

Digital Systems

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IT131

Sequential Circuits – Part I

Lecture 7



Sequential Circuits Part I

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1. Sequential circuits
2. Flip-flops
3. Analysis of clocked sequential circuits
4. State reduction and assignment
5. Design procedure

Sequential Circuits Part I

Sequential circuits

- A sequential circuit consists of a combinational circuit and a feedback through the storage elements in the circuit.

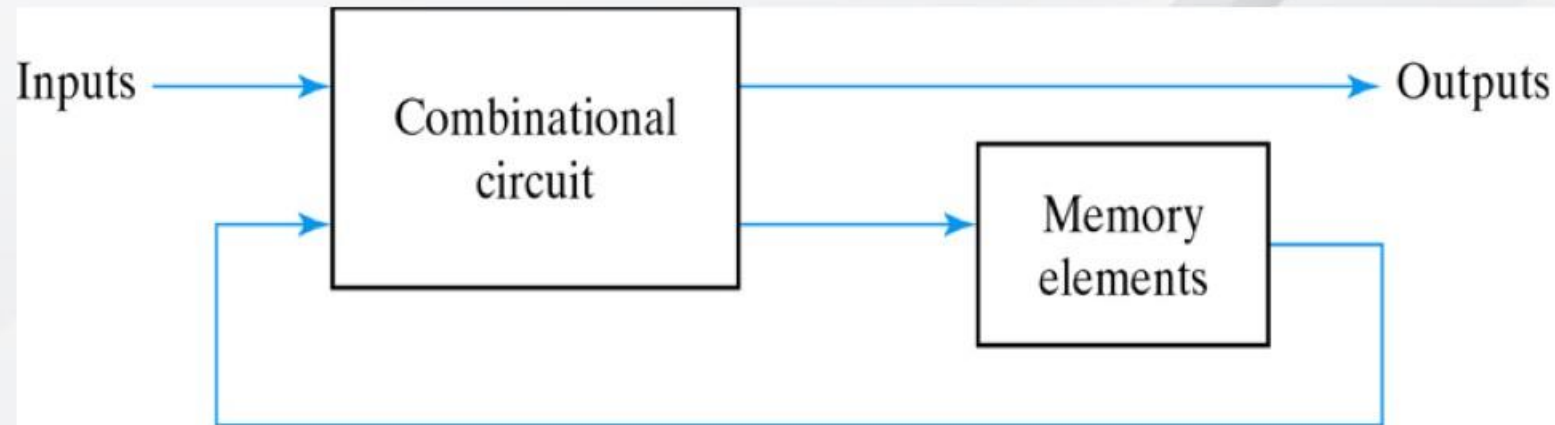


Fig. Block Diagram of Sequential Circuit

Sequential Circuits Part I

Sequential circuits

- Which type of the logic circuits are faster than the other Combinational or sequential?
- The combinational circuits are often faster than sequential circuits.
- **WHY:**
 - The combinational circuits do not require memory elements whereas the sequential circuits need memory devices to perform their operations in sequence

Sequential Circuits Part I

Sequential circuits

- Sequential circuits can be categorized as being synchronous or asynchronous
- A synchronous sequential circuit usually has a clock pulse (clocked sequential circuits)
- Flip-flops are storage elements which are used in clocked sequential circuits
- Each flip-flop can store one bit.

Sequential Circuits Part I

What Exactly is Memory?

A memory unit should support at least three operations.

- It should be able to **hold** a value.
- We should be able to **read** the value that is saved.
- We should be able to **change** that value.

Sequential Circuits Part I

What Exactly is Memory?

Example: One-bit Memory

- It should be able to hold a single bit, 0 or 1.
- We should be able to read the bit that is saved.
- We should be able to change the bit.
 - can **set** the bit to 1
 - can **reset** or **clear** the bit to 0

Sequential Circuits Part I

Flip-Flops

- A circuit that has *2 stable states* and can be used to store state information.
- A basic storage element in sequential logic.
- A **binary cell** capable of storing one bit of information, and has 2 outputs: normal and complement values.
- It is used in computers to store program like RAM memory and registers

Sequential Circuits Part I

What is Clock?

- In sequential circuits the output of a circuit is an input to another. So they should be control over thus circuit processes and it cannot operate randomly.
- So, Clock is needed to time the circuits or to sequence the sequential circuits.

Sequential Circuits Part I

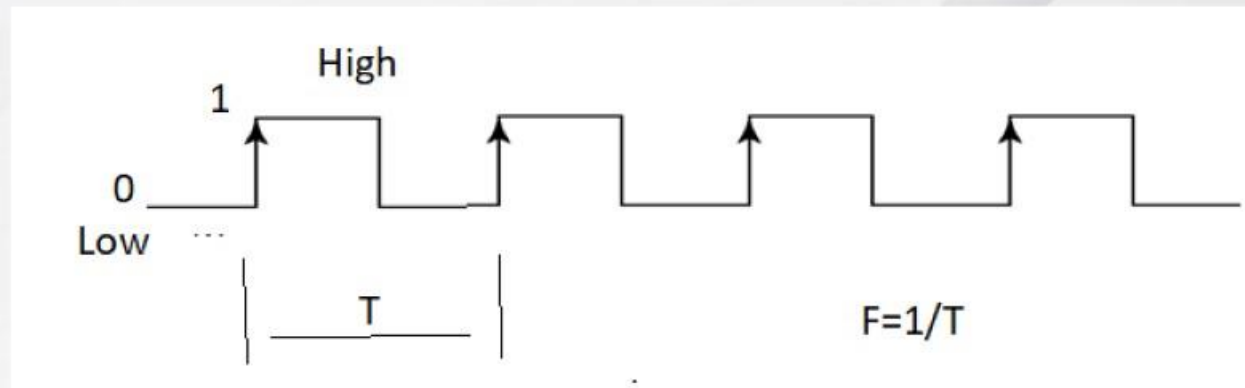
What is Clock?

