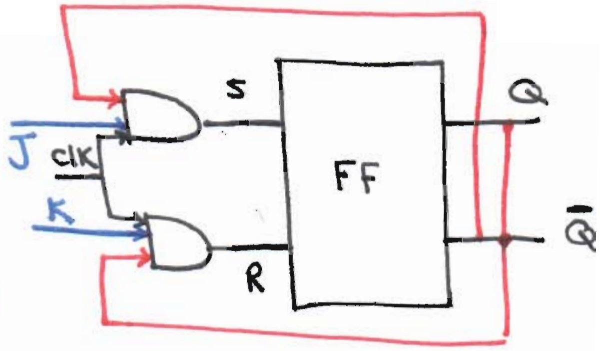
③ J-K Flip-flop

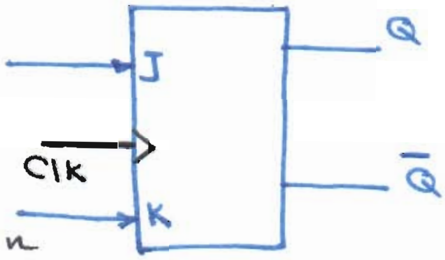
The J-K flip-flop combines the features of the S-R and T flip-flops.

ClK	J	K	Q(t+1)
↑	0	0	Q(t) - No change
↑	0	1	0 - Reset
↑	1	0	1 - Set
↑	1	1	$\bar{Q}(t)$ - Complement



1) **Characteristics Table:** A characteristics table defines the logical properties of a flip-flop by describing its operation in tabular form, it defines the next state (the state that results from a clock transition) as a function of inputs and the present state Q(t).

2) **Characteristic Equation:**



$$Q(t+1) = J\bar{Q} + \bar{K}Q$$

To get the characteristics equation we use the truth table and Karnaugh map to minimize the output:

Inputs 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

→ Q(t+1) = Q(t) (no change)

→ Q(t+1) = 0 (Reset)

→ Q(t+1) = 1 (set)

→ $Q(t+1) = \bar{Q}(t)$ → Complement

this table called "Next-State table"

Q(t) \ JK	00	01	11	10
0	0	0	1	1
1	1	0	0	1

$$\Rightarrow Q(t+1) = J\bar{Q} + \bar{K}Q$$

Characteristics (Next state) equation.

3) Excitation Table :

During the design process we usually know the transition from present state to the next state and wish to find the flip-flop input conditions that will cause the required transition.

We can derive the excitation table from the truth table.

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

"State table"

from it ⇒ we get

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

excitation table for J-K flip-flop

4 T- flip flop (Trigger flip-flop)

1) T- flip-flop characteristics table (Next-state table)

T	Q(t+1)
0	Q(t) (No change)
1	$\overline{Q(t)}$ (Complement)

⇓

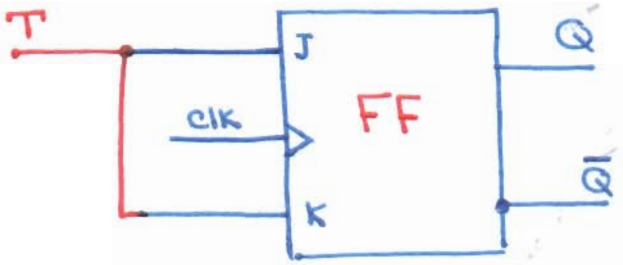
Q(t)	T	Q(t+1)
0	0	0
0	1	1
1	0	1
1	1	0

State table

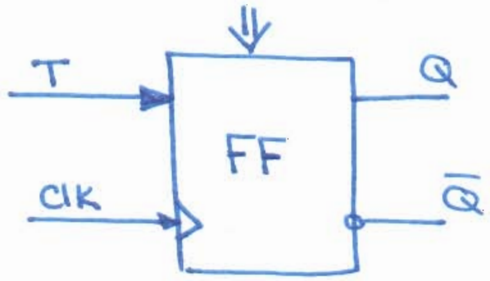
⇒

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

excitation table



⇓



Graphic symbol for T- trigger

Q \ T	0	1
0	0	1
1	1	0

K-map

$$\Rightarrow Q(t+1) = T \oplus Q(t) = T\overline{Q}(t) + \overline{T}Q(t)$$

Characteristics equation (State equation for T-trigger.

