous Counter

- Synchronous counter known as parallel counter.
- All flip flops of the counter changes their states at the same time in synchronous with the input clock signal.
- All flip-flops of the counter driven by same clock.
- Circuit delay is equal to the propagation delay of one flip flop.

## Asynchronous Counter

- Known as Ripple counter.
- Also known as Serial counter.
- Output of one flip flop is used as clock input of other flip flop.
- Circuit delay is equal to the sum of propagation delay of all flip flops.

# Synchronous Counter

## Binary Counter

| Count Sequences | | | Flip Flop Inputs | | |
|---|---|---|---|---|---|
| A | B | C | TA | TB | TC |
| 0 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 | 1 |
| 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 0 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 |

| | B'C' | B'C | BC | BC' |
|---|---|---|---|---|
| A' | | | 1 | |
| A | | | 1 | |

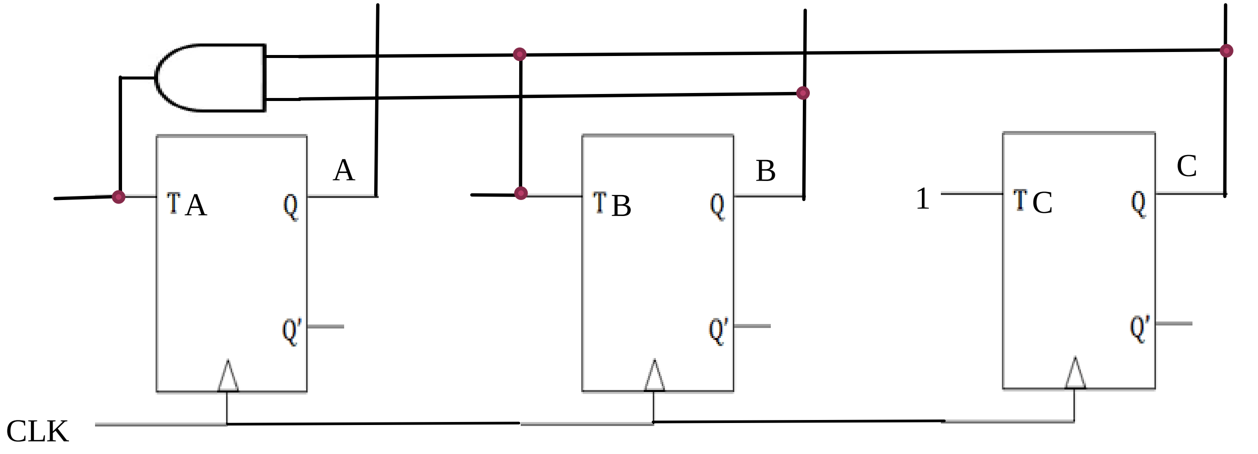
TA = BC

| | B'C' | B'C | BC | BC' |
|---|---|---|---|---|
| A' | | 1 | 1 | |
| A | | 1 | 1 | |

TB = C

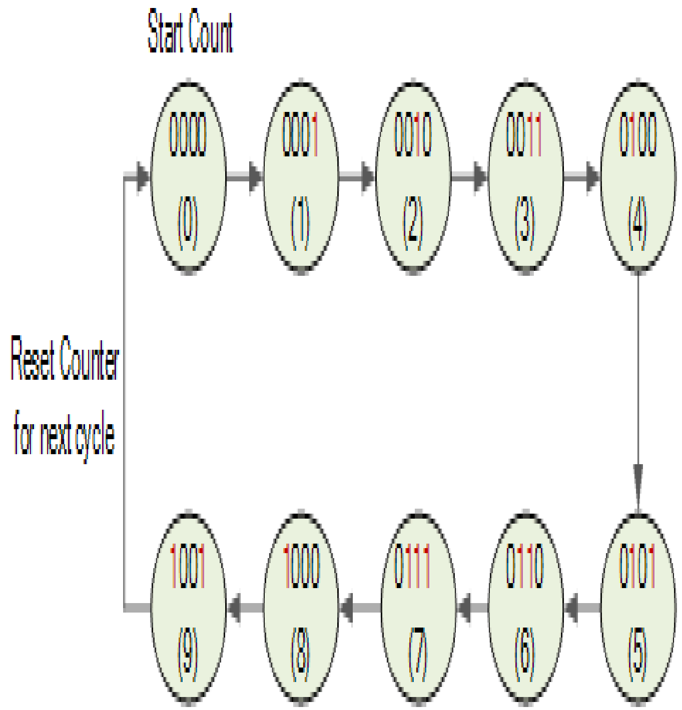
| | B'C' | B'C | BC | BC' |
|---|---|---|---|---|
| A' | 1 | 1 | 1 | 1 |
| A | 1 | 1 | 1 | 1 |