- It is called clocks, because it decide the time of the inputs and outputs like the real clocks which decide the time of our daily routines.
- Also, we can decide the circuit speed by changing the clock frequency.

Sequential Circuits Part I

What is Clock?

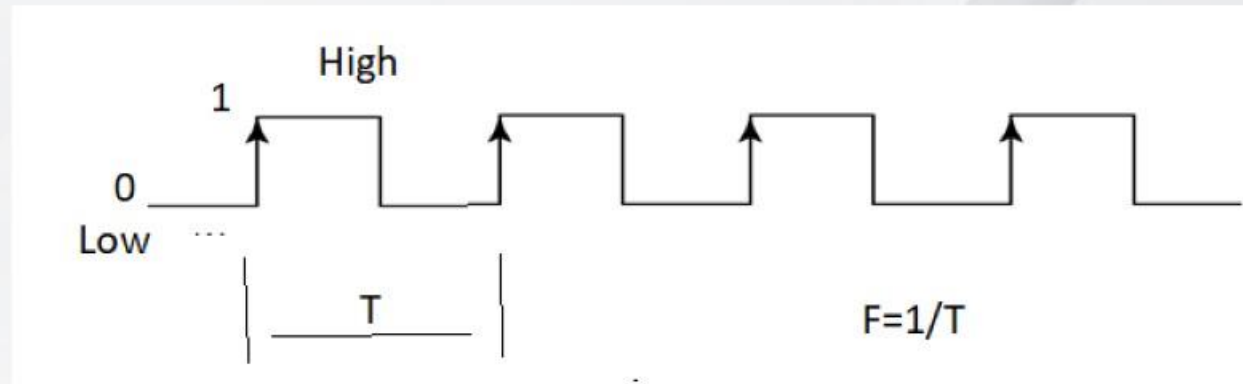
- The clock is nothing but signal that goes from **low (0)** to **high(1)** then again low and high and repeat.
- The time of high period = the time of low period



Sequential Circuits Part I

What is Clock?

- **Time period** of the clock is T
- **Frequency** of the clock $F = 1/T$
- To increase the speed of the circuit, the frequency should be increased and consequently the time period decrease.



Sequential Circuits Part I

What is Clock?

Positive (Rising) Edge: Describe a circuit or component that changes its state only when an input signal becomes high.

Negative (Falling) Edge: Describe a circuit or component that changes its state only when an input signal becomes low.



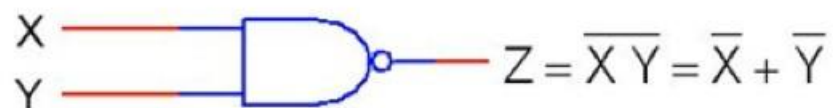
Positive (Rising) Edge Triggered



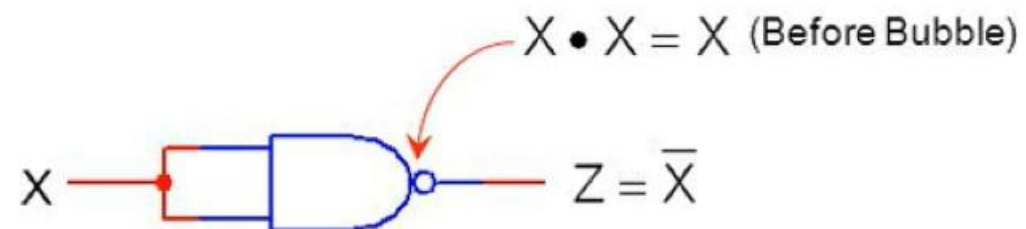
Negative (Falling) Edge Triggered

Sequential Circuits Part I

NAND Gate



X	Y	Z
0	0	1
0	1	1
1	0	1
1	1	0



X	Z
0	1
1	0

Equivalent to Inverter

Sequential Circuits Part I

SR Flip Flop

- The **SR flip-flop**, also known as a *SR Latch*, can be considered as one of the most basic sequential logic circuit possible.
- The SR flip-flop is basically a one-bit memory bistable device that has two inputs:
 - The first input will “**SET**” the device (meaning the output = “1”) labelled **S**
 - The Second input will “**RESET**” the device (meaning the output = “0”), labelled **R**.

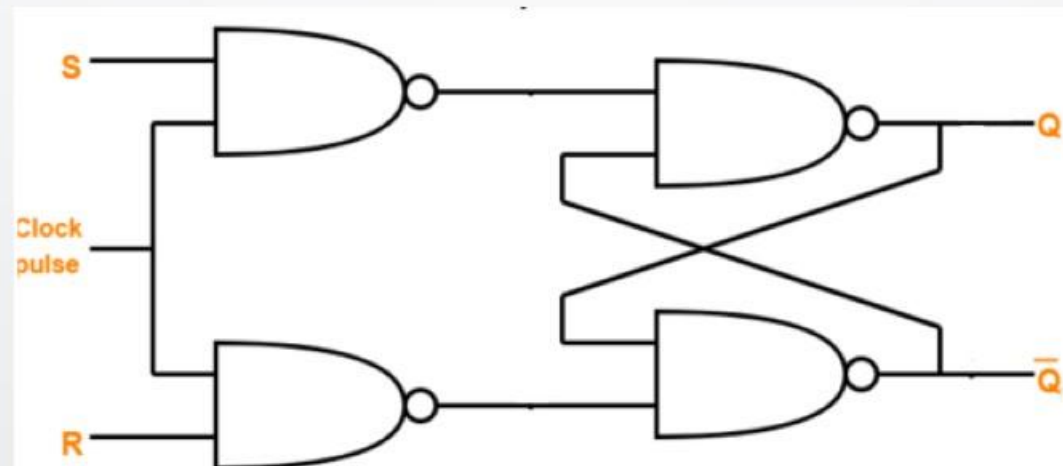
Sequential Circuits Part I

SR Flip Flop (Contd.)