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

Next State table

$\Rightarrow$

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

"excitation table"

* Any illegal input combinations should be treated as don't cares

Q(t) \ SR	00	01	11	10
0	0	0	X	1
1	1	0	X	1

$$Q(t+1) = S + Q(t)\cdot\overline{R}$$

" State equation for S-R flip flop.

D- flip flop

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

State table

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

truth table (state)

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

State-equation

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

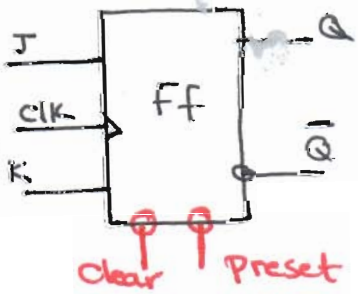
$\Rightarrow$ excitation table

* Clicked Flip-flops with Clear and Reset Inputs. (Direct Inputs)

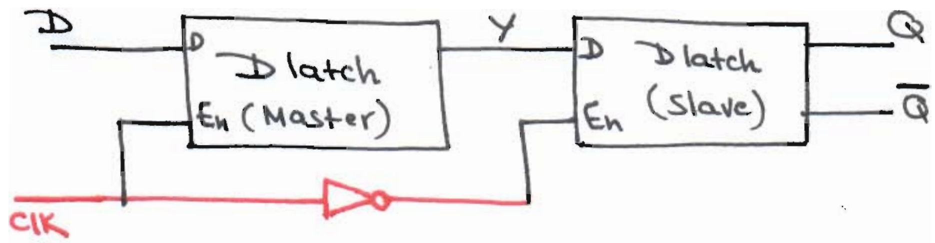
Clocked integrated circuit flip-flops often have additional inputs which can be used to set the flip-flop to an initial state independent of the clock.

in most cases the logic "0" is used (required) to clear or set the flip-flop

* These inputs can be used for other flip-flops.



Master-slave D flip-flop.



The construction of a D flip-flop with two latches and an inverter. (the first is called the master and the second the slave)

- clk = 0 : The slave latch is enabled and its output Q is equal to the master output Y, the master is disabled because clk = 0.
- clk = 1 :

  master D latch is enabled: the data from the external D input are transferred to the master, the slave is disable.

  Any change in the input changes the master output at Y, but cannot affect the slave output.

We can construct Master-slave design with other flip-flop kinds.

Analysis of Clocked Sequential Circuits

Analysis describes what a given circuit will do under certian operating conditions.

