Sequential Circuits

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Flip-Flops

- Flip-flop is a basic memory element.
- It can store "one bit of information".
- A flip-flop has 2 outputs, which are always complementary to each other.
- A flip-flop has 2 stable state hence it is known as bi-stable multivibrator.
- A simplest form of flip-flop is called "latch". It can be constructed with two cross coupled NAND gates or NOR gates.

Triggering

Triggering is used to initiate the operation of latches or flip-flops.

(i) **Level trigger:** Input signal affects the flip-flop only when the clock is at logic '1' or logic '0'.

(ii) **Edge trigger:** Input signal affects the flip-flop only if they are present at the positive or negative going edge of the clock pulse.

Setup Time

It is minimum time required to keep input at proper level before applying clock.

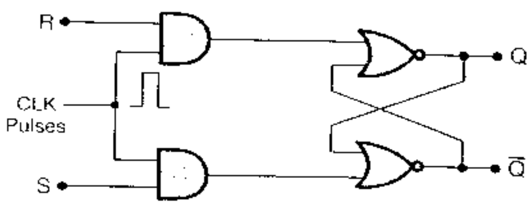
Hold Time

Hold time is minimum time required to keep input at same level after applying clock.

Note:

- **If set-up time and hold time is not properly given, the output may go to meta stable state.**

Clocked S-R Flip-Flop



Truth table

Clock	S_n	R_n	Q_{n+1}	
0	X	X	Q_n	
1	0	0	Q_n	→ HOLD state
1	0	1	0	→ RESET state
1	1	0	1	→ SET state
1	1	1	Invalid	→ FORBIDDEN state

- S_n and R_n denotes the inputs and Q_n the output during the bit time 'n'.
- 'Q_{n+1}' denotes the output Q after CLK passes, i.e. in bit time (n + 1).

Characteristic table

S	R	Q_n	Q_{n+1}	
0	0	0	0	→ Q_n
0	0	1	1	
0	1	0	0	→ 0
0	1	1	0	
1	0	0	1	→ 1
1	0	1	1	
1	1	0	X	→ Invalid
1	1	1	X	

Characteristics equation

$$Q_{n+1} = S + \bar{R} Q_n$$

Remember:

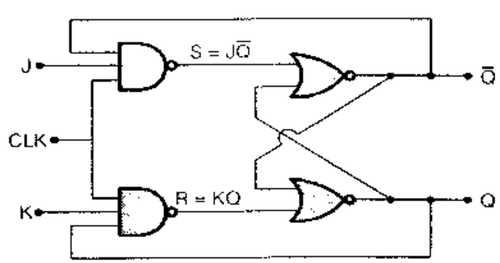
Disadvantage of SR flip-flop is invalid state will present when both inputs are 1 or high. To avoid this J-K flip-flop is used.

J-K Flip-Flop

JK-FF is called an universal FF because the FFs like D-FFs, SR-FF and T-FF can be derived from it.

$$S = J\bar{Q} \text{ and } R = KQ$$

Logic diagram



Truth table

Clock	J	K	Q_{n+1}	
0	X	X	Q_n	
1	0	0	Q_n	→ HOLD state
1	0	1	0	→ RESET state
1	1	0	1	→ SET state
1	1	1	$\bar{Q}_n$	→ TOGGLE state

Characteristic table

J	K	Q_n	Q_{n+1}	
0	0	0	0	→ Q_n
0	0	1	1	
0	1	0	0	→ 0
0	1	1	0	
1	0	0	1	→ 1
1	0	1	1	
1	1	0	1	→ $\bar{Q}_n$
1	1	1	0	

Characteristic equation

$$Q_{n+1} = J\bar{Q}_n + \bar{K} Q_n$$

Race Around Condition

- The Race around condition will occur when
  - (i) J = K = 1
  - (ii) $t_{pd(FF)} < t_{pw}$
  - (iii) Flip-flop is level triggered.
- For the duration "t_{pw}" of the clock pulse, the output Q will oscillate back and forth between 0 and 1. At the end of the clock pulse, the value "Q" is uncertain. This situation is referred as "race around condition".
- To avoid this, we should maintained

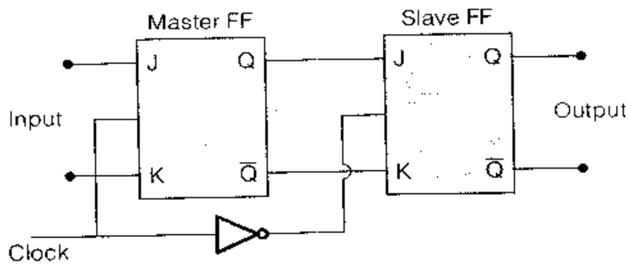
$$t_{pw} < t_{pd(FF)} < T$$

Remember:

Race around condition does not occur in edge triggered flip-flop.