- The simplest way to make any basic single bit set-reset SR flip-flop is to connect together a pair of cross-coupled 2-input NAND gates
- This device consists of two inputs, one called the *Set*, S and the other called the *Reset*, R with two corresponding outputs Q and its inverse or complement Q (Q') .

Sequential Circuits Part I

SR Flip Flop (Contd.)

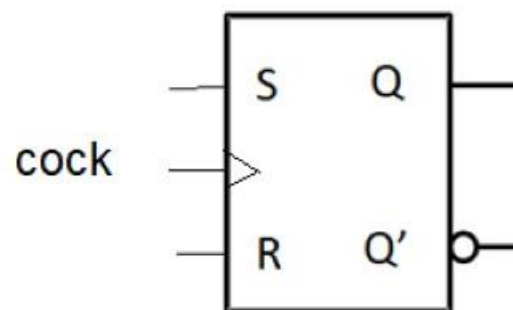


$Q(t)$ means the value of the output at time t .

$Q(t+1)$ is the value of Q after the next clock pulse

S	R	$Q(t+1)$
0	0	$Q(t)$ (no change)
0	1	0 (reset to 0)
1	0	1 (set to 1)
1	1	undefined

Function Table



Sequential Circuits Part I

D (Data) Flip Flop ;

- The D flip flop is the most important flip flop from other types.
- It ensures that at the same time, both the inputs, i.e., S and R, are never equal to 1. The D flip-flop is designed using a gated SR flip-flop with an inverter connected between the inputs allowing for a single input D(Data).
- This single data input, which is labeled as "D" used in place of the "Set" input and for the complementary "Reset" input.

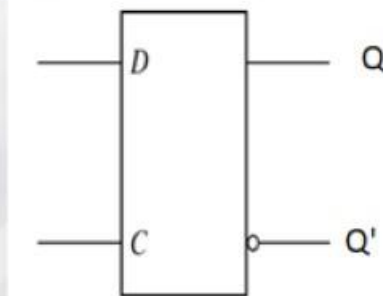
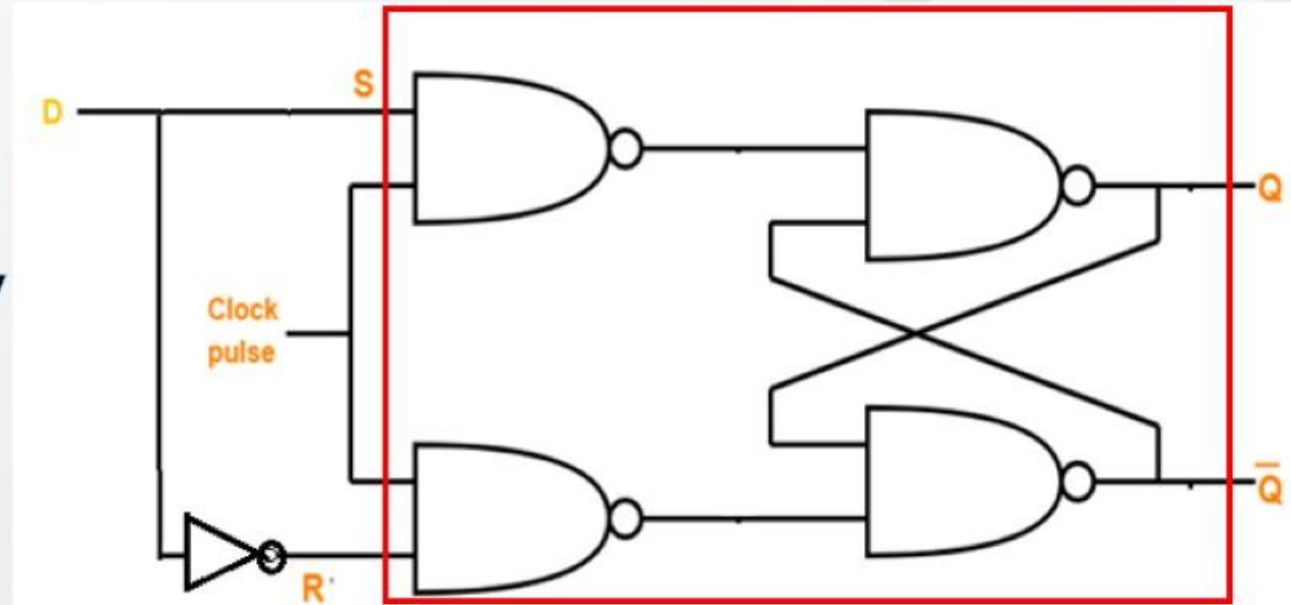
Sequential Circuits Part I

D (Data) Flip Flop (Contd.);

➤ The D-type Flip-flop

overcomes one of the main disadvantages of the basic SR NAND Gate Bistable circuit by forbidding the the undefined (indeterminate) input condition.

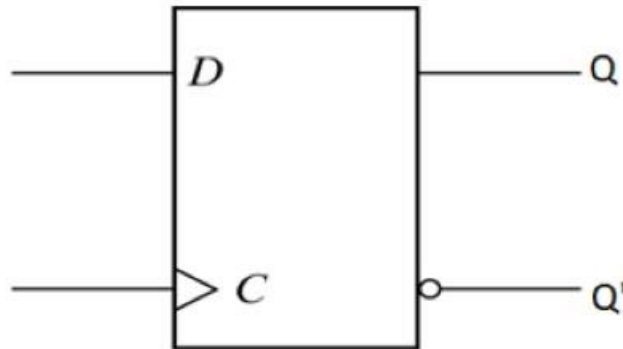
D	$Q(t+1)$
1	1 (set to 1)
0	0 (reset to 0)



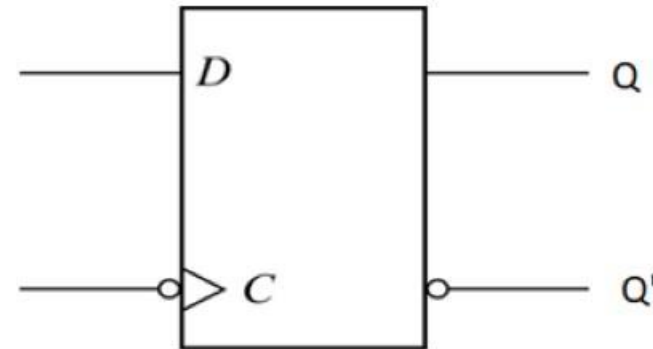
Sequential Circuits Part I

D Flip-flop (Contd.)