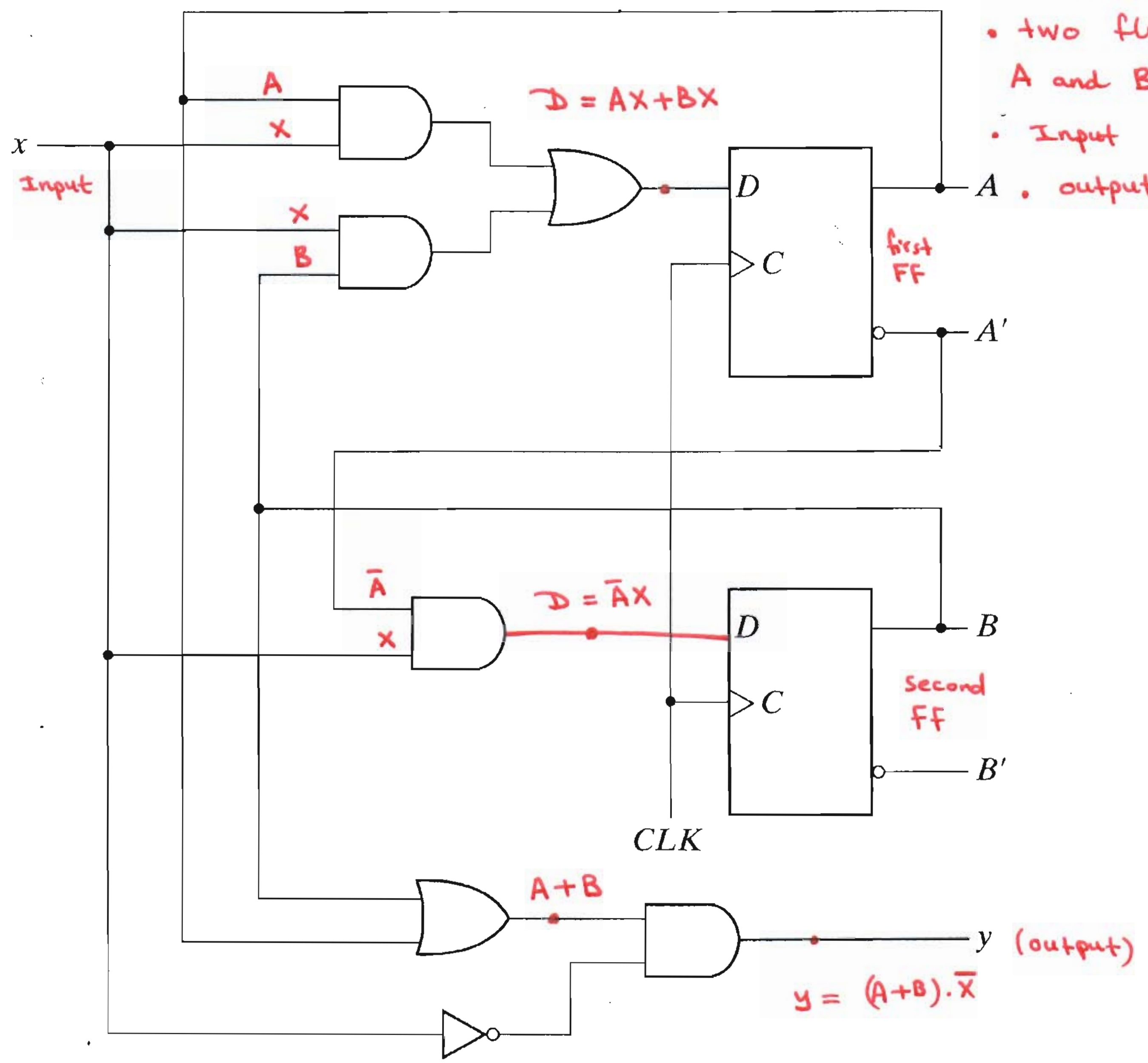
The outputs and the next state are both a function of the inputs and the present state.

Analysis steps:

1. Construct the state table.
2. Construct the state diagram.
3. Write the state equations.
4. State Reduction.
5. State assignment.
6. Construct the excitation table

Example:

Consider the sequential circuit shown in figure :



We have
- two flip-flops A and B.
- Input X . output y.

The behavior of a clocked sequential circuit can be described by state equation (or transition equation) specifies the next state as a function of the present state and inputs.

① The state equations for the circuits are the following : ⇒

$$A(t+1) = A(t)\,X(t) + B(t)\,X(t)$$
$$B(t+1) = \bar{A}(t)\cdot X(t)$$

→ Boolean expression that specifies the present state and input conditions that make the next state equal to 1.

next state of the flip-flop one clock edge later

* The boolean expressions for the state equations can be derived directly from the gates that form the combinational circuit part of the sequential circuit.

