CSE 4205
Digital Logic Design

Counter

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Introduction

- The simplest type of MSI sequential circuit
  - Made of one or more flip flops (building block of sequential circuit)
- Definition: Basically, a counter changes its state in a prescribed sequence when input pulses are received
  - Driven by a clock signal (common input pulse)
- Application: count number of pulses/cycles (Hz), to measure time (T) and frequency (f)
- Basically, we use T flip flop which has the toggling feature (input, T = 1) best suited for counting operation

Types

- Broadly categorized in different ways:
  1. Asynchronous and synchronous counter
  2. Single and multimode counter
  3. Modulus counter

All of them has further classifications

Asynchronous and Synchronous Counter

- Asynchronous Counter
    - Simple and straightforward in operation and construction
    - Each flip flop is triggered by the previous flip flop
    - Also known as ripple or serial counter
- Synchronous Counter
    - Clock pulses are simultaneously applied to all flip flops
    - To increase the speed of the counter, more sophisticated hardware is required
    - Also known as parallel counter

Single and Multimode Counter

- Modes of counting
    - Count-Up
    - Count-Down
- Single-mode Counter
    - Either count-up mode or count-down mode is in operation
- Multimode Counter
    - Both modes are in operation

Modulus Counter

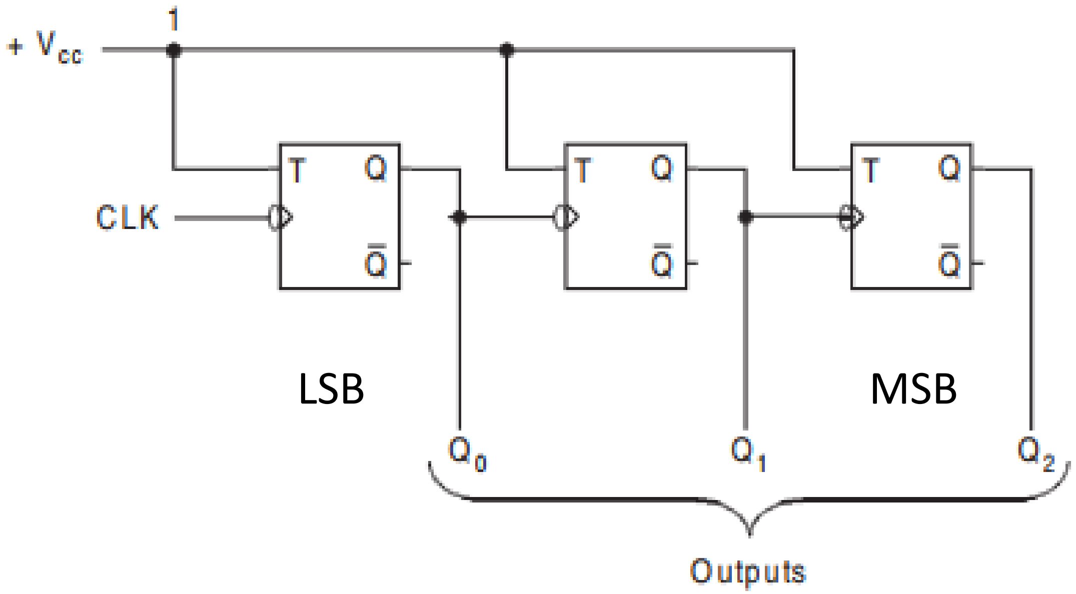
- It is defined by the number of states it is capable of counting.
  - To define all states, if *n* bits are required to represent each state, in total 2^n (=N) states are possible (maximum count)
- Types:
  - Mod-N or Mod-2^n
  - Mod “<N”

Asynchronous Counter

- All the flip flops are not driven by same clock pulse
- It has cumulative settling time of all flip flops
- It causes the ripple through the changes of the states of the flip flops successively