➤ The symbols for D flip-flop are shown in the following figures



(a) Positive-edge



(a) Negative-edge

Fig. Graphic Symbol for Edge-Triggered D Flip-Flop

Sequential Circuits Part I

D Flip-flop (Contd.)

- The **characteristic table** and the **characteristic equation** describe the operation of a flip-flop through a table and an algebraic equation, respectively
- The characteristic equation of the *D* flip-flop:

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

D	Q(t+1)	
0	0	Reset
1	1	Set

characteristic Table

Sequential Circuits Part I

- **The letter D** in “D Flip-Flops” stands for “Data” since the output Q follows the input D. Also, it indicates that the value of the input (1 or 0) is transferred into the flip flops output Q

A D Flip-Flop is like a one-bit memory that remembers the data you give it – the “D” – and outputs it (Q) when the clock is positive triggered or negative triggered.

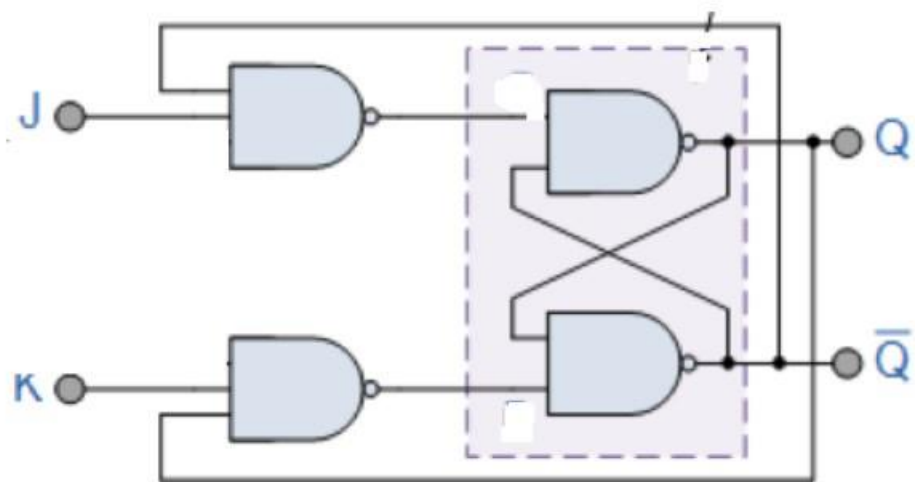
Sequential Circuits Part I

JK Flip-flop

- This simple JK flip Flop is the most widely used of all the flip-flop designs and is considered to be a universal flip-flop circuit.
- The two inputs labelled “J” and “K” are not shortened abbreviated letters of other words, such as “S” for Set and “R” for Reset, but are themselves autonomous letters chosen by its inventor Jack Kilby to distinguish the flip-flop design from other types.

Sequential Circuits Part I

JK Flip-flop (Contd.)



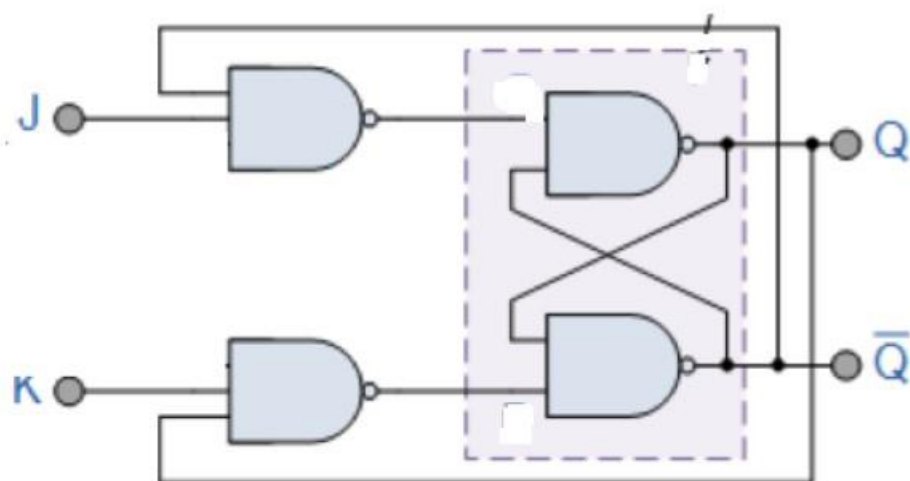
Circuit

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

Sequential Circuits Part I

JK Flip-flop (Contd.)

➤ There are four operations that can be performed with a flip-flop: no change, set, reset, or complement the output