TC = 1



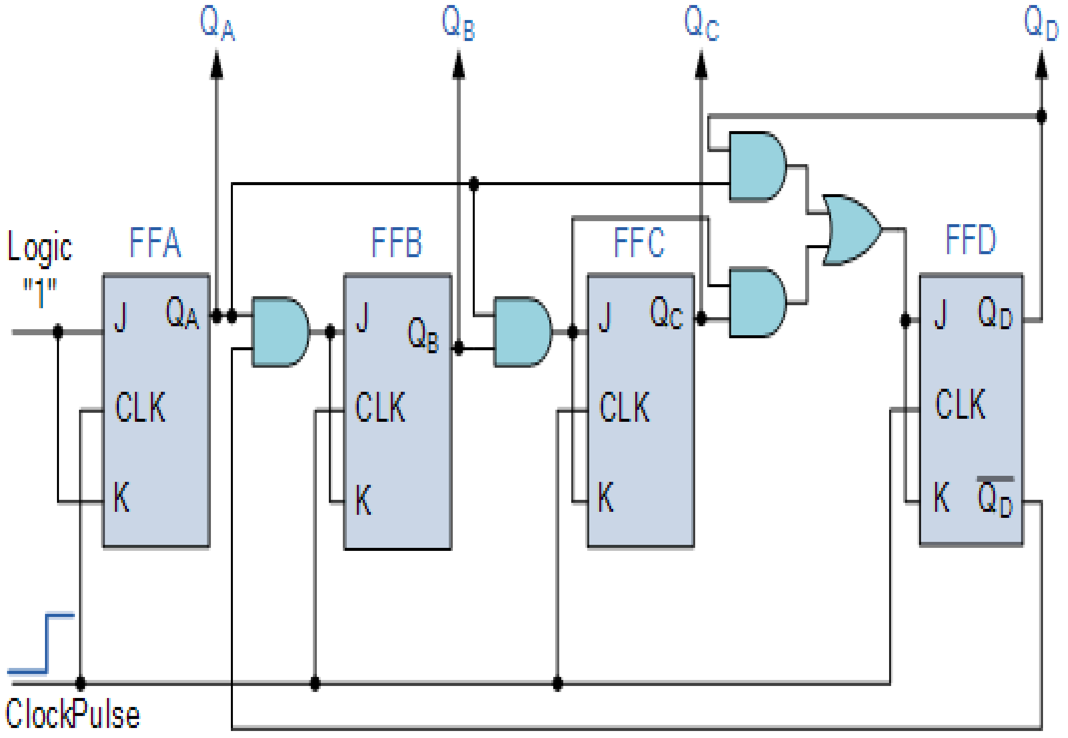
# Decade or BCD synchronous counter

- A 4-bit decade synchronous counter can also be built using synchronous binary counters to produce a count sequence from 0 to 9.
- A standard binary counter can be converted to a decade (decimal 10) counter with the aid of some additional logic to implement the desired state sequence.
- After reaching the count of “1001”, the counter recycles back to “0000”. We now have a **Decade** or **Modulo-10** counter or **MOD-10** counter.
- In the Truth Table count sequences are given. Using Excitation Table of J-K Flip Flops input sequences to be decided.
- Then using K-Map simplified Boolean equations of J-K inputs can be found.




Truth Table

| count | $Q_D$ | $Q_C$ | $Q_B$ | $Q_A$ |
|---|---|---|---|---|
| 0 [start] | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 1 | 0 |
| 3 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 0 | 0 |
| 5 | 0 | 1 | 0 | 1 |
| 6 | 0 | 1 | 1 | 0 |
| 7 | 0 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 1 |
| 10 [new cycle] | 0 | 0 | 0 | 0 |



# Asynchronous Counter

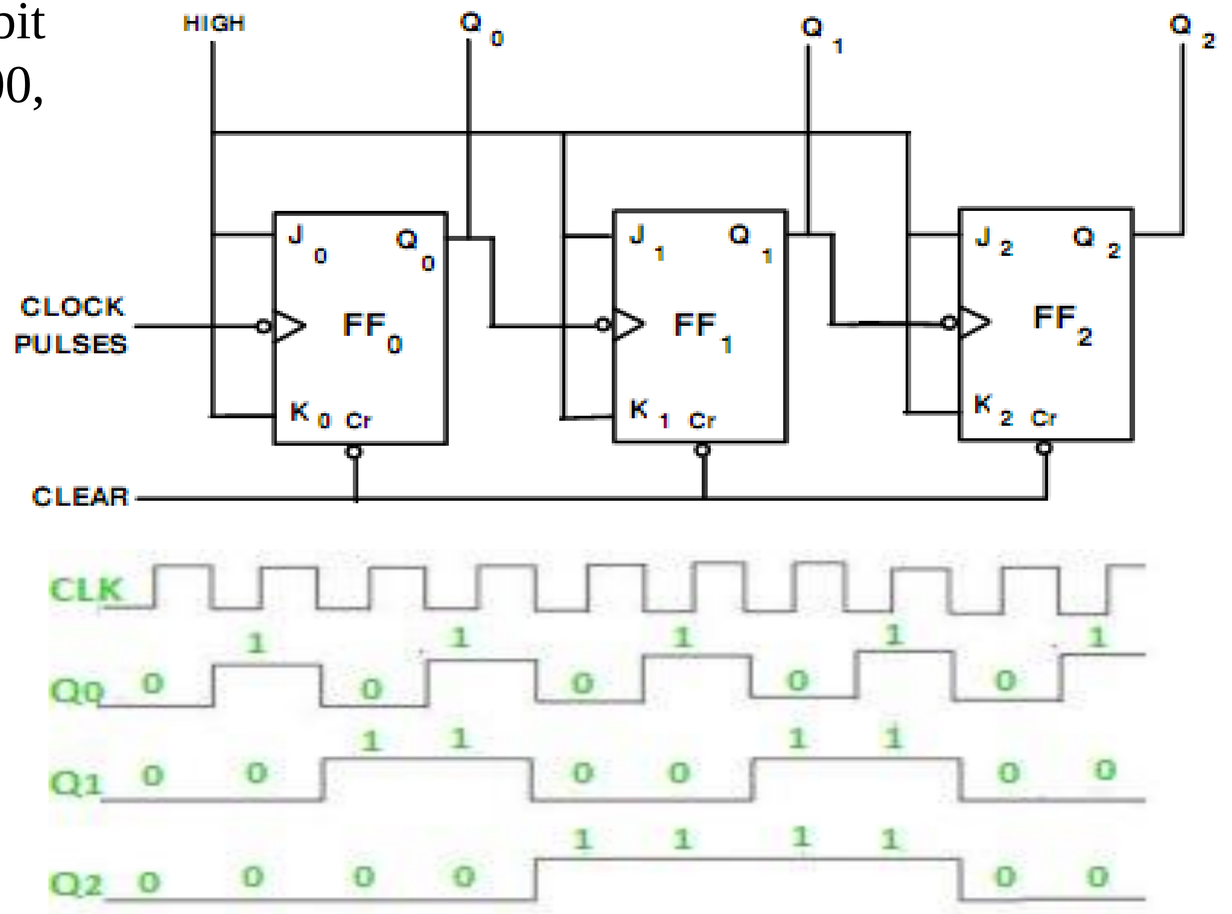
- Ripple counter is an Asynchronous counter. It got its name because the clock pulse ripples through the circuit.
- It is an asynchronous counter.
- Different flip-flops are used with a different clock pulse.
- All the flip-flops are used in toggle mode.
- Only one flip-flop is applied with an external clock pulse and another flip-flop clock is obtained from the output of the previous flip-flop.