3 Bit Asynchronous Up Counter

Logic Diagram



3 Bit Asynchronous Up Counter

Count Sequence

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

Asynchronous Down Counter

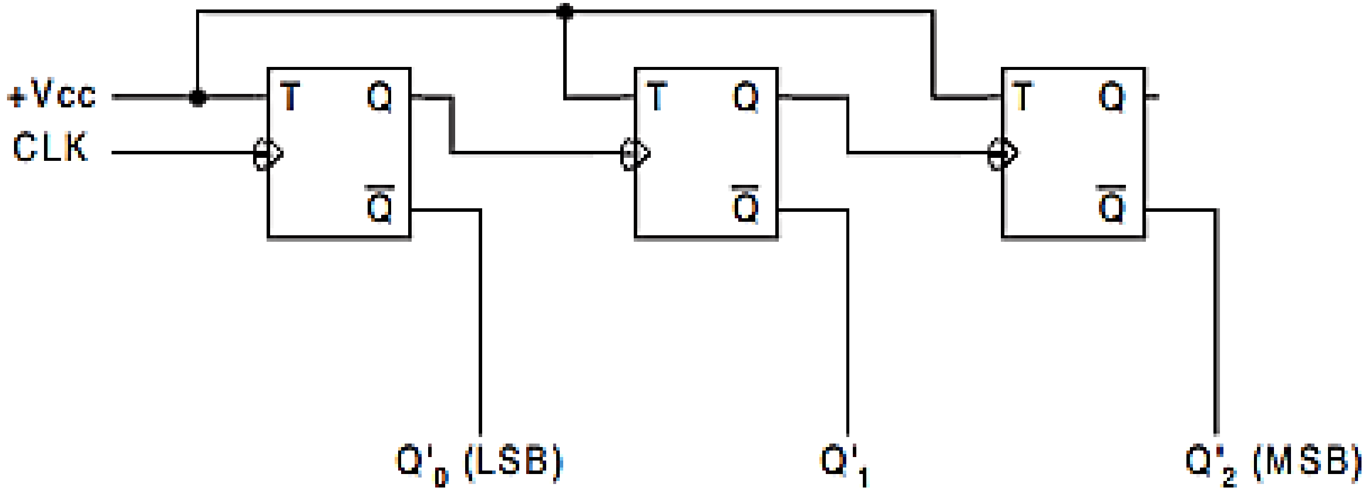
- Counts downward starting from a maximum count of (2^n-1) to 0

Counter State	Q_2	Q_1	Q_0
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

- Application: Count-down timer
- There are three different ways to implement…

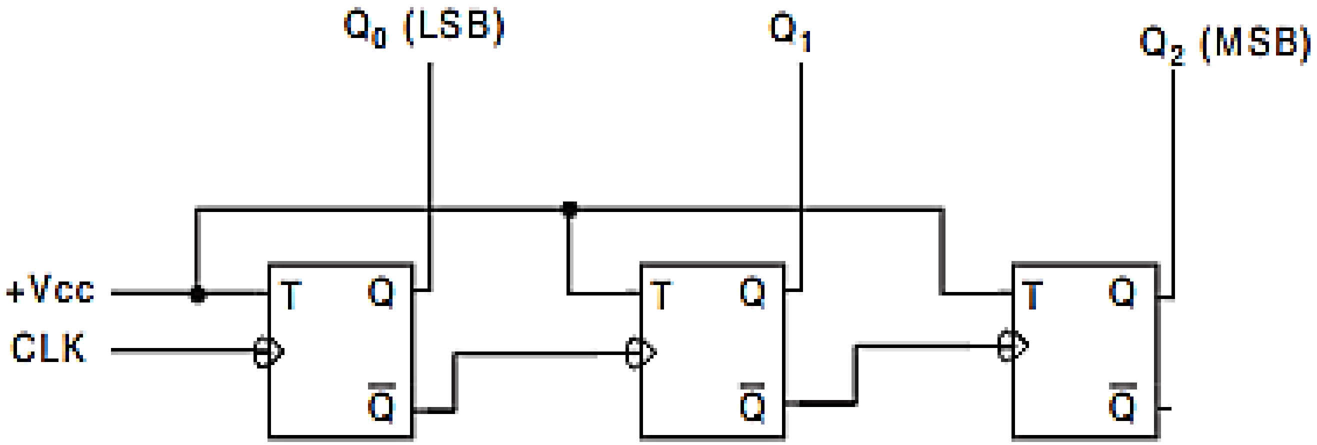
Asynchronous Down Counter: Way 1

- With same circuit as previous, only outputs of the counter may be taken from the complement outputs (Q’) of the flip-flops



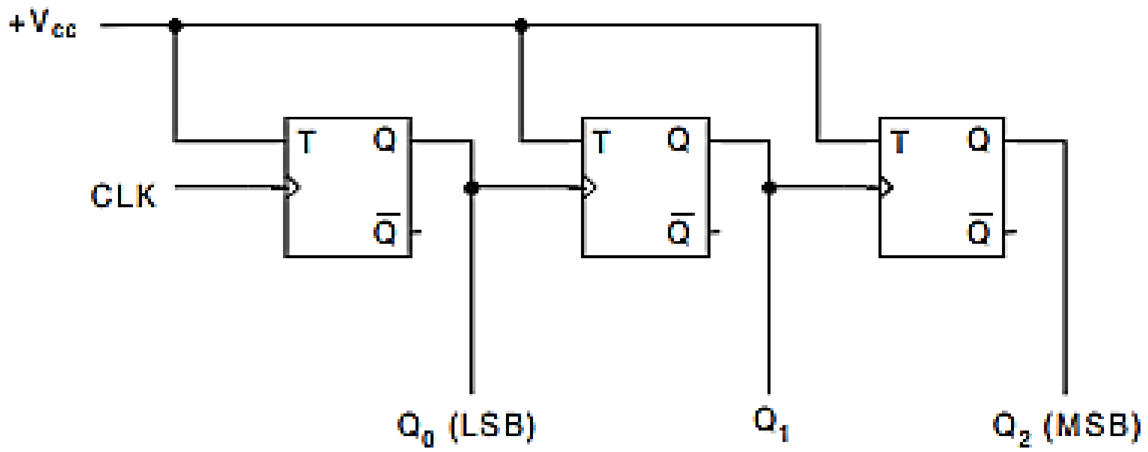
Asynchronous Down Counter: Way 2

- The circuit will be slightly modified so that the clock inputs of successive flip-flops will be driven by the Q' output of preceding stages (flip-flops)



