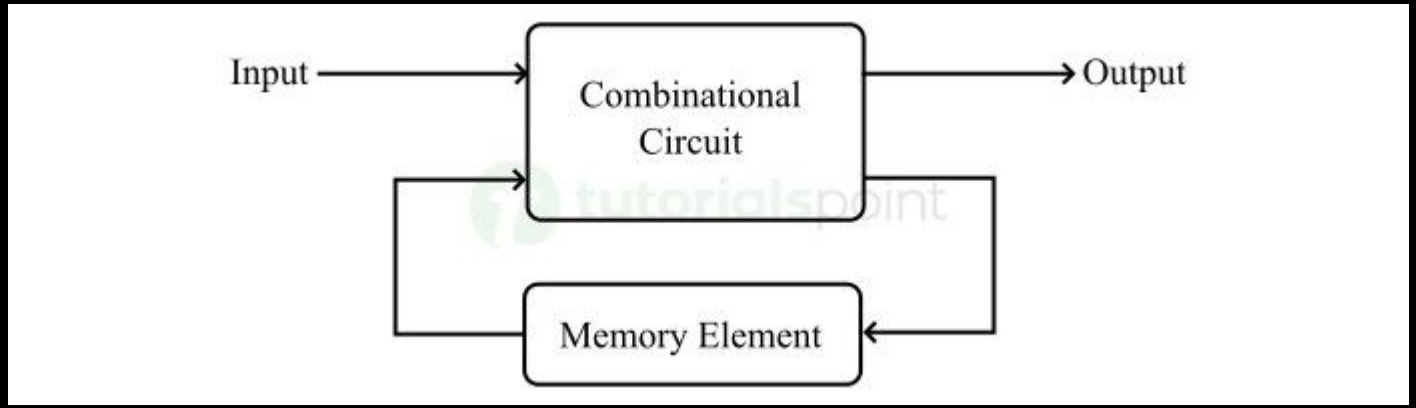
Sequential Logic Circuits

Chapter 7

Sequential Circuit

A **sequential circuit** is a logic circuit that consists of a memory element to store history of past operation of the circuit. Therefore, the output of a sequential circuit depends on present inputs as well as past outputs of the circuit.

The **block diagram of a typical sequential circuit** is shown in the following figure



Sequential Circuit

Here, it can be seen that a sequential circuit is basically a combination of a combinational circuit and a memory element. The combinational circuit performs the logical operations specified, while the memory element records the history of operation of the circuit. This history is then used to perform various logical operations in future.

The sequential circuits are named so because they use a series of latest and previous inputs to determine the new output.

Main Components of Sequential Circuit

A sequential circuit consists of several different digital components to process and hold information in the system. Here are some key components of a sequential circuit explained −

Logic Gates

The logic gates like AND, OR, NOT, etc. are used to implement the data processing mechanism of the sequential circuits. These logic gates are basically interconnected in a specific manner to implement combinational circuits to perform logical operations on input data.

Memory Element

In sequential circuits, the memory element is another crucial component that holds history of circuit operation. Generally, flip-flops are used as the memory element in sequential circuits.

In sequential circuits, a feedback path is provided between the output and the input that transfers information from output end to the memory element and from memory element to the input end.

Types of Sequential Circuits

Based on structure, operation, and applications, the sequential circuits are classified into the following two types −

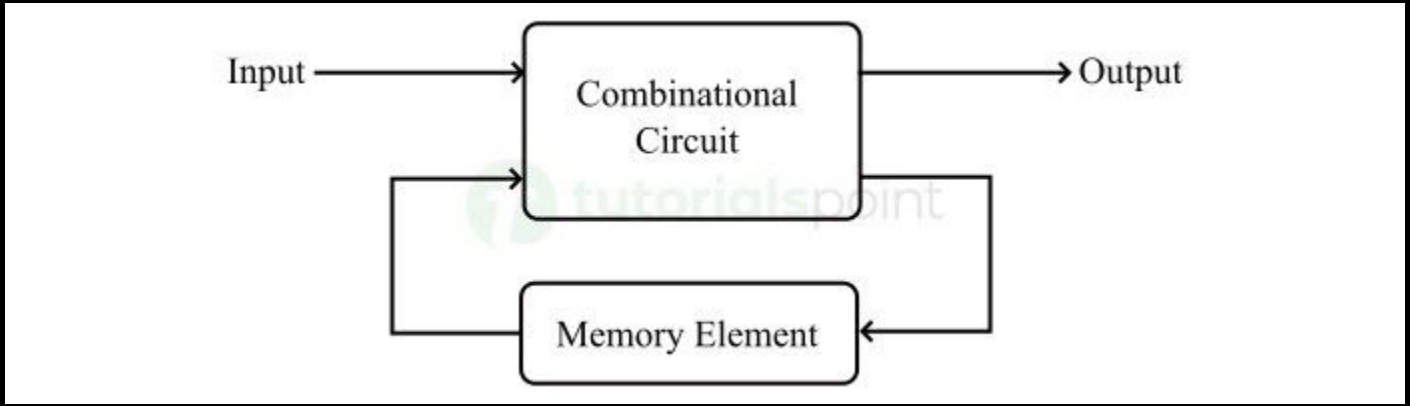
1. **Asynchronous Sequential Circuit**
2. **Synchronous Sequential Circuit**