Circuit

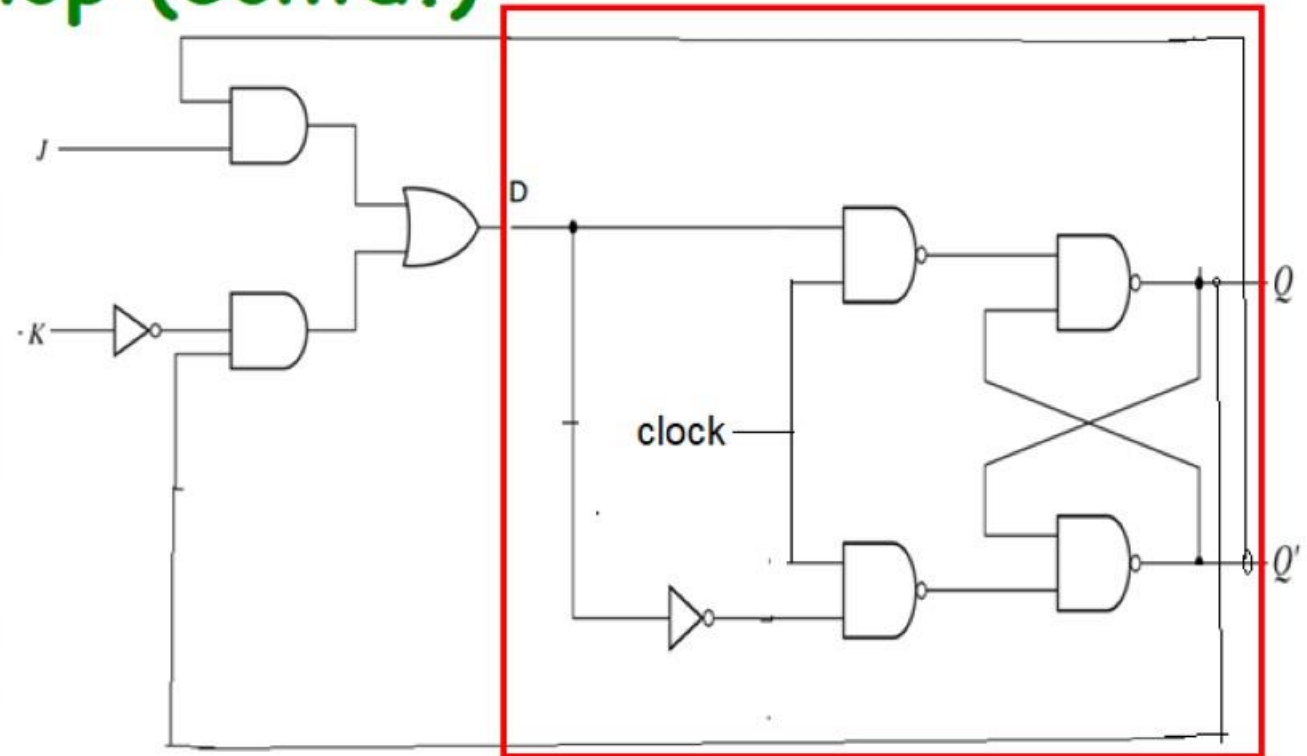
J	K	$Q(t+1)$	
0	0	$Q(t)$	No change
0	1	0	Reset
1	0	1	Set
1	1	$Q'(t)$	Complement

Sequential Circuits Part I

JK Flip-flop (Contd.)

➤ The JK flip-flop can be derived from the D flip-flop using the Boolean function

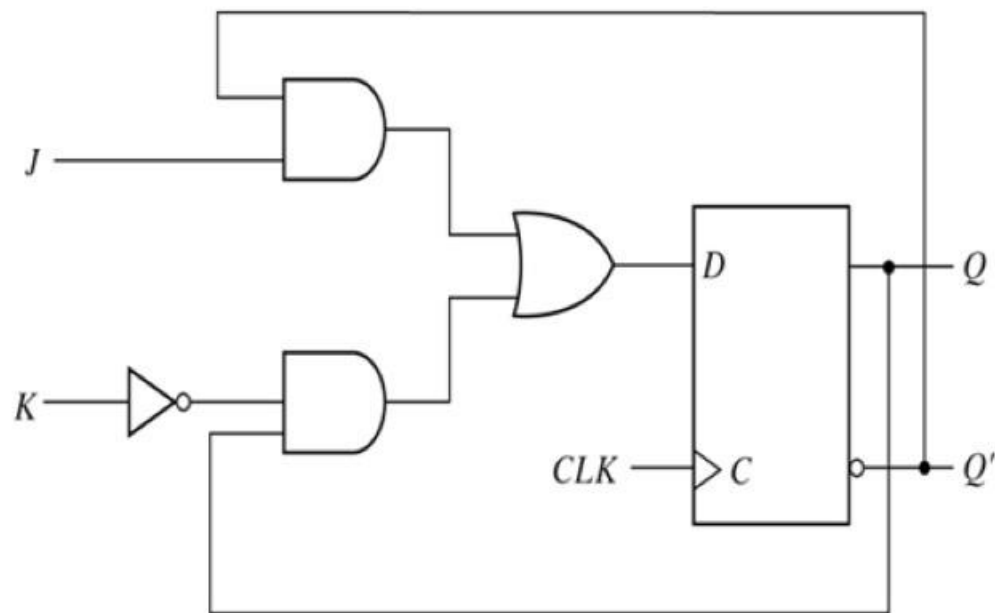
$[D = J.Q' + K'.Q]$ as follows:



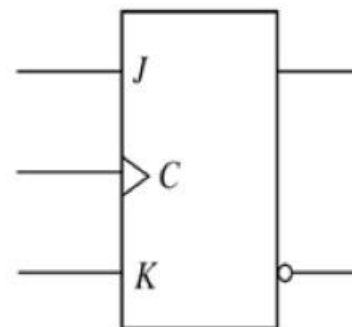
Logic diagram

Sequential Circuits Part I

JK Flip-flop (Contd.)



(a) Circuit diagram



(b) Graphic symbol

J	K	$Q(t+1)$	
0	0	$Q(t)$	No change
0	1	0	Reset
1	0	1	Set
1	1	$Q'(t)$	Complement

Fig. JK Flip-Flop

Sequential Circuits Part I

JK Flip-flop (Contd.)

➤ The characteristic equation of the JK flip-flop:

$$Q(t+1) = J \cdot Q'(t) + K' \cdot Q(t)$$

J	K	Q(t+1)	
0	0	Q(t)	No change
0	1	0	Reset
1	0	1	Set
1	1	Q'(t)	Complement

characteristic Table

Sequential Circuits Part I

T (Toggle)Flip-flop

- In T flip flop, "T" defines the term "Toggle".
- This flip-flop works as a Toggle switch. The next output state is changed with the complement of the present state output. This process is known as "Toggling".