Asynchronous Down Counter: Way 3

- The circuit will be similar to the up-counter circuit replacing the negative edge triggering flip-flops to the positive edge triggering flip-flops

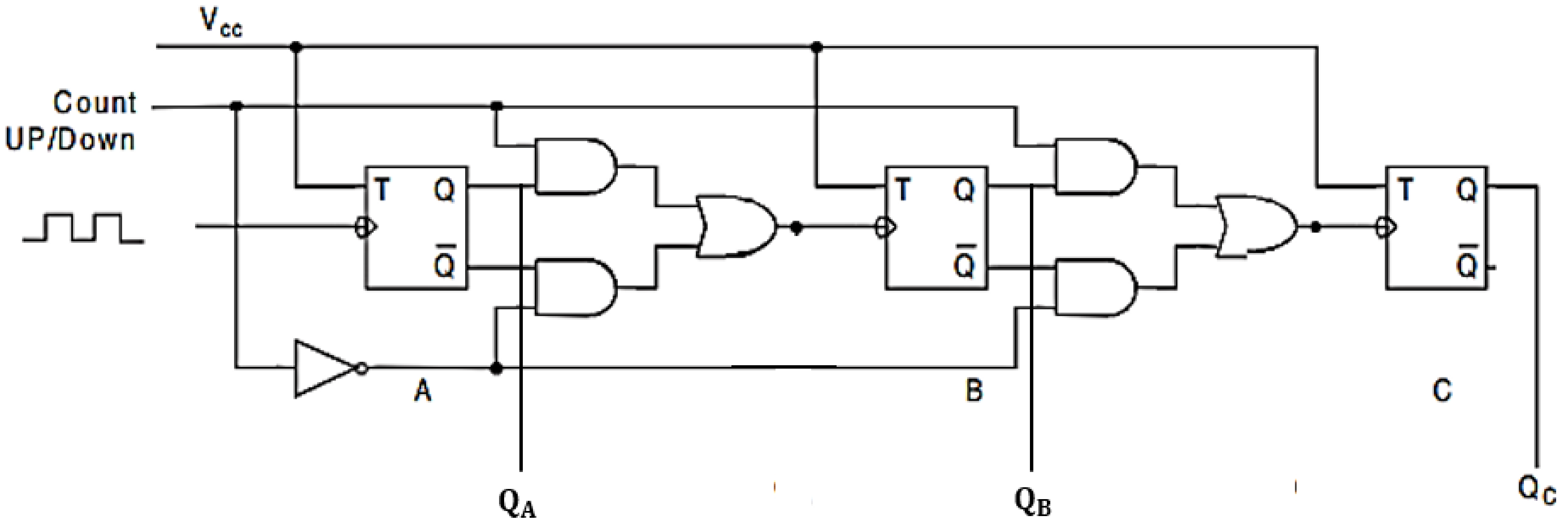


Asynchronous Up-Down Counter

- We combine the up and down modes in a single up-down counter
  - Count both upward as well as downward
  - It is also called the “multimode” counter
- The operation of such counter is controlled by up-down controller
  - To select the mode – up or down

Asynchronous Up-Down Counter

Circuit Diagram



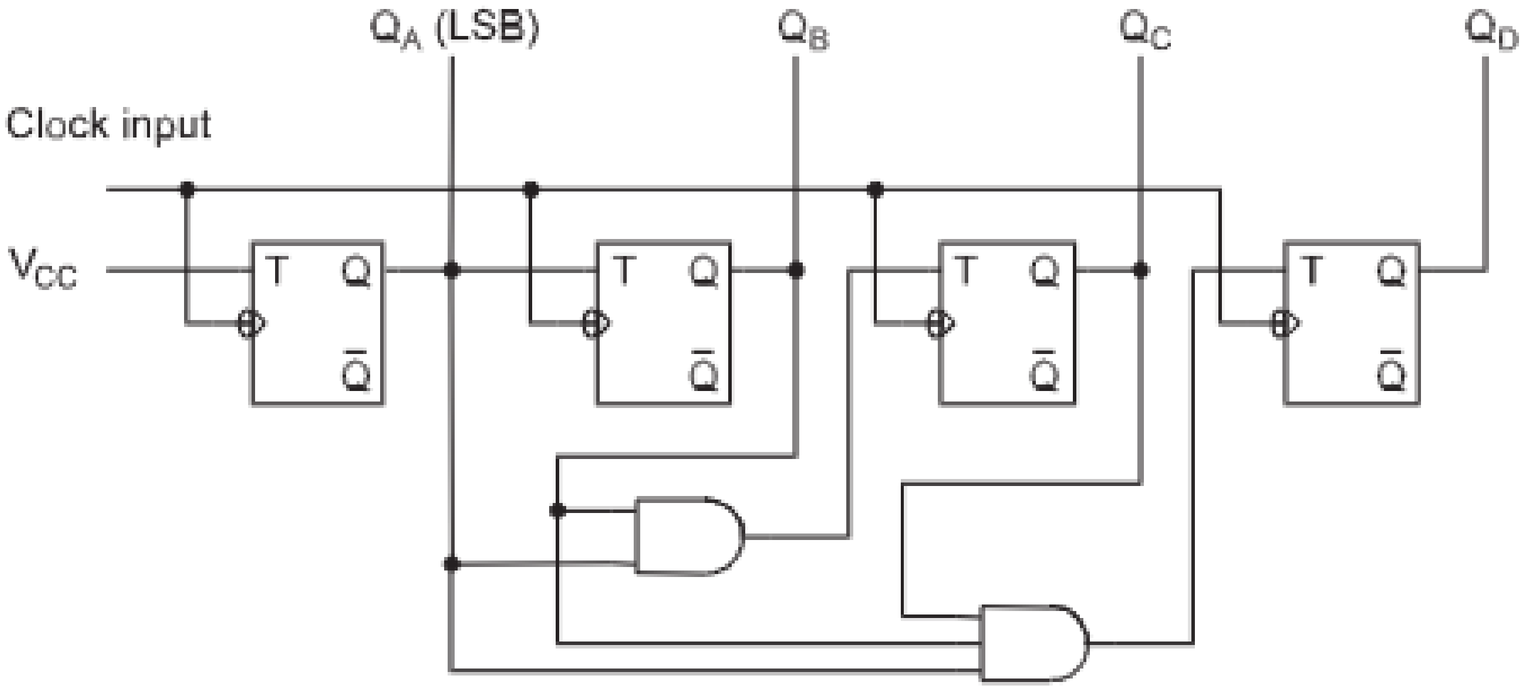
Propagation Delay of Asynchronous Counter