Asynchronous Sequential Circuit:

A type of sequential circuit whose operation does not depend on the clock signals is known as an asynchronous sequential circuit. This type of sequential circuits operates using the input pulses that means their state changes with the change in the input pulses.

The main components of the asynchronous sequential circuits include un-clocked flip flops and combinational logic circuits. The block diagram of a typical asynchronous sequential circuit is shown in the following figure.

Types of Sequential Circuits



From this diagram, it is clear that an asynchronous sequential circuit is similar to a combinational logic circuit with a feedback mechanism.

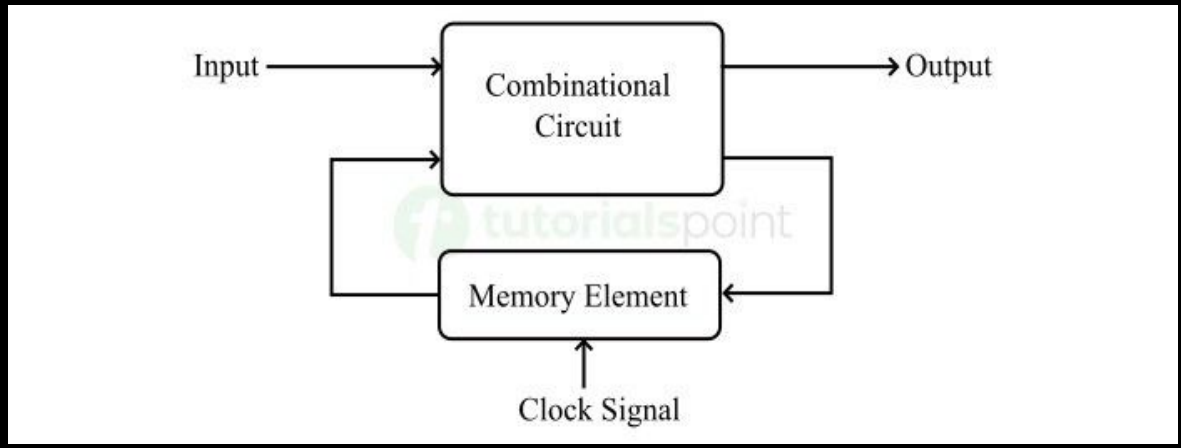
Asynchronous sequential circuits are mainly used in applications where the clock signals are not available or practical to use. For example, in conditions when speed of the task execution is important.

The ripple counter is a common example of asynchronous sequential circuit.

Types of Sequential Circuits

Synchronous Sequential Circuit

A synchronous sequential circuit is a type of sequential circuit in which all the memory elements are synchronized by a common clock signal. Hence, synchronous sequential circuits take a clock signal along with input signals.
In synchronous sequential circuits, the duration of the output pulse is equivalent to the duration of the clock pulse applied. Take a look at the block diagram of a typical synchronous sequential circuit −



Types of Sequential Circuits

In this figure, it can be seen that the memory element of the sequential circuit is synchronized by a clock signal.
The major disadvantage of the synchronous sequential circuits is that their operation is quite slow. This is because, every time the circuit has to wait for a clock pulse for the operation to take place.

Flip-Flops

A flip-flop is a sequential digital electronic circuit having two stable states that can be used to store one bit of binary data. Flip-flops are the fundamental building blocks of all memory devices.