Sequential Circuits Part I

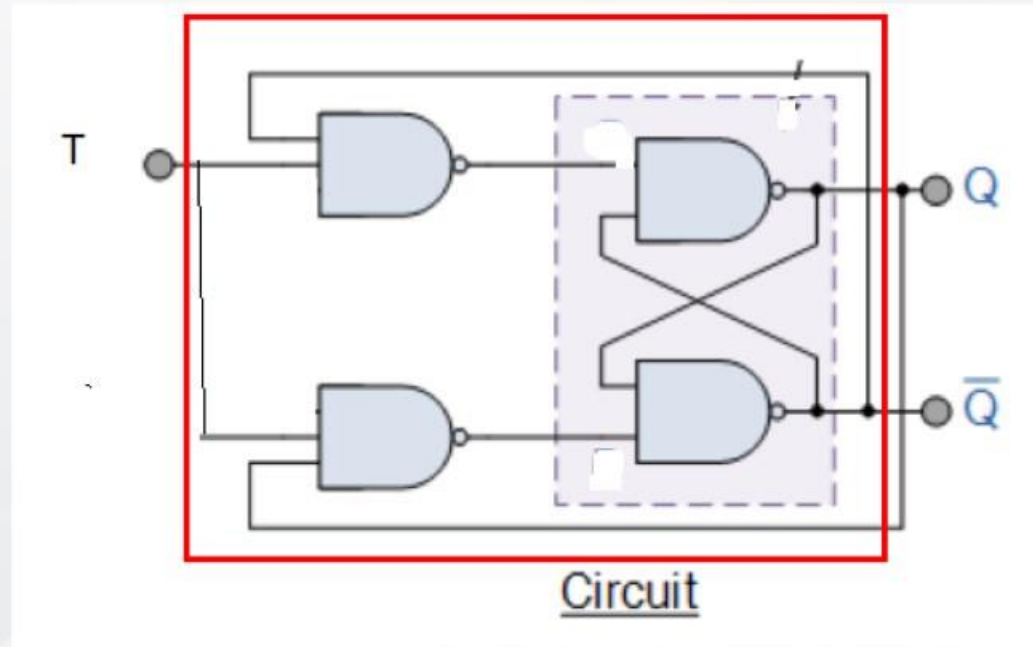
T (Toggle)Flip-flop (Contd.)

- There are the following two methods which are used to form the "T Flip Flop:
 - By connecting the input of JK flip flop together. This new single input is called T.
 - By Connecting an XOR with T input and Q (PREVIOUS) output to the Data input in D flip – flop.

Sequential Circuits Part I

T (Toggle) Flip-flop (Contd.)

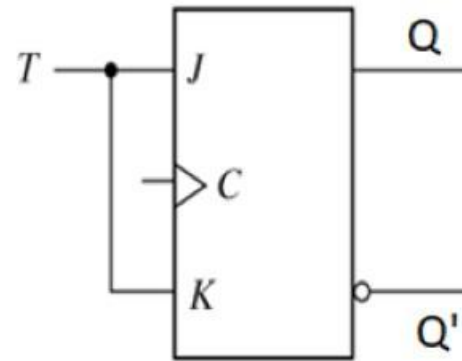
- The T (toggle) flip-flop can be derived from the J-K Flip flop as follows:



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

Sequential Circuits Part I

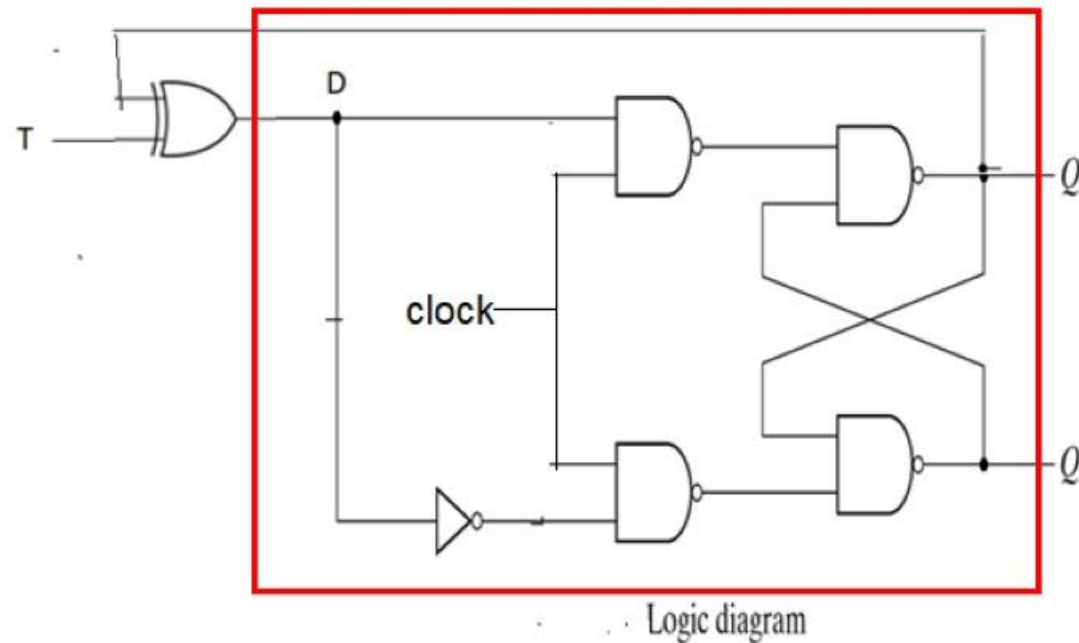
T (Toggle)Flip-flop (Contd.)



(a) From JK flip-flop

Sequential Circuits Part I

- By Connecting an XOR with T input and Q (PREVIOUS) output to the Data input in D flip – flop.