- Self Study

Synchronous Counter

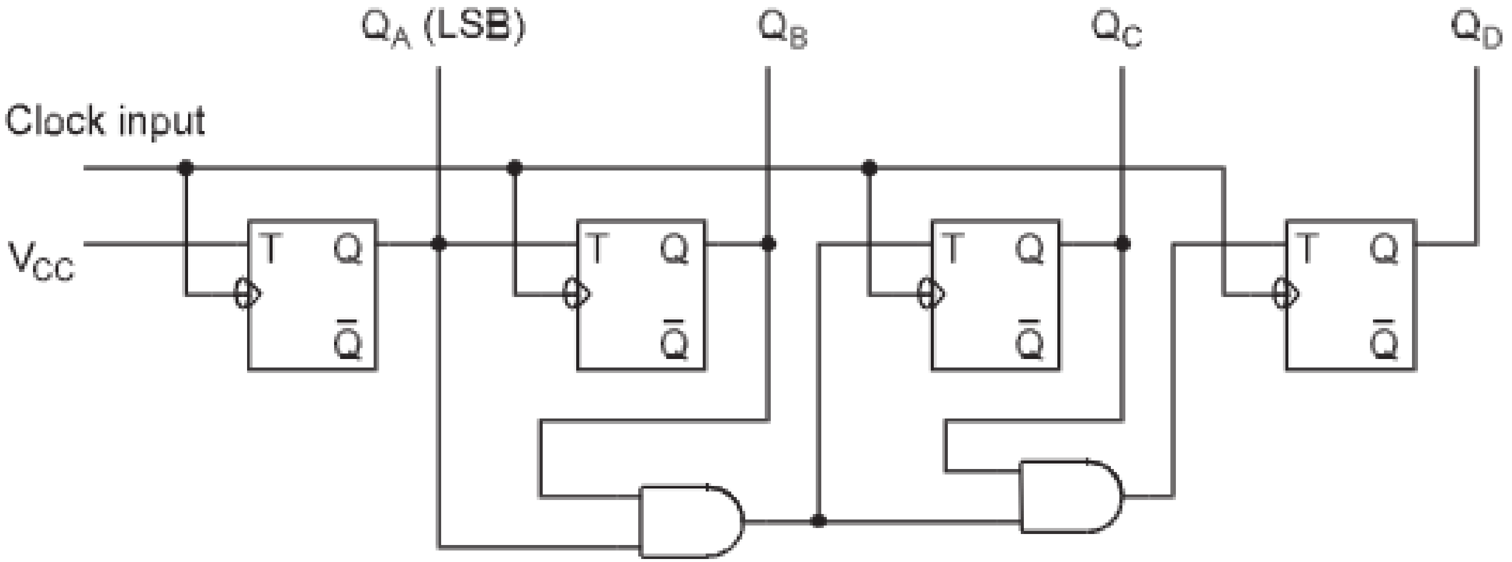
- All flip-flops are clocked synchronously
- But T inputs of different flip-flops could be varied based on necessity