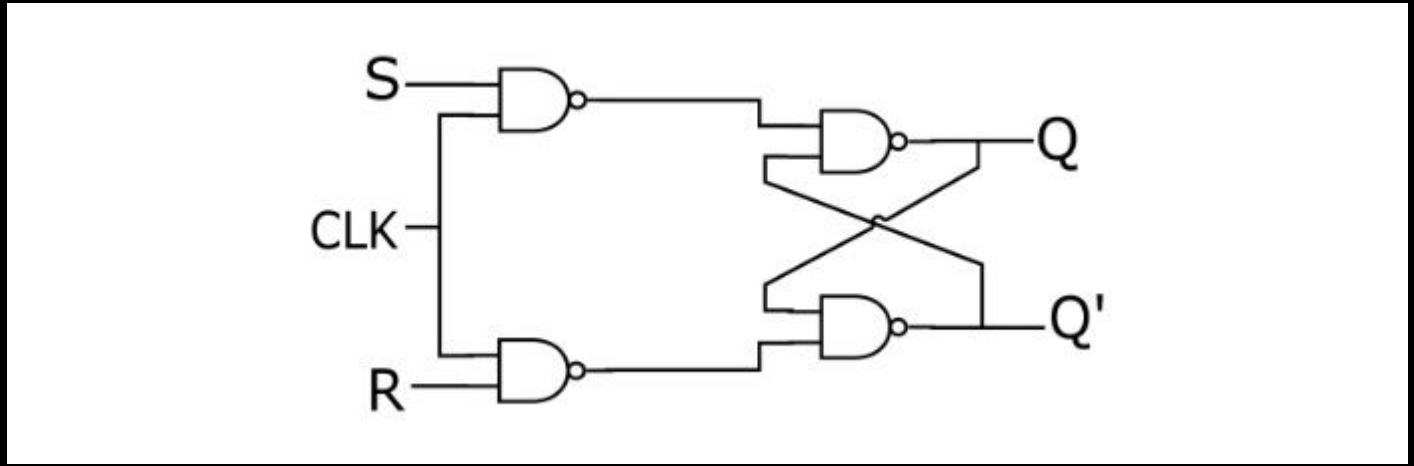
Types of Flip-Flops

1. **S-R Flip-Flop**
2. **J-K Flip-Flop**
3. **D Flip-Flop**
4. **T Flip-Flop**

S-R Flip-Flops

S-R Flip-Flop

This is the simplest flip-flop circuit. It has a set input (S) and a reset input (R). When in this circuit when S is set as active, the output Q would be high and the Q' will be low. If R is set to active then the output Q is low and the Q' is high. Once the outputs are established, the results of the circuit are maintained until S or R get changed, or the power is turned off.



