

Chapter 5 – Flip-Flops and Related Devices

ELEVENTH EDITION

Digital Systems

Principles and Applications

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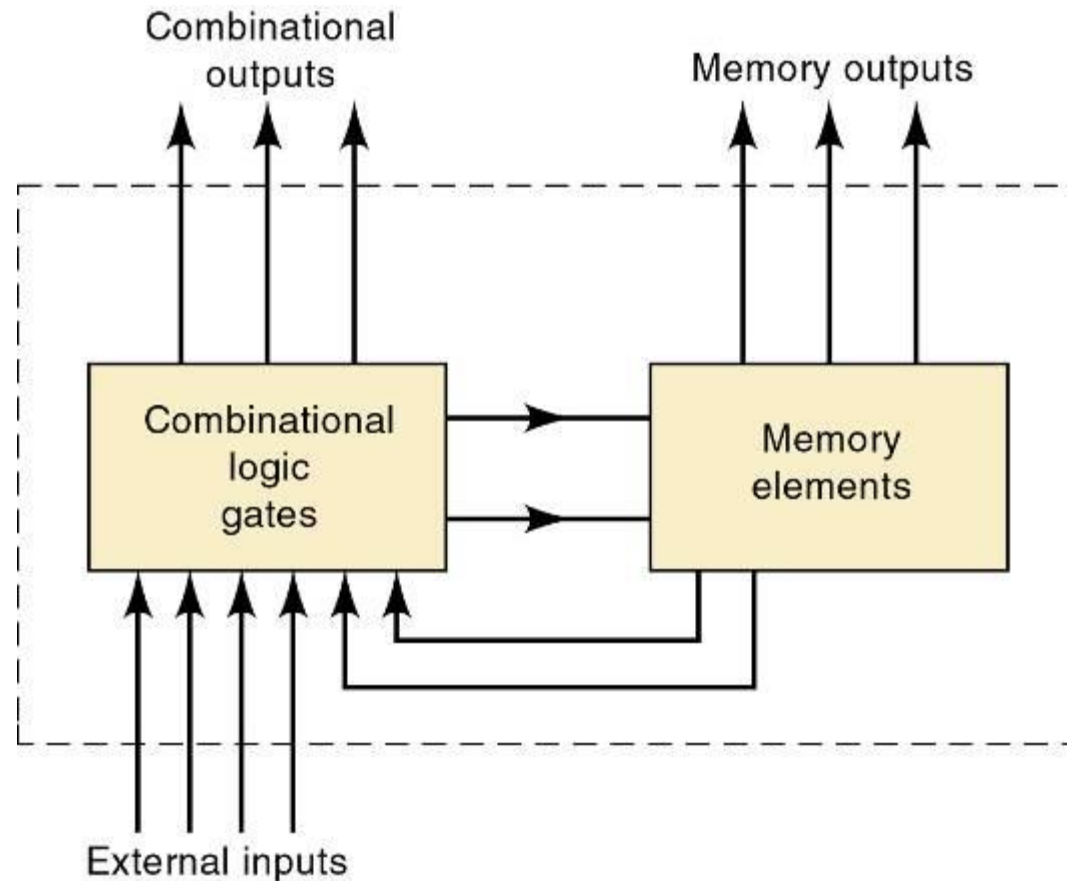
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Chapter 5 Objectives

- *Selected areas covered in this chapter:*
 - Constructing/analyzing operation of latch flip-flops made from NAND or NOR gates.
 - Differences of synchronous/asynchronous systems.
 - Major differences between parallel & serial transfers.
 - Operation of edge-triggered flip-flops.
 - Typical characteristics of Schmitt triggers.
 - Effects of clock skew on synchronous circuits.
 - Troubleshoot various types of flip-flop circuits.
 - Sequential circuits with PLDs using schematic entry.
 - Logic primitives, components & libraries in HDL code.
 - Structural level circuits from components.