- The flip-flop applied with external clock pulse act as LSB (Least Significant Bit) in the counting sequence.
- A counter may be an up counter that counts upwards or can be a down counter that counts downwards or can do both i.e. count up as well as count downwards depending on the input control.
- When counting up, for n-bit counter the count sequence goes from 000, 001, 010, … 110, 111, 000, 001, … etc.
- When counting down the count sequence goes in the opposite manner: 111, 110, … 010, 001, 000, 111, 110, … etc.

# Ripple Counter

Count Up: When counting up, for n-bit counter the count sequence goes from 000, 001, 010, … 110, 111, 000, 001, … etc.

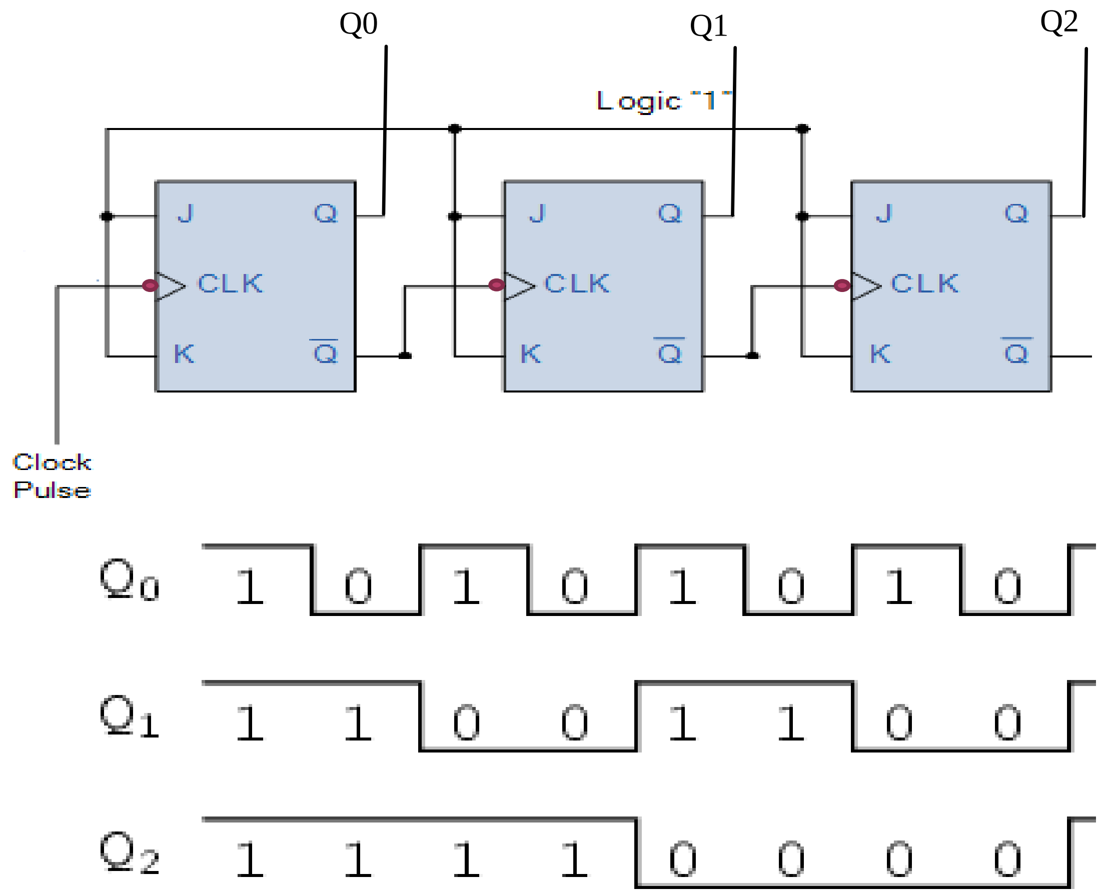
| Counter State | $Q_2$ | $Q_1$ | $Q_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 1 |
| 2 | 0 | 1 | 0 |
| 3 | 0 | 1 | 1 |
| 4 | 1 | 0 | 0 |
| 5 | 1 | 0 | 1 |
| 6 | 1 | 1 | 0 |
| 7 | 1 | 1 | 1 |