Synchronous Up Counter with Parallel Carry

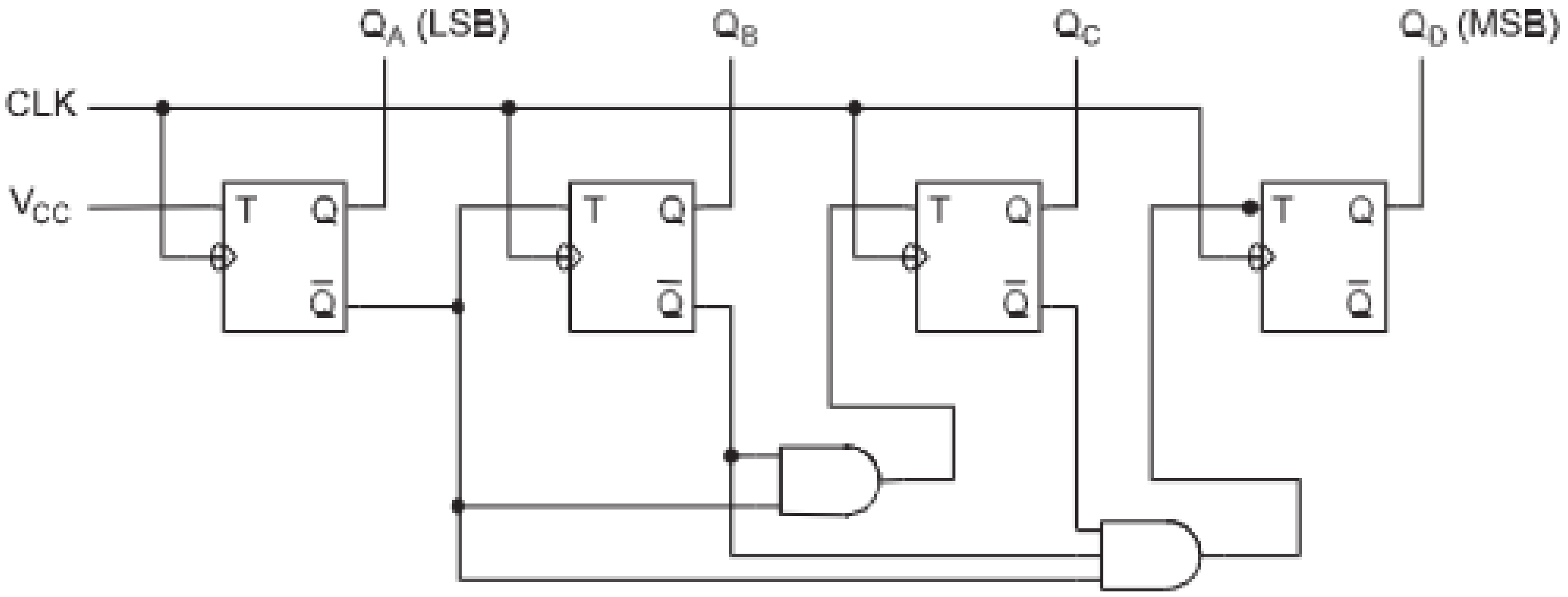


For the first FF (LSB), T=1. It changes the output constantly.

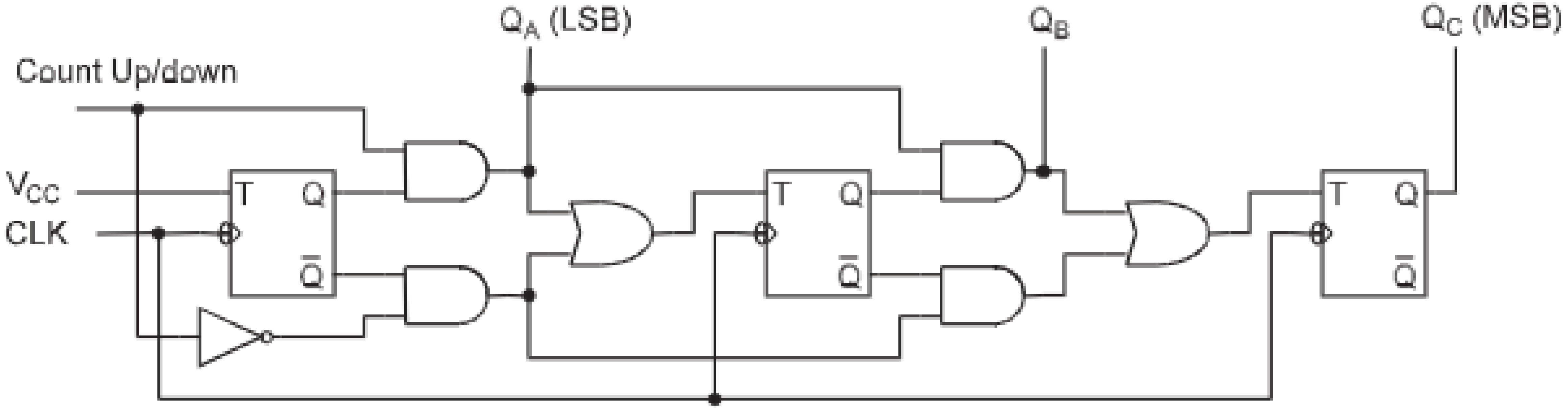
Synchronous Up Counter with Ripple Carry



Synchronous Down Counter



Synchronous Up-Down Counter



Other Synchronous Counter

- Same as **design procedure** of Sequential circuit to design any synchronous counter
  - **Example:**
    - Modulus < N (2^n) counter
    - BCD Counter
    - Gray code counter
    - Irregular counter
    - Sequence Generator