S-R Flip-Flops

S-R Flip-Flop

Truth Table of S-R Flip-Flop

S	R	Q	State
0	0	0	No Change
0	1	0	Reset
1	0	1	Set
1	1	X	

S-R Flip-Flops

Characteristics Table of S-R Flip-Flop

Characteristics Table of S-R Flip-Flop

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

Characteristics Equation of S-R Flip-Flop

$$Q(t+1) = S + R' Q(t)$$

J-K Flip-Flops

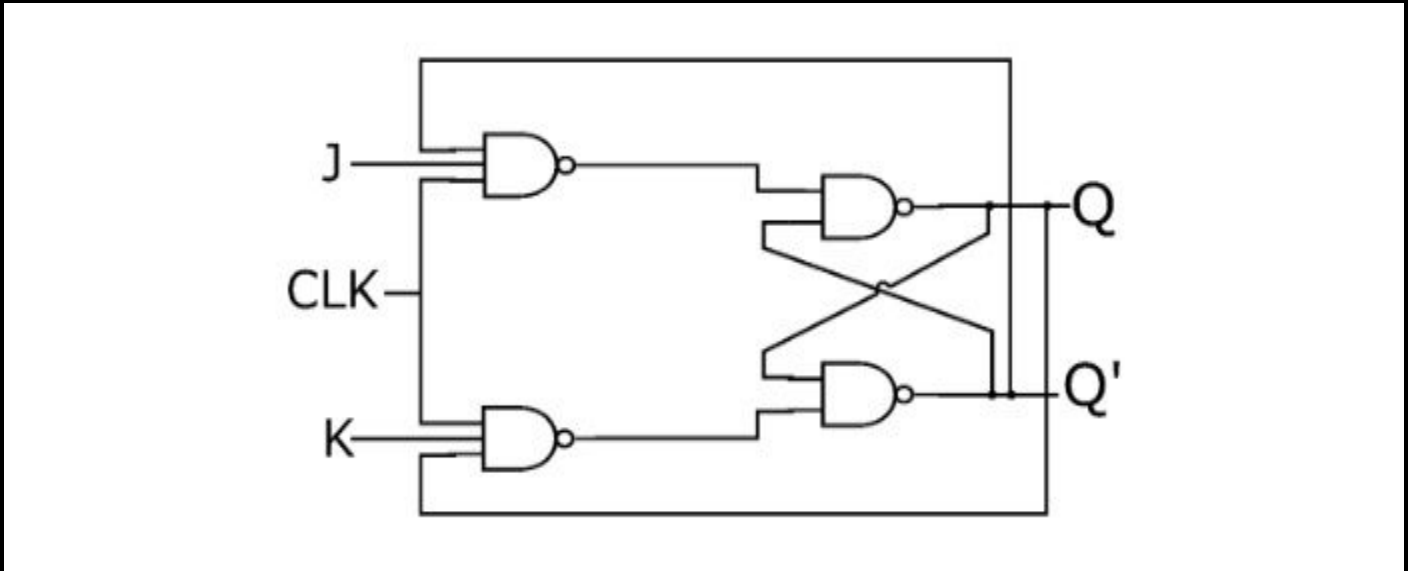
J-K Flip-Flop

Because of the invalid state corresponding to S=R=1 in the SR flip-flop, there is a need of another flip-flop. The JK flip-flop operates with only positive or negative clock transitions. The operation of the JK flip-flop is similar to the SR flip-flop. When the input J and K are different then the output Q takes the value of J at the next clock edge.

When J and K both are low then NO change occurs at the output. If both J and K are high, then at the clock edge, the output will toggle from one state to the other.

J-K Flip-Flops

J-K Flip-Flop



J-K Flip-Flops

Truth table of J-K Flip-Flop

J	K	Q	State
0	0	0	No Change
0	1	0	Reset
1	0	1	Set
1	1	Toggles	Toggle

J-K Flip-Flops

Characteristic Table of J-K Flip-Flop

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

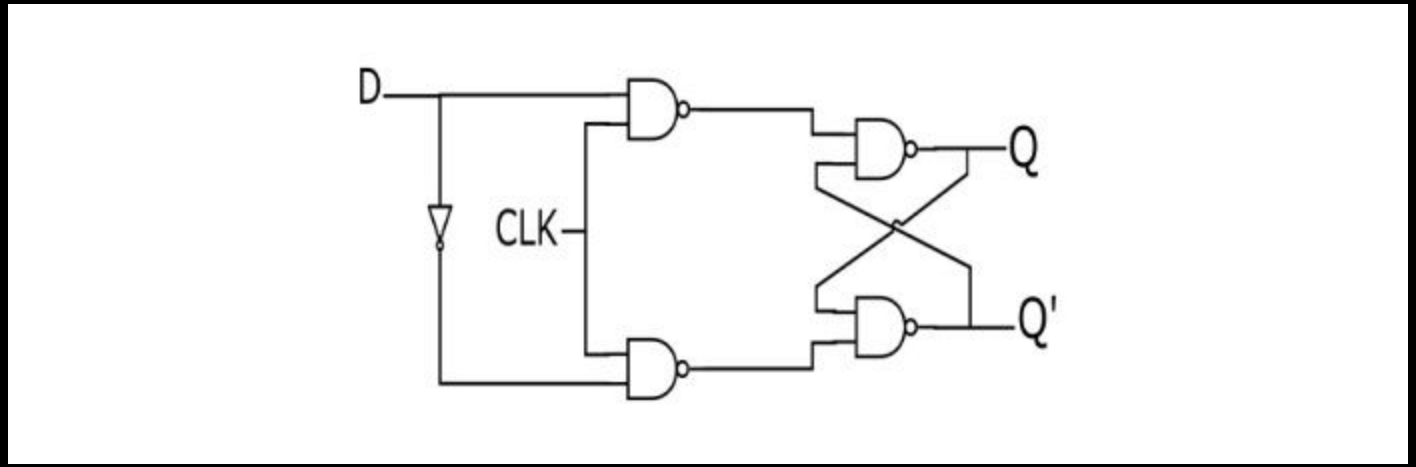
Characteristic Equation of J-K Flip-Flop