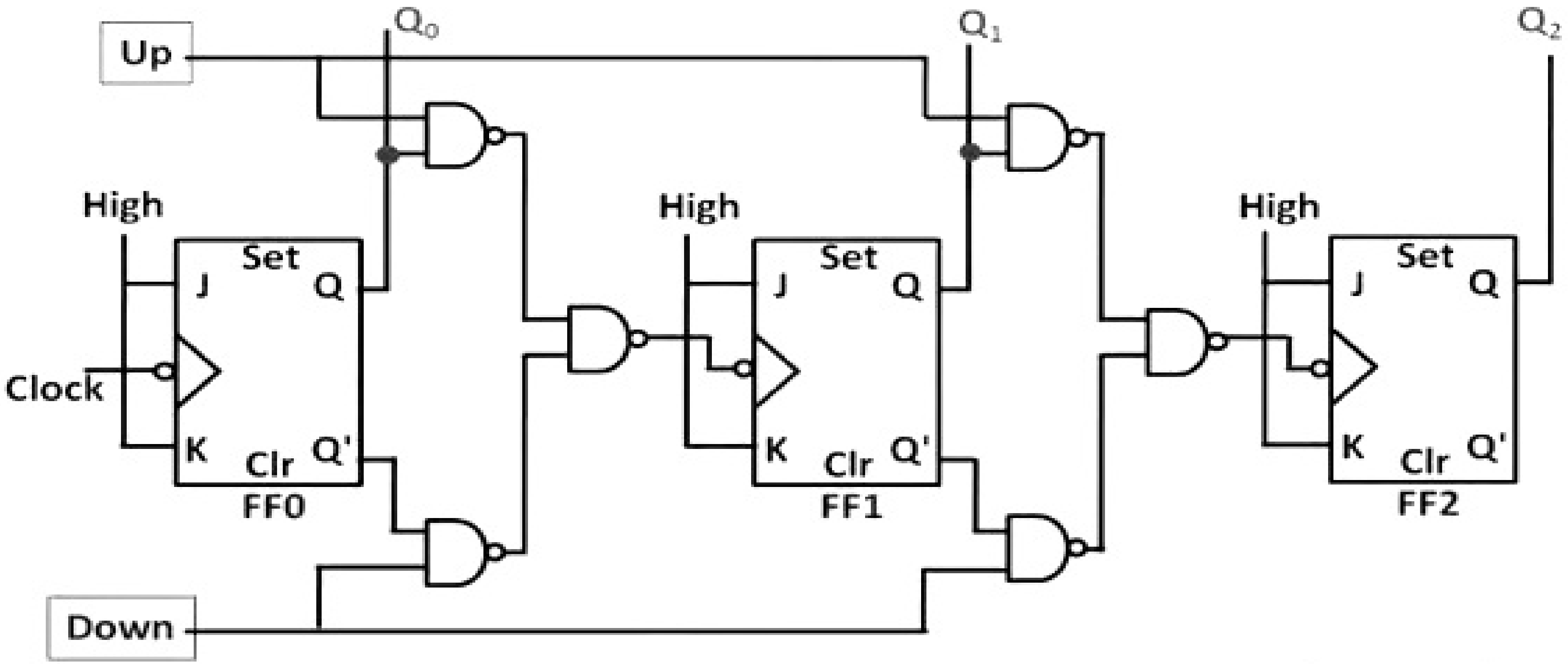
# Ripple Counter

Count Down: When counting down the count sequence goes in the opposite manner: 111, 110, … 010, 001, 000, 111, 110, … etc.

| Count States | Q2 | Q1 | Q0 |
|---|---|---|---|
| 7 | 1 | 1 | 1 |
| 6 | 1 | 1 | 0 |
| 5 | 1 | 0 | 1 |
| 4 | 1 | 0 | 0 |
| 3 | 0 | 1 | 1 |
| 2 | 0 | 1 | 0 |
| 1 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 |



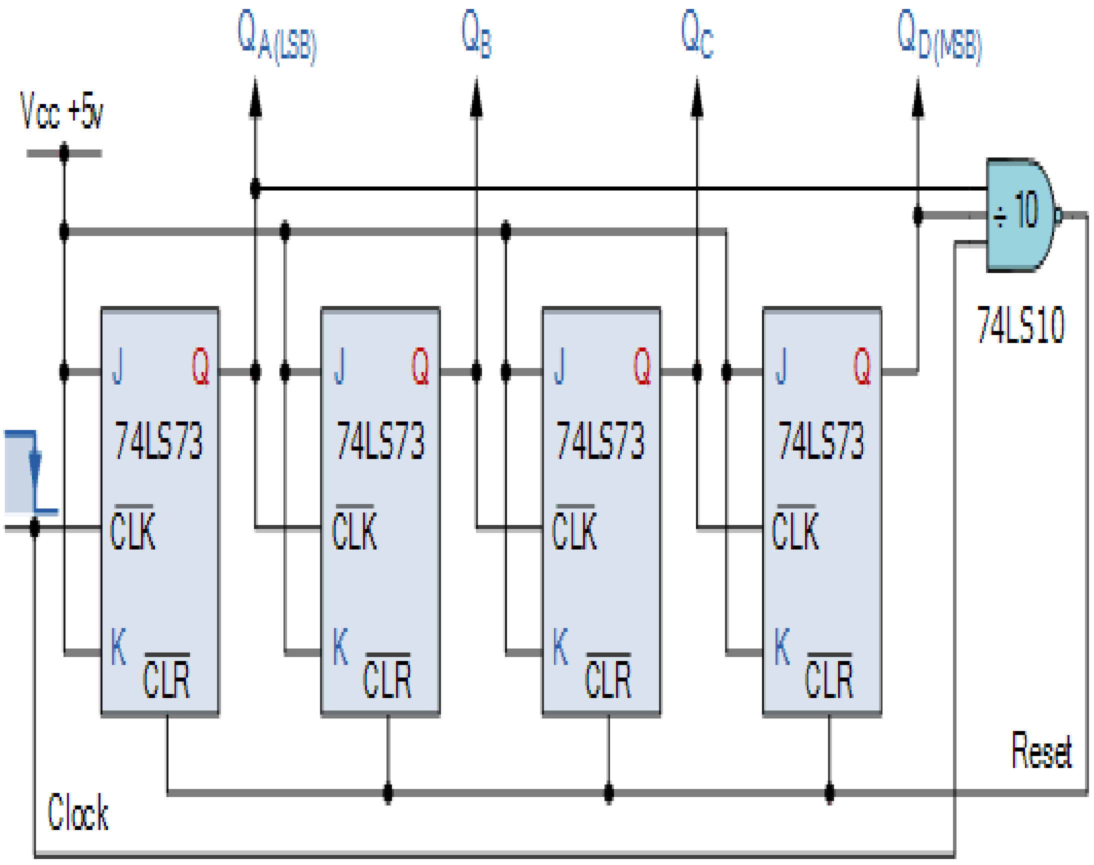
# Up/Down Counter (Asynchronous)