* The present state value of the output equal

$y(t) = [A(t) + B(t)] . \bar{x}(t)$

Simply, we can write :

$y = (A + B) . \bar{x}$

State Table for Circuit

Present State		Input	Next State		Output
A	B	X	A	B	Y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	1
0	1	1	1	1	0
1	0	0	0	0	1
1	0	1	1	0	0
1	1	0	0	0	1
1	1	1	1	0	0

State Table for Circuit : Table 1

② State Table

The state table (also called a transition table) consists of four sections (Table 1): present state, input, next state and output.

- present state : states of flip-flops A and B at any given time t.
- input section gives a value of x for each possible present states
- next state section: shows the states of flip-flops after one clock cycle later, at time t+1
- The output section gives the value of y at time t.

Two-Dimensional State Table for the Circuit

Present state		Next state X = 0		Next state X = 1		Output X = 0	Output X = 1
A	B	A	B	A	B	Y	Y
0	0	0	0	0	1	0	0
0	1	0	0	1	1	1	0
1	0	0	0	1	0	1	0
1	1	0	0	1	0	1	0

Two-Dimensional State Table for the Circuit : Table 2

* The next state values are calculated from the state equations

* The output values are calculated from the output equation.

Some times the state table is expressed using Two-dimensional state table as Table 2.
(The input conditions are enumerated under the next-state and output sections.

3. State Diagram :

- The information available in a State table can be represented graphically in the form of a state diagram

- State is represented by Circle.
- Transitions between states are indicated by directed lines

* The state diagram provides the same information as the state table and is obtained directly from table 1 or table 2

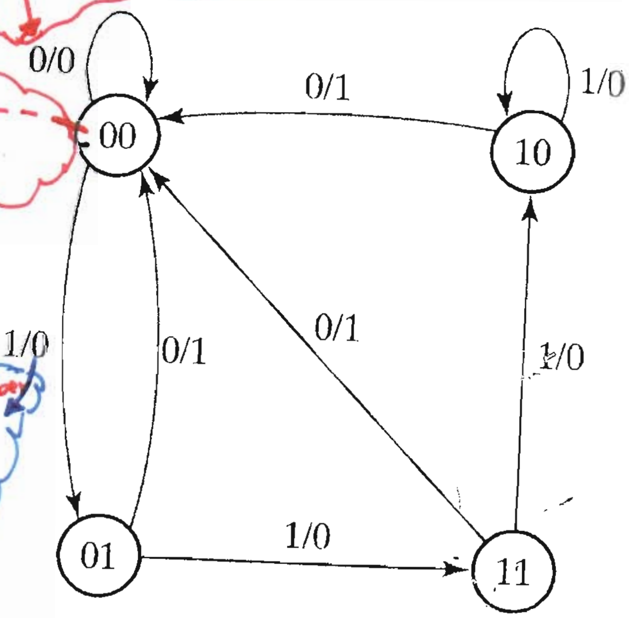
* The state table is easier to derive from a given logic diagram or/and the state equation.

first number
input value during the present state.

* The state diagram gives a pictorial view of state transitions

The state of flip-flops

second number
Output value during the present State



State Diagram of the Circuit

Flip-Flop Input Equation (Important !!)

* The Knowledge of the type of flip-flops and a list of the boolean expressions of the combinational Circuit provide the information needed to draw the logic diagram of the sequential circuit.

output equations : The part of the combinational Circuit that generates external output.

input equations : (excitation equation): The part of the Circuit that generates the inputs to flip-flop.

examples:

① $D_q = x + y$

this input equation specifies the OR gate with inputs x and y connected to the D input of a flip-flop.

② The logic diagram of the circuit (in previous section) can be expressed algebraically with two flip-flop input equations and one output equation:

$$D_A = Ax + Bx$$
$$D_B = \bar{A}x$$
$$y = (A + B)\bar{x}$$

The three equations provide the necessary information for drawing the logic diagram of the sequential circuit.