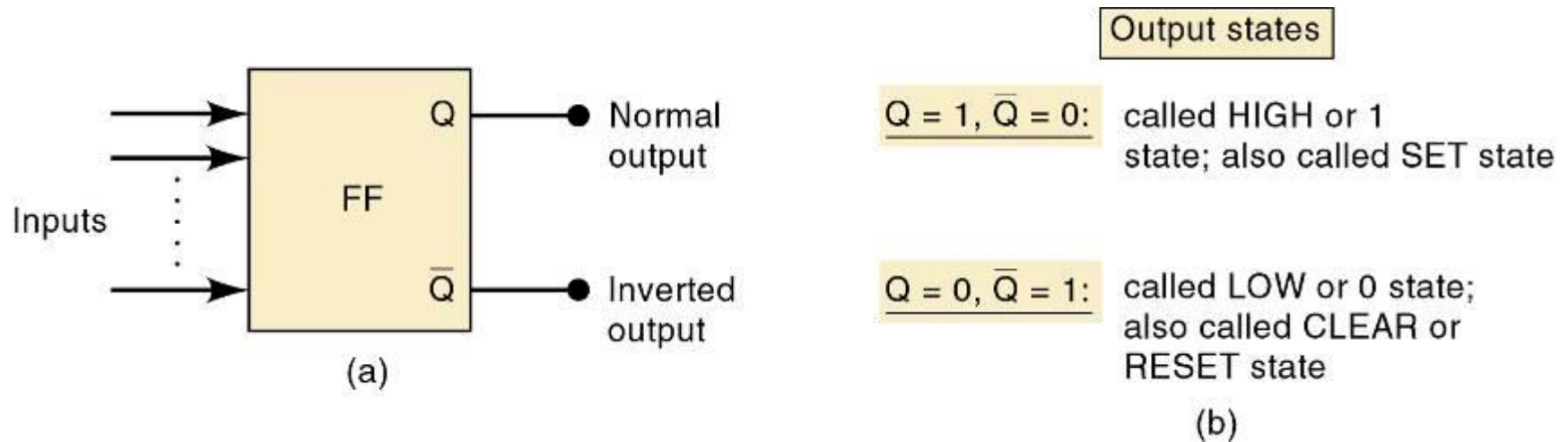
Chapter 5 Introduction

- Block diagram of a general digital system that combines combinational logic gates with memory devices.



Chapter 5 Introduction

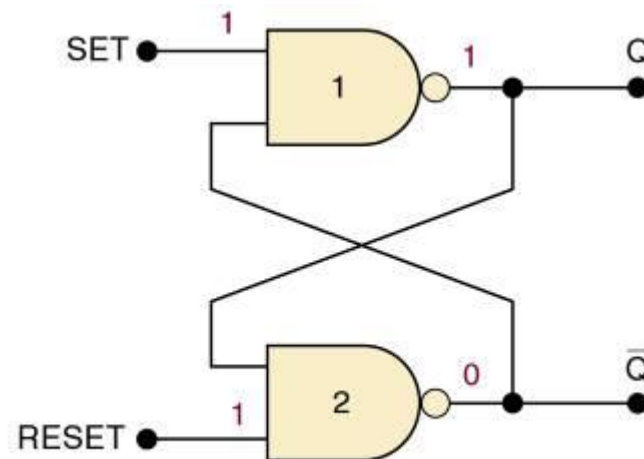
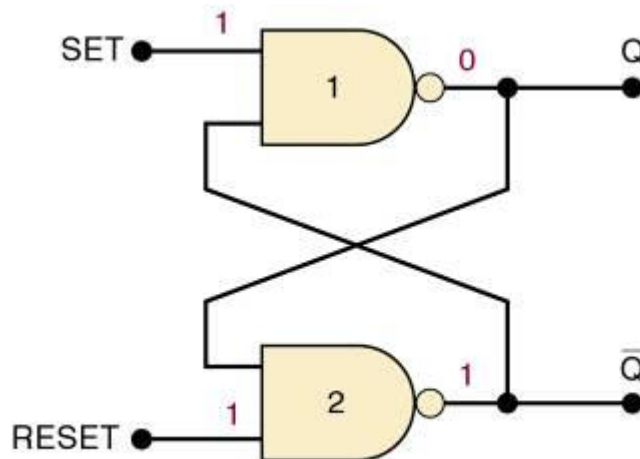
- The most important memory element is the **flip-flop (FF)**—made up of an assembly of logic gates.



The flip-flop is known by other names, including *latch* and *bistable multivibrator*.