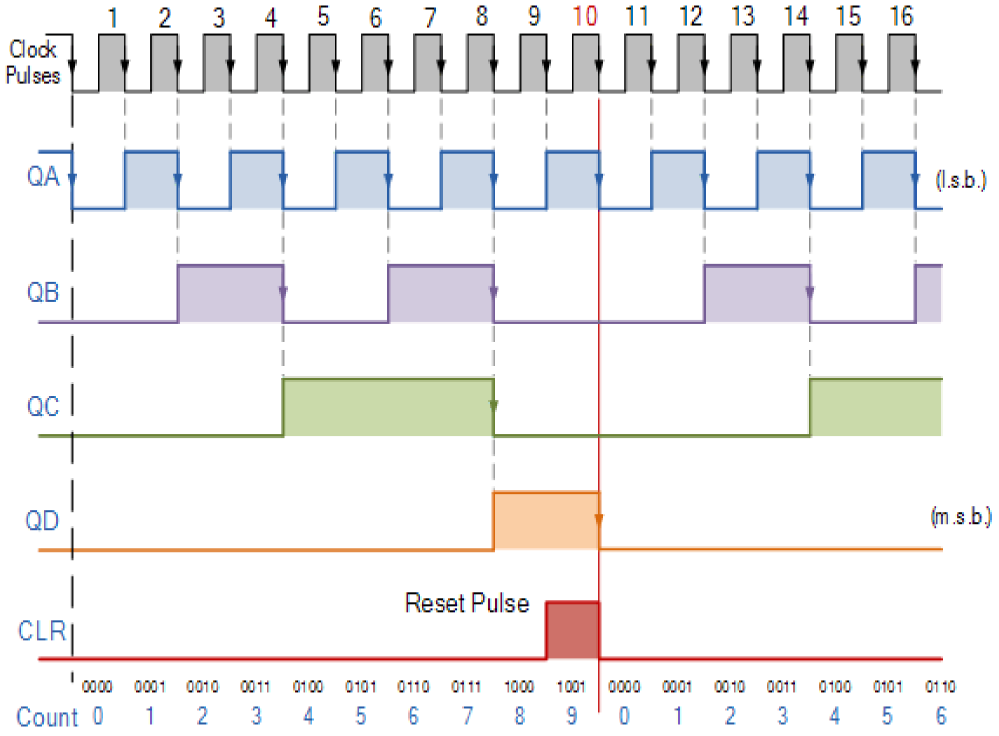


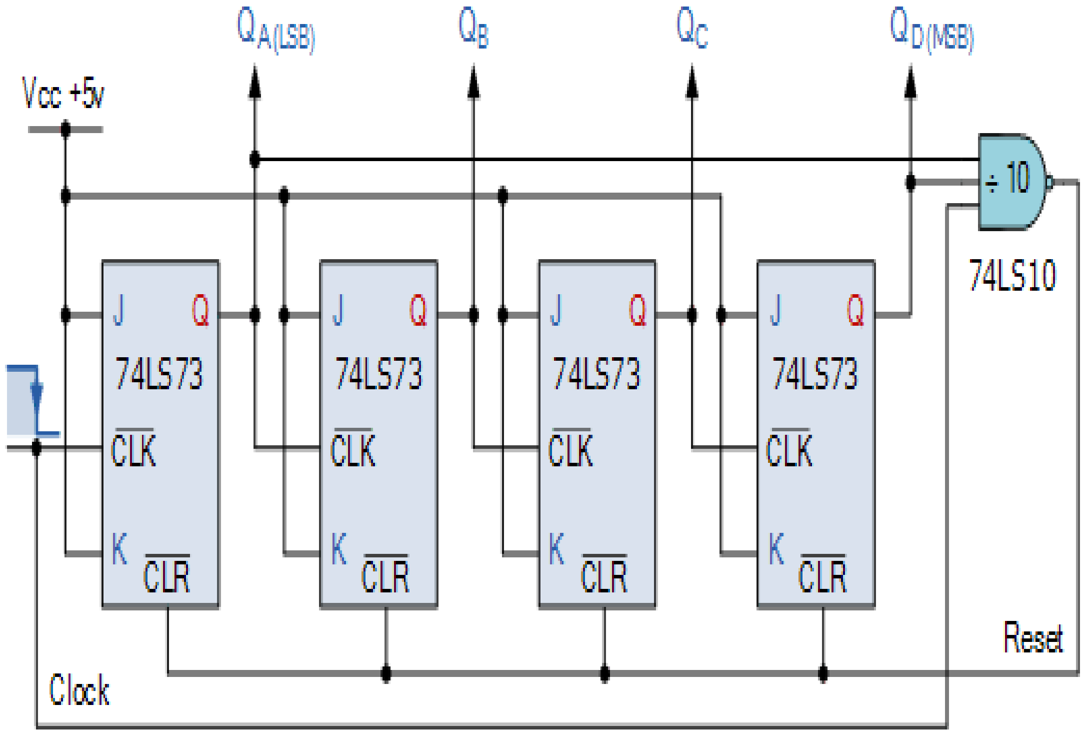
# Decade or BCD asynchronous counter

- If we take the modulo-16 asynchronous counter and modify it with additional logic gates it can be made to give a Decade counter output for use in standard decimal counting and arithmetic circuits. Such counters are generally referred to as **Decade Counters or BCD Counters.**
- A decade counter requires resetting to zero after the output count reaches the decimal value of 9, i.e. when DCBA = 1001.
- This type of asynchronous counter counts upwards on each input clock signal starting from 0000 until it reaches an output 1001 (decimal 9).