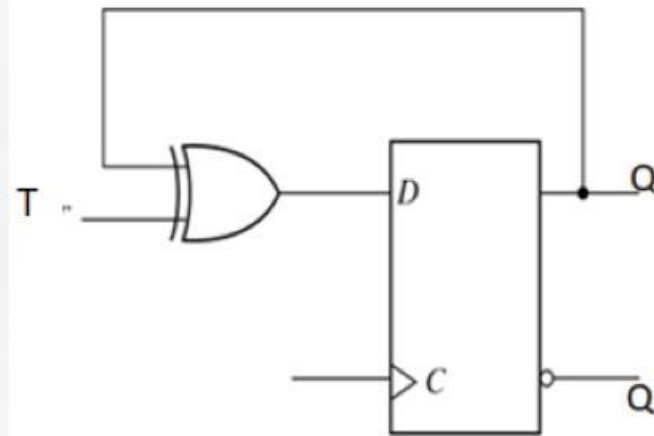


Sequential Circuits Part I

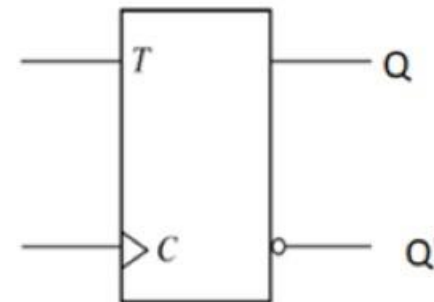
T (Toggle) Flip-flop (Contd.)

➤ The T (toggle) flip-flop can be derived from the D flip-flop using the Boolean function:

➤ $D = T \oplus Q = T.Q + T'.Q$ as follows



(b) From D flip-flop



(c) Graphic symbol

Sequential Circuits Part I

T (Toggle)Flip-flop (Contd.)