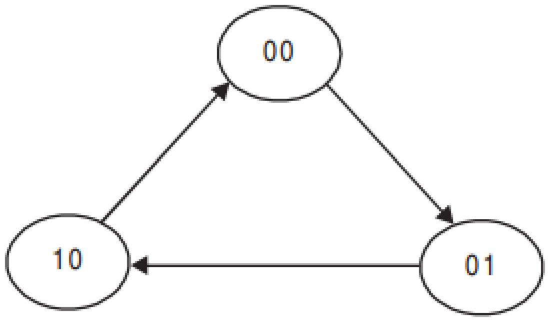
Synchronous Counter: Design Procedure

- From the problem statement, draw the **state diagram** that describes the operation of a counter
- Derive the **state table** and **circuit excitation table** from the state diagram maintaining the count sequence
- Find the **number** of the flip-flops
- Determine the flip-flop **type** and its inputs
- Prepare the **K-maps to get the simplified expressions** for each inputs in term of the outputs and external inputs of flip-flops
- Connect the circuit using the flip-flops and other gates corresponding to the simplified expressions

SC: Design Procedure – Example

Design of a MOD-3 counter

- **State Diagram:**



- **State Table and Circuit Excitation Table:**

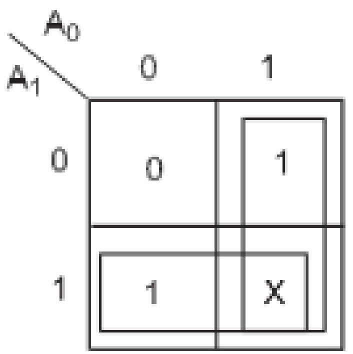
Present state	*Next state*
00	01
01	10
10	00

Count Sequence		*Flip-flop inputs*	
A_1	A_0	TA_1	TA_0
0	0	0	1
0	1	1	1
1	0	1	0

SC: Design Procedure – Example…

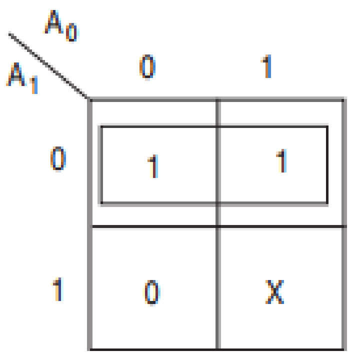
Design of a MOD-3 counter

- **K-map for simplification:**



(a) For TA_1

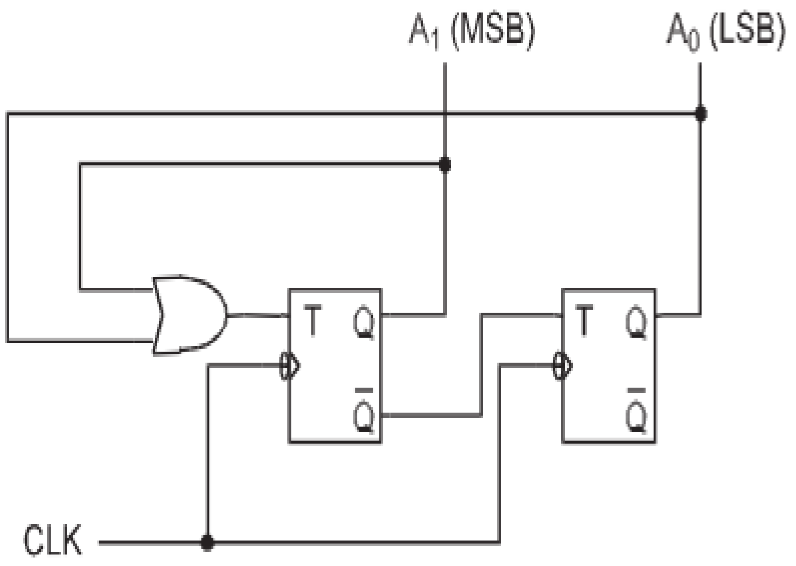
$TA_1 = A_1 + A_0$



(b) For TA_0

$TA_0 = A'_1$

- **Logic Diagram:**



Propagation Delay of Synchronous Counter

- Self Study

Synchronous-Asynchronous Counter

- Some hybrid counters combines the good feature of these both
  - Simplicity of the asynchronous counter and speed of the synchronous counter
  - **Example:** BCD synchronous-asynchronous counter
  - **Explanation:** Self-study