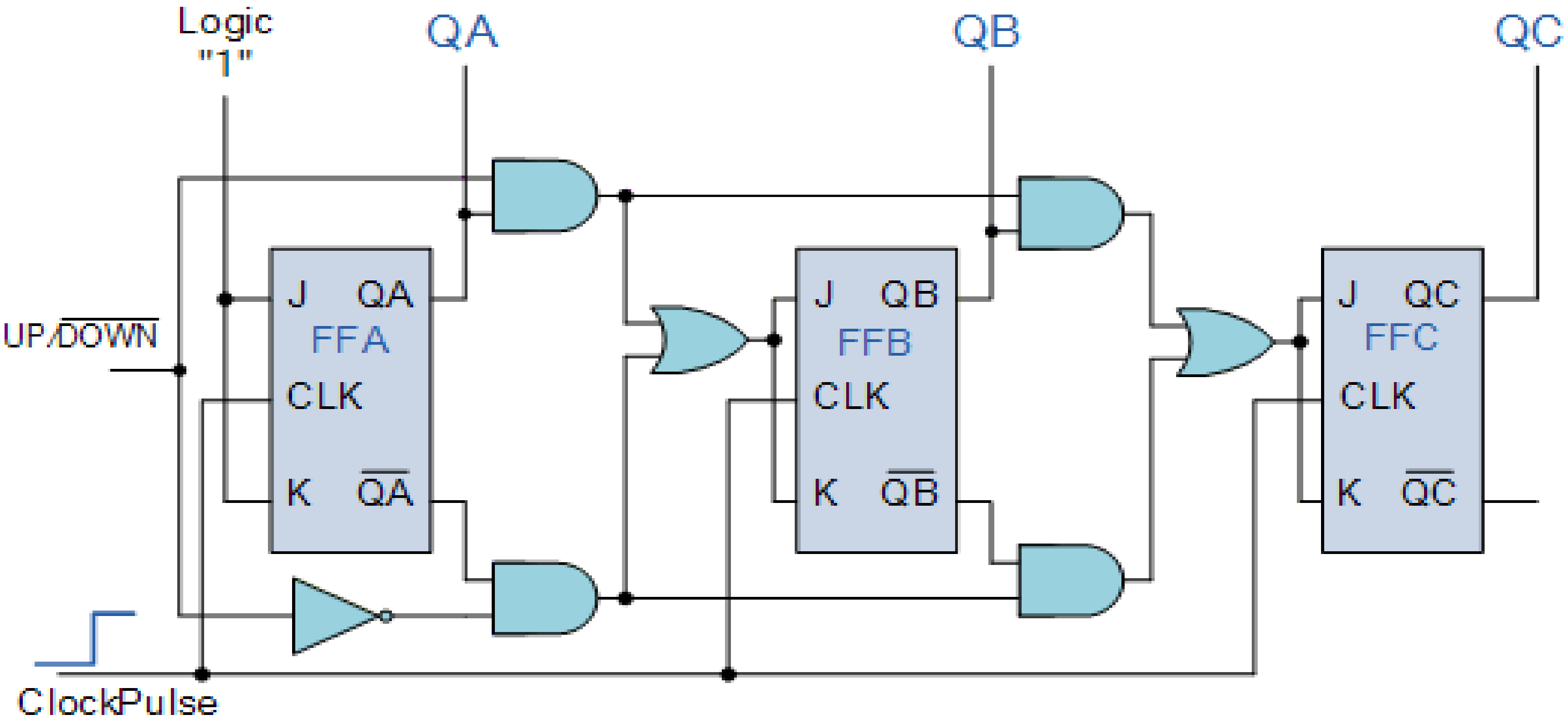
- When it is 1001, both outputs QA and QD are now equal to logic “1”. On the application of the next clock pulse, by connection NAND gate to QA and QD, the output from the NAND gate changes state from logic “1” to a logic “0” level.
- The output of NAND gate is connected to CLEAR inputs of flip flpops.
- As, the output of the NAND gate is connected to the CLEAR ( CLR ) inputs of all the flip-flops, this signal causes all of the Q outputs to be reset back to binary 0000 after the count 9.
- So, the counter restarts again from 0000. We now have a Decade or Modulo-10 up-counter.




Clock Pulses
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
QA
(l.s.b.)
QB
QC
QD
(m.s.b.)
Reset Pulse
CLR
0000 0001 0010 0011 0100 0101 0110 0111 1000 1001 0000 0001 0010 0011 0100 0101 0110
Count 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6


Vcc +5v
QA(LSB)
QB
QC
QD(MSB)
÷ 10
74LS10
J Q
74LS73
CLK
K CLR
Reset
Clock

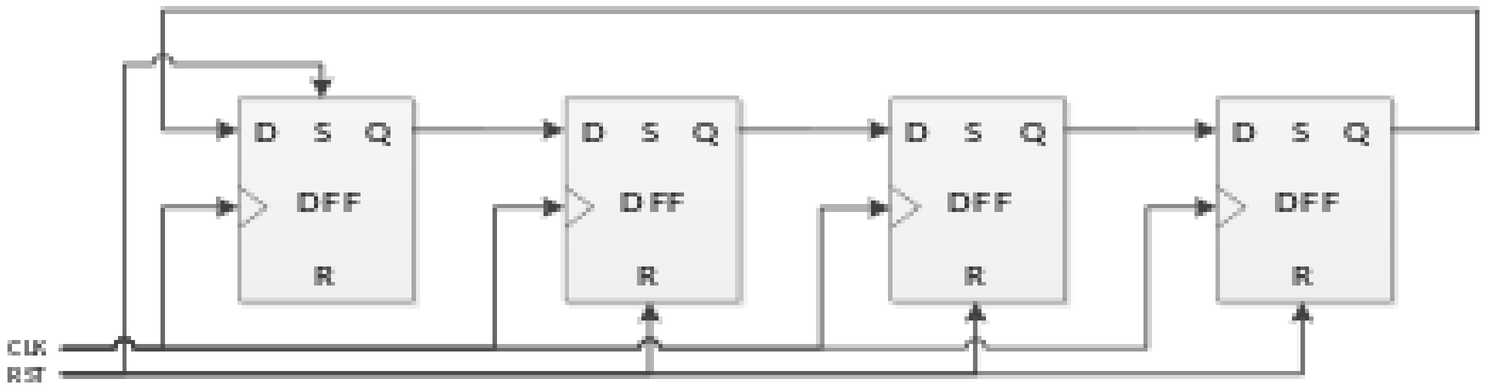
# Up/Down Counter (Synchronous)