$$Q(t + 1) = JKQ(t)' + K'Q(t)$$

D Flip-Flops

D Flip-Flop

In a D flip-flop, the output can only be changed at positive or negative clock transitions, and when the inputs changed at other times, the output will remain unaffected. The D flip-flops are generally used for shift-registers and counters. The change in output state of D flip-flop depends upon the active transition of clock. The output (Q) is same as input and changes only at active transition of clock



D Flip-Flops

Truth table of D Flip-Flop

D	Q
0	0
1	1

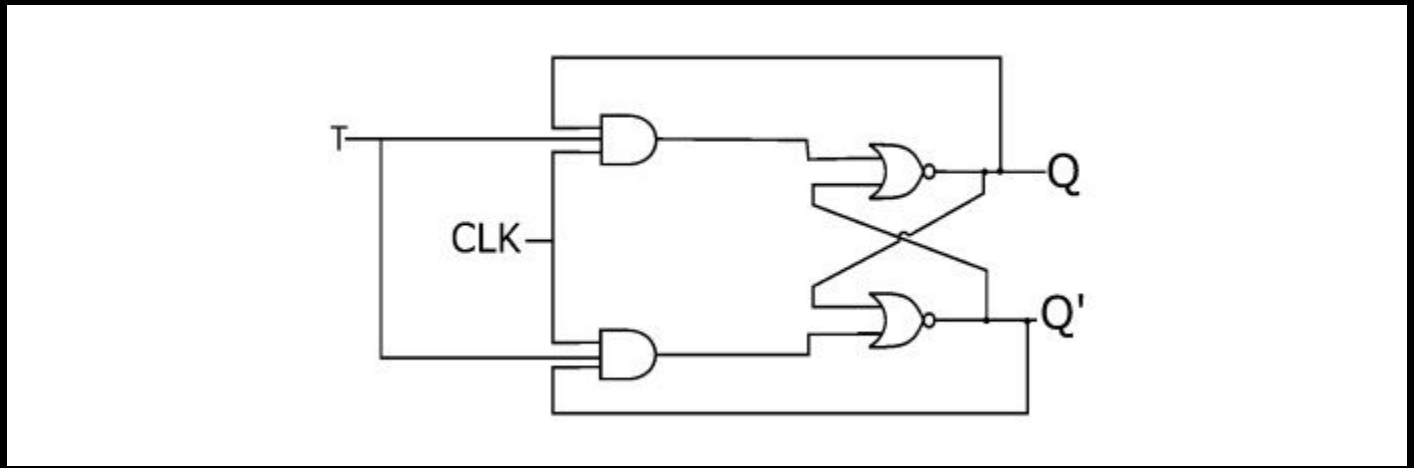
Characteristics Equation of D flip flops

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

T Flip-Flops

T Flip-Flop

A T flip-flop (Toggle Flip-flop) is a simplified version of JK flip-flop. The T flop is obtained by connecting the J and K inputs together. The flip-flop has one input terminal and clock input. These flip-flops are said to be T flip-flops because of their ability to toggle the input state. Toggle flip-flops are mostly used in counters.



T Flip-Flops

Truth table of T Flip-Flop

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

Characteristics Equation of T flip flops

$$Q(t + 1) = T'Q(t) + TQ(t)' = T \oplus Q(t)$$

Shift Register

Shift Register

A group of flip flops which is used to store multiple bits of data and the data is moved from one flip flop to another is known as Shift Register. The bits stored in registers shifted when the clock pulse is applied within and inside or outside the registers. To form an n-bit shift register, we have to connect n number of flip flops. So, the number of bits of the binary number is directly proportional to the number of flip flops. The flip flops are connected in such a way that the first flip flop's output becomes the input of the other flip flop.

A Shift Register can shift the bits either to the left or to the right. A Shift Register, which shifts the bit to the left, is known as "Shift left register", and it shifts the bit to the right, known as "Right left register".

Shift Register

Shift Register

The shift register is classified into the following types:

- Serial In Serial Out
- Serial In Parallel Out
- Parallel In Serial Out
- Parallel In Parallel Out