➤ The characteristic equation of the T flip-flop can be obtained as follows

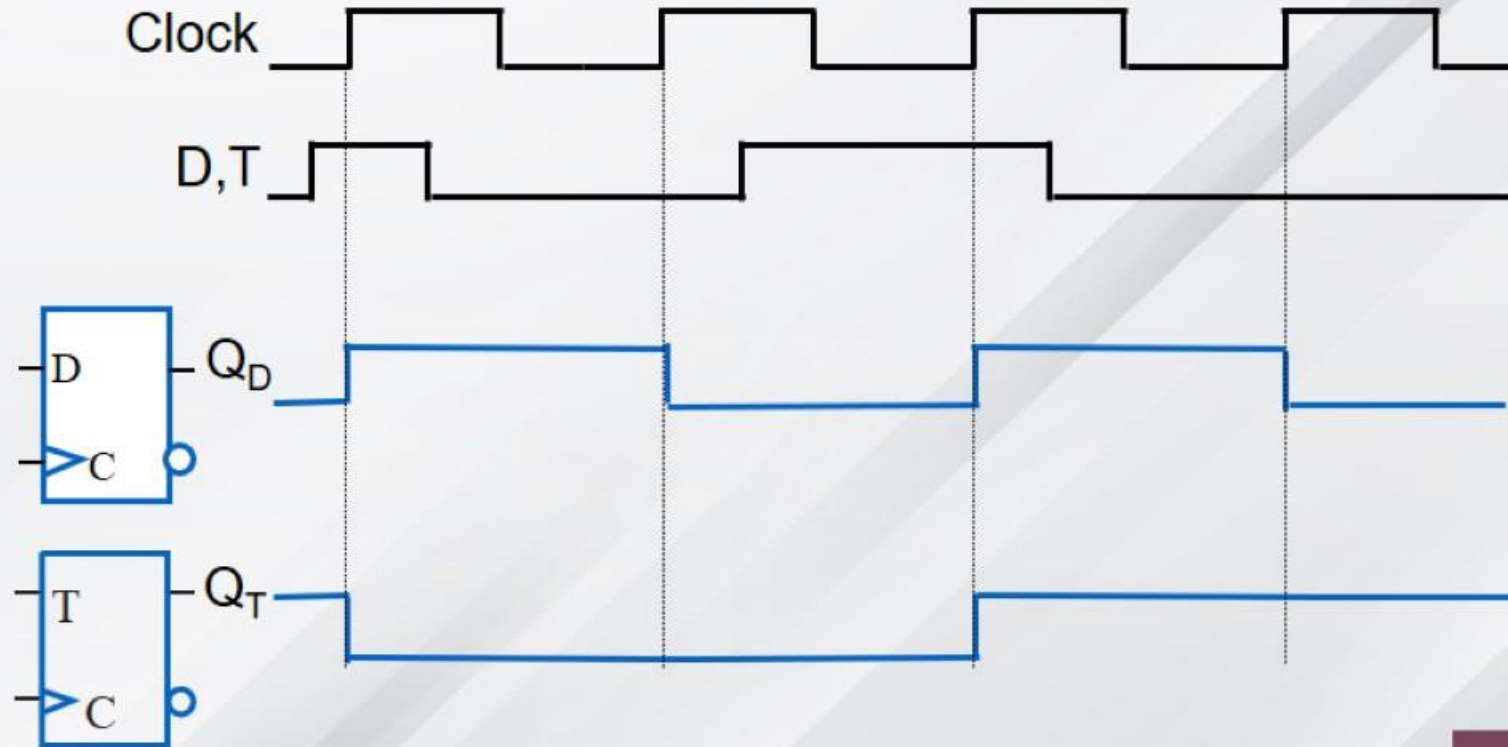
$$Q(t+1) = T.Q(t) + T'.Q(t)$$

➤ The characteristic table of the T flip-flop is given below

T	Q(t+1)	
0	Q(t)	No change
1	Q'(t)	Complement

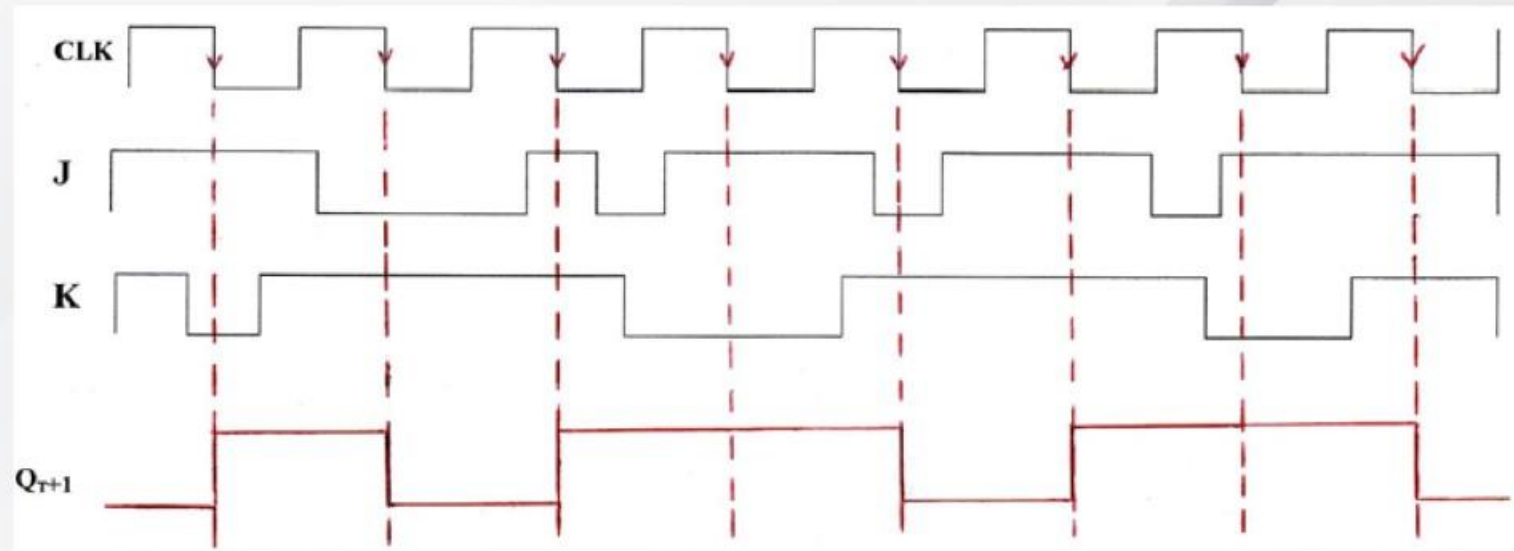
Sequential Circuits Part I

➤ **Exercise:** Use the characteristic tables to find the output waveforms for the flip-flops shown:



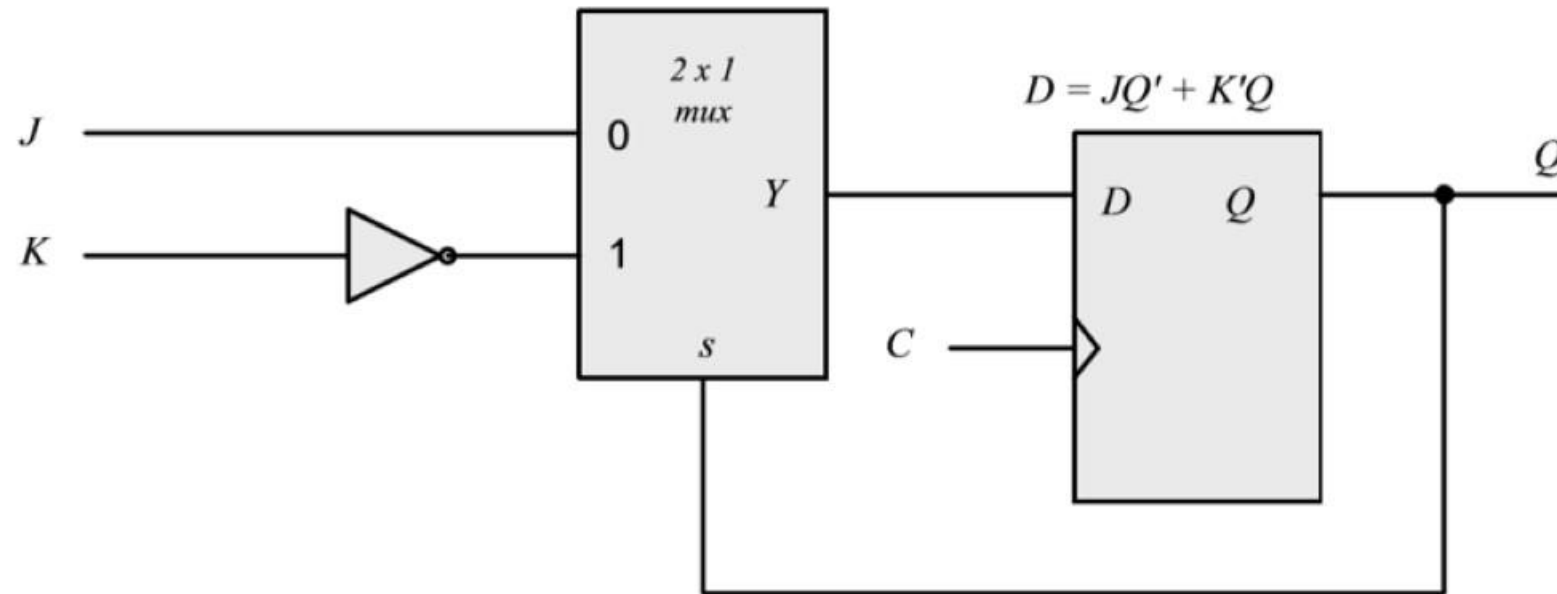
Sequential Circuits Part I

Exercise: Complete the following timing diagram consider that the used JK flip flop is a negative edge triggered, and $Q(t+1)$ is initially equal 0.



Sequential Circuits Part I

Exercise: Construct a JK Flip Flop using a D Flip Flop , a two to one line multiplexer and inverter.



Sequential Circuits Part I

Exercise: To convert a JK flip-flop into a D flip-flop, what should the inputs J and K be in terms of D?





Thank You