Comparison between Synchronous and Asynchronous Counter

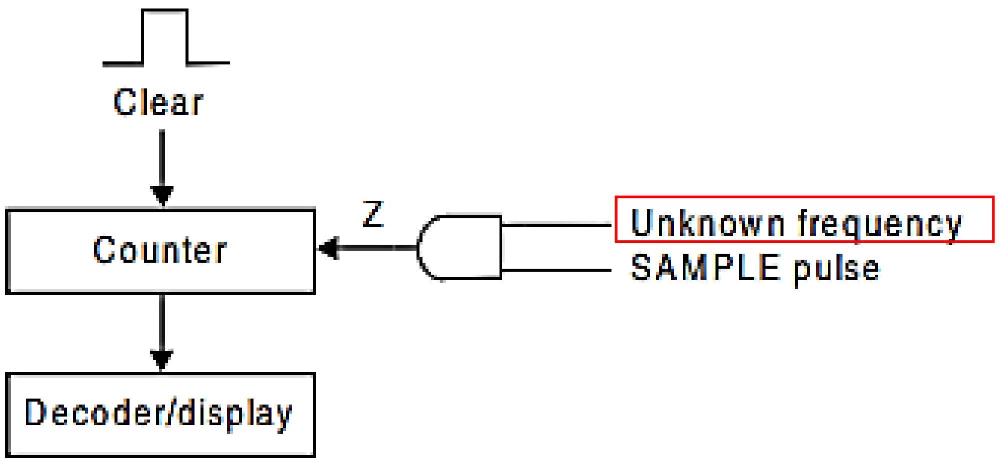
- Self Study

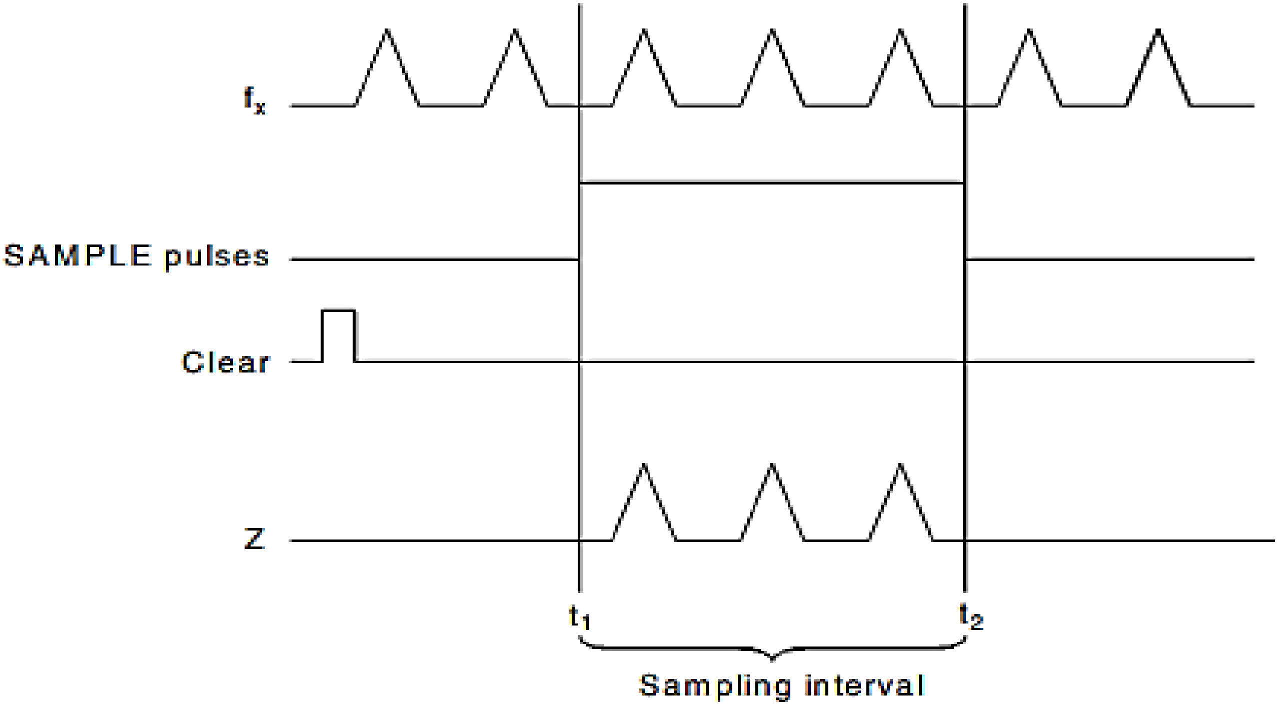
Some Other Terms

- Lock out states/conditions:
  - Some unused states may not have the known next state. A counter with such unused states may suffer from lock out problem.
- Presettable/programmable counter:
  - A counter that has the capability to start counting from any desired state maintaining an appropriate logic circuit.