Master-Slave J-K Flip-Flop

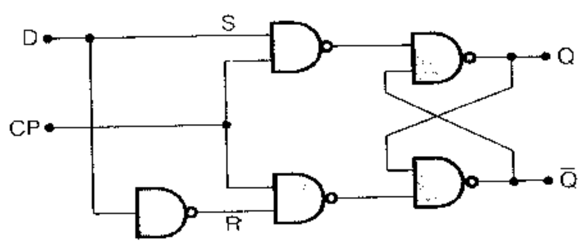
To avoid race around condition master slave FF is used.



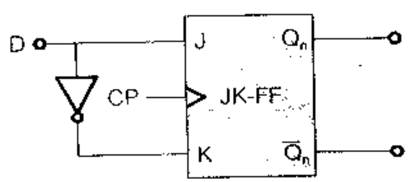
- In master slave flip-flop master is applied with input clock and slave is applied with inverted clock. Due to this when master output is changing slave output remains in previous state.
- In master slave flip-flop, output will changes only when slave output change.
- Output of master can change many times but, slave output can change only 1 time so master FF act as level trigger and slave FF act as edge trigger. Therefore there is no "race around condition" at the output of the slave.

D-Flip-Flop

It is a FF with a delay equal to exactly one cycle of CLK.



Graphical diagram



J = D and K = $\bar{D}$

Truth table and characteristic table

CLK	D	Q_{n+1}
0	X	Q_n
1	0	0
1	1	1

Truth Table

D	Q_n	Q_{n+1}
0	0	0
0	1	0
1	0	1
1	1	1

Characteristic Table

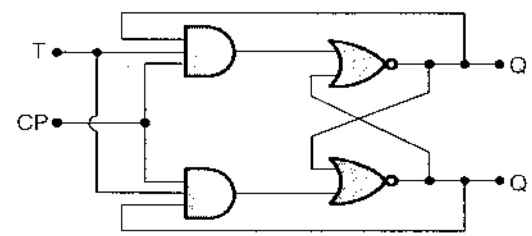
Characteristic equation

$$Q_{n+1} = D$$

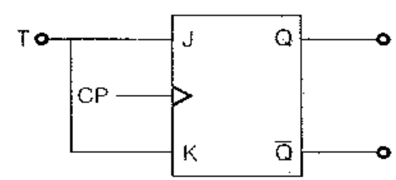
Note: It is also known as "Transparent Latch" because $Q_{n+1} = D$.

Toggle Flip-Flop (T-FF)

- The T-FF is a single input version of the J-K FF.
- T-FF can be obtained from a J-K FF if J and K tied together as in figure shown below.
- The designation 'T', comes from the ability of the FF to "toggle" or "change state".



Graphical symbol of T-FF



J = K = T

Truth table and characteristic table

CLK	T	Q_{n+1}	
0	X	Q_n	
1	0	Q_n	→ HOLD state
1	1	$\overline{Q}_n$	→ Toggle state

Truth Table

T	Q_n	Q_{n+1}
0	0	0
0	1	1
1	0	1
1	1	0

Characteristic Table

Characteristic equation

$$Q_{n+1} = \overline{T}\, Q_n + T\, \overline{Q}_n = T \oplus Q_n$$

Conversion of Flip-Flops

SR FF to other FFs	JK FF to other FFs	D-FF to other FFs	T-FF to other FFS
$S = J\overline{Q}_n$ & $R = KQ_n$	$J = S$ & $K = R$	$D = S + \overline{R}Q_n$	$T = S\overline{Q}_n + RQ_n$
$S = D$ & $R = \overline{D}$	$J = D$ & $K = \overline{D}$	$D = J\overline{Q}_n + \overline{K}Q_n$	$T = J\overline{Q}_n + KQ_n$
$S = T\overline{Q}_n$ & $R = TQ_n$	$J = K = T$	$D = T \oplus Q_n$	$T = D \oplus Q_n$

Excitation Table of Flip-Flops

Q_n	Q_{n+1}	S	R	J	K	D	T
0	0	0	X	0	X	0	0
0	1	1	0	1	X	1	1
1	0	0	1	X	1	0	1
1	1	X	0	X	0	1	0

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