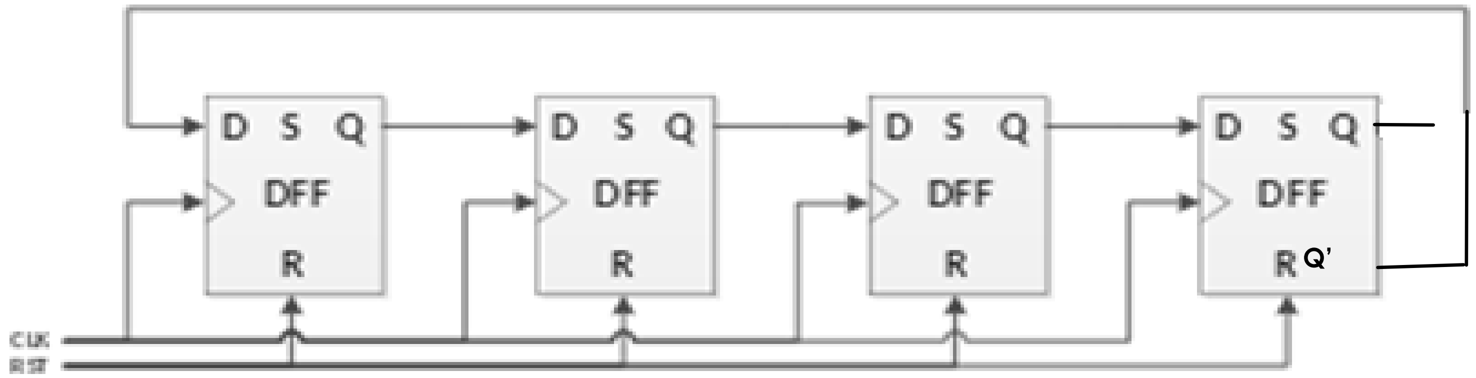
# Ring Counter

- A **Ring counter** is a type of counter composed of flip flops working as shift register, with the output of the last flip-flop fed to the input of the first, making a "circular" or "ring" structure.
- There are two types of ring counters:
- A **straight ring counter**, connects the output of the last flip flop of the shift register to the first flip flop of the shift register input and circulates a single one bit around the ring.
- A **twisted ring counter**, also called **switch-tail ring counter**, **Johnson counter** connects the complement output of the last flip flop of the shift register to the input of the first flip flop of the shift register and circulates a stream of ones followed by zeros around the ring.

Ring Counter




Johnson Counter



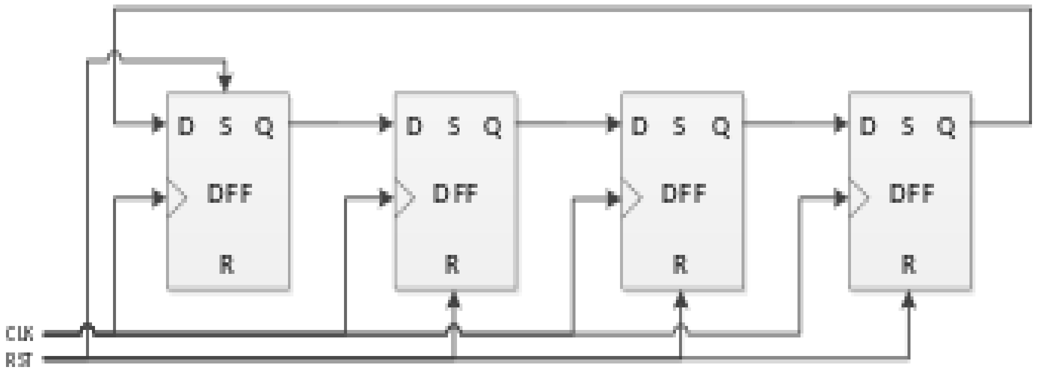
- The straight and twisted forms have different properties, and relative advantages and disadvantages.
- A binary counter can represent 2^N states, where N is the number of bits (flip flops).
- Whereas a straight ring counter can represent only N states.
- Johnson counter can represent 2N states.
- Johnson counters are sometimes favored, because they offer twice as many count states from the same number of flip flops in the shift registers, and because they are able to self-initialize from the all-zeros state, without requiring the first count bit to be injected externally at start-up.

- The Johnson counter generates a code in which adjacent states differ by only one bit (that is, have a Hamming distance of 1), as in a Gray code, which is advantageous in communication system.
- When a fully decoded representation of the counter state is needed, as in some sequence controllers, the straight ring counter is preferred.
- So, there are two types of ring counters:

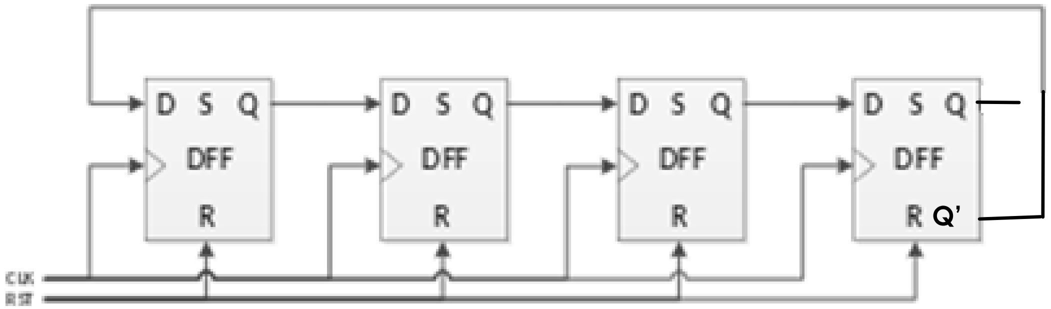
  **Straight ring counter**

  **Twisted ring counter**

| Straight ring counter | | | | | Johnson counter | | | | |
|---|---|---|---|---|---|---|---|---|---|
| State | Q0 | Q1 | Q2 | Q3 | State | Q0 | Q1 | Q2 | Q3 |
| **0** | 1 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 |
| **1** | 0 | 1 | 0 | 0 | **1** | 1 | 0 | 0 | 0 |
| **2** | 0 | 0 | 1 | 0 | **2** | 1 | 1 | 0 | 0 |
| **3** | 0 | 0 | 0 | 1 | **3** | 1 | 1 | 1 | 0 |
| ***0*** | 1 | 0 | 0 | 0 | **4** | 1 | 1 | 1 | 1 |
| ***1*** | 0 | 1 | 0 | 0 | **5** | 0 | 1 | 1 | 1 |
| ***2*** | 0 | 0 | 1 | 0 | **6** | 0 | 0 | 1 | 1 |
| ***3*** | 0 | 0 | 0 | 1 | **7** | 0 | 0 | 0 | 1 |
| **0** | 1 | 0 | 0 | 0 | ***0*** | 0 | 0 | 0 | 0 |



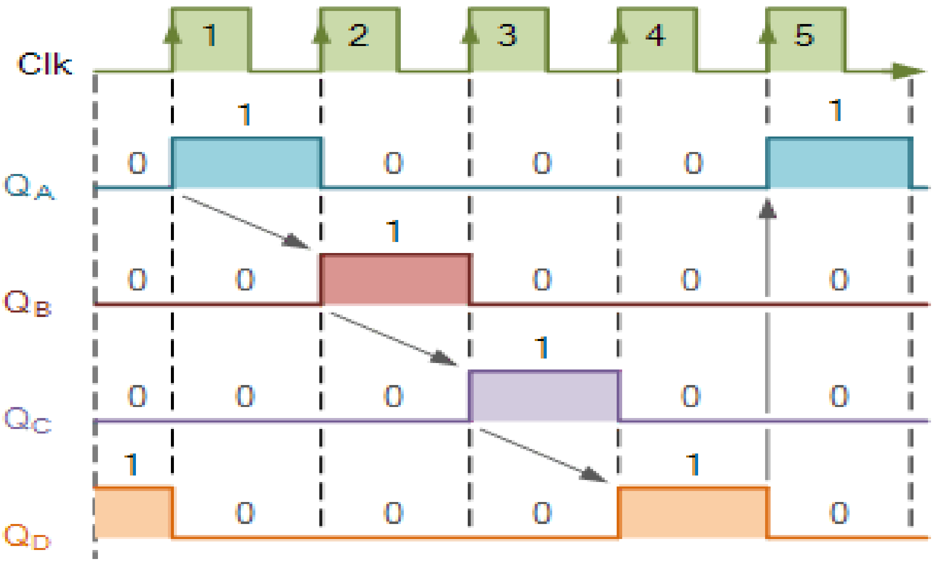

**Ring Counter**



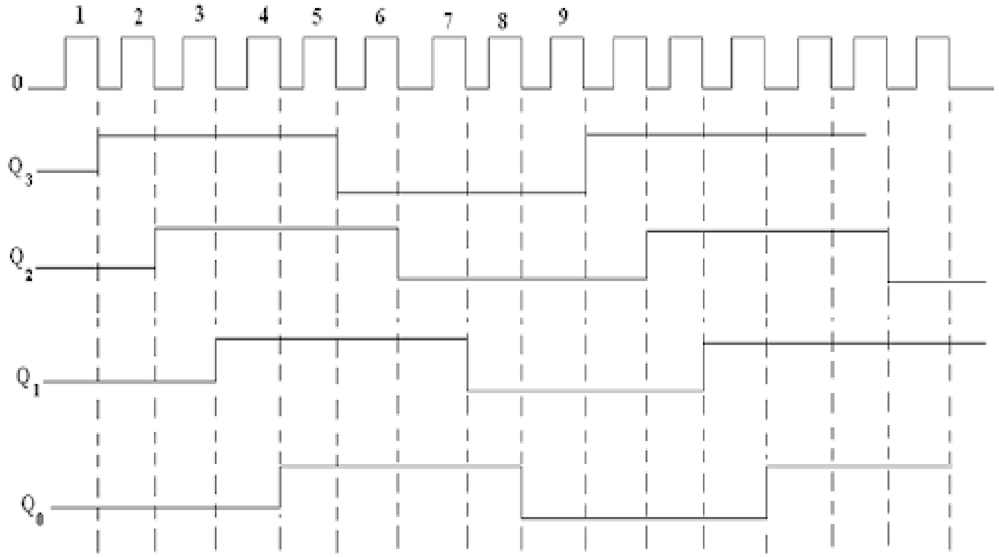

**Johnson Counter**

Ring counter has 4 sequences: 1000, 0100, 0010, 0001.

Johnson ring counter has sequences like “1000”, “1100”, “1110”, “1111”, “0111”, “0011”, “0001”, “0000”.



Timing Diagram of Ring Counter



Timing Diagram of Johnson Counter

# Differences of Synchronous and Asynchronous Counter

| SYNCHRONOUS COUNTERS | ASYNCHRONOUS COUNTERS |
|---|---|
| The propagation delay is very low. | Propagation delay is higher than that of synchronous counters. |
| Its operational frequency is very high. | The maximum frequency of operation is very low. |
| These are faster than that of ripple counters. | These are slow in operation. |
| Large number of logic gates are required to design | Less number of logic gates required. |
| High cost. | Low cost. |
| Synchronous circuits are easy to design. | Complex to design. |
| Standard logic packages available for synchronous. | For asynchronous counters, Standard logic packages are not available. |

# Applications

Some of the counter applications are listed below.

- Frequency counters
- Digital clocks
- With some changes in their design, counters can be used as frequency divider circuits. The frequency divider circuit is that which divides the input frequency exactly by '2'.
- Counter used as a timer in electronic devices like ovens and washing machines.
- Alarm Clock, AC Timer, timer in camera to take the picture, flashing light indicator in automobiles, car parking control etc.
- Counting the time allotted for special process or event by the scheduler.
- They are also used in machine moving control.