Application of Counter

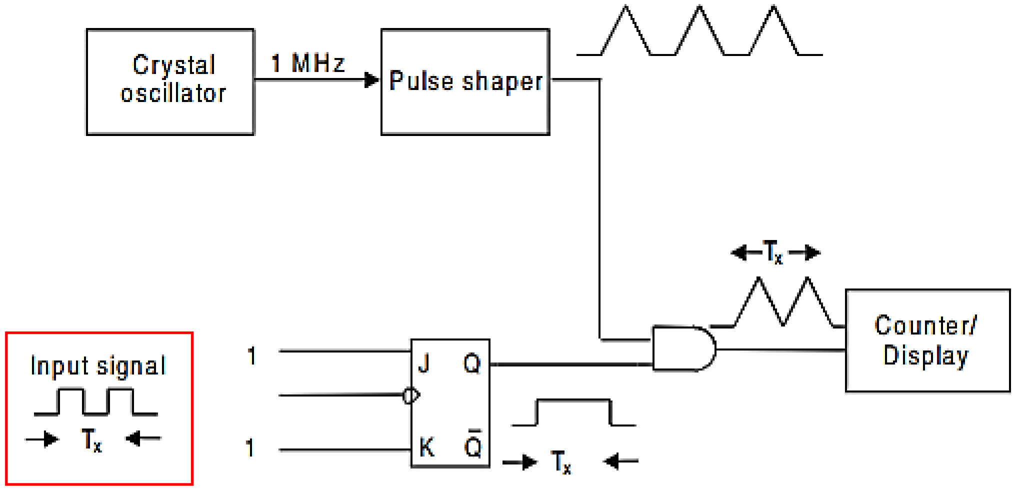
- **Frequency Counter**
  - Measure and display the frequency of a signal
  - It will measure the unknown frequency (f_x) against a known SAMPLE pulse





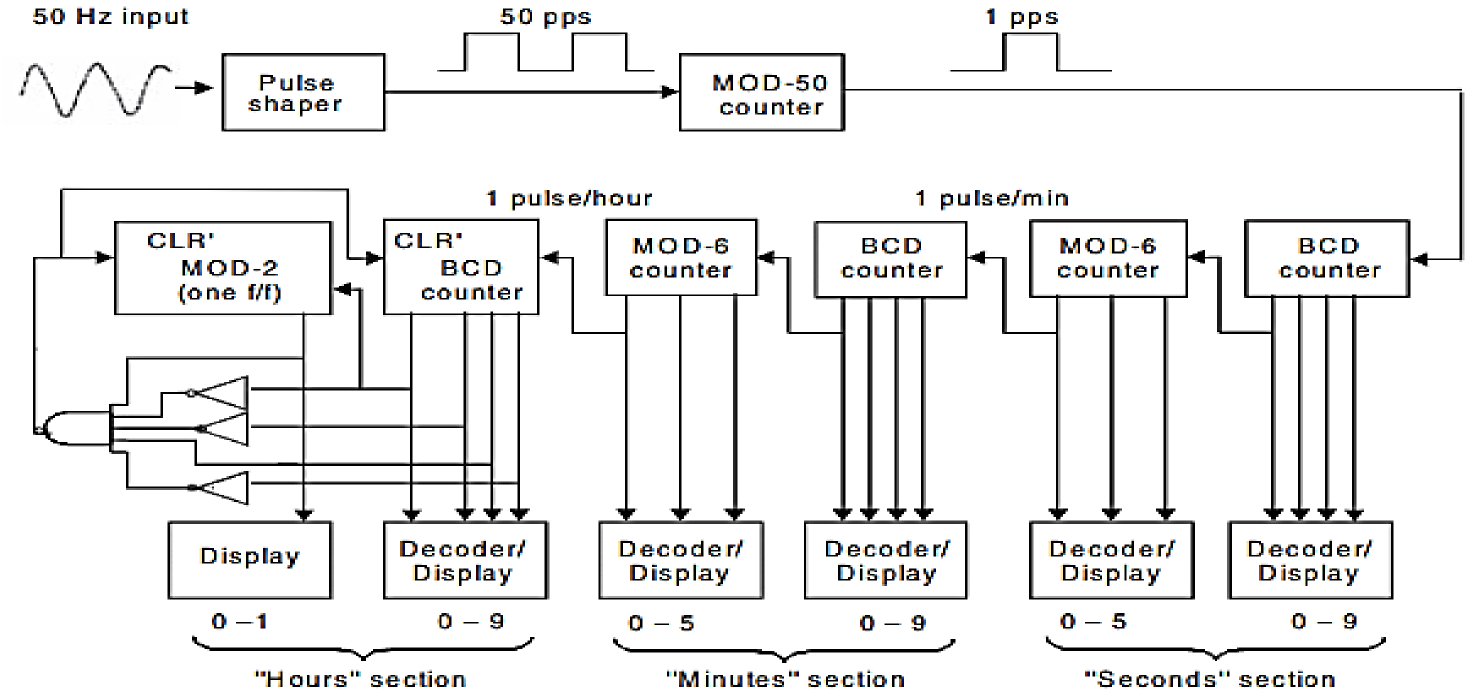
Application of Counter…

- **Measurement of Period**
  - An accurate 1 MHz reference frequency is gated into the counter for any time duration T_x
    - The counter counts and displays the values of Tx in units of micro-seconds
    - **Example:** for 1.17 milli-second, the gate will allow 1170 pulses into the counter



Application of Counter…

- **Digital Clock**
  - Displays time of day in hours, minutes and seconds
  - To get accurate clock, a very highly controlled basic clock frequency is required



Self Study

- **Hazards in digital circuits**
    - Due to some undesirable glitches and propagation delay
        - Static hazard
        - Dynamic hazard
        - Essential hazard

Self Study…

- **Frequency Division:**
  - If the clock is not the same for all flip flops, frequency for n^{th} flip-flop (stages) will be $f_{CLK}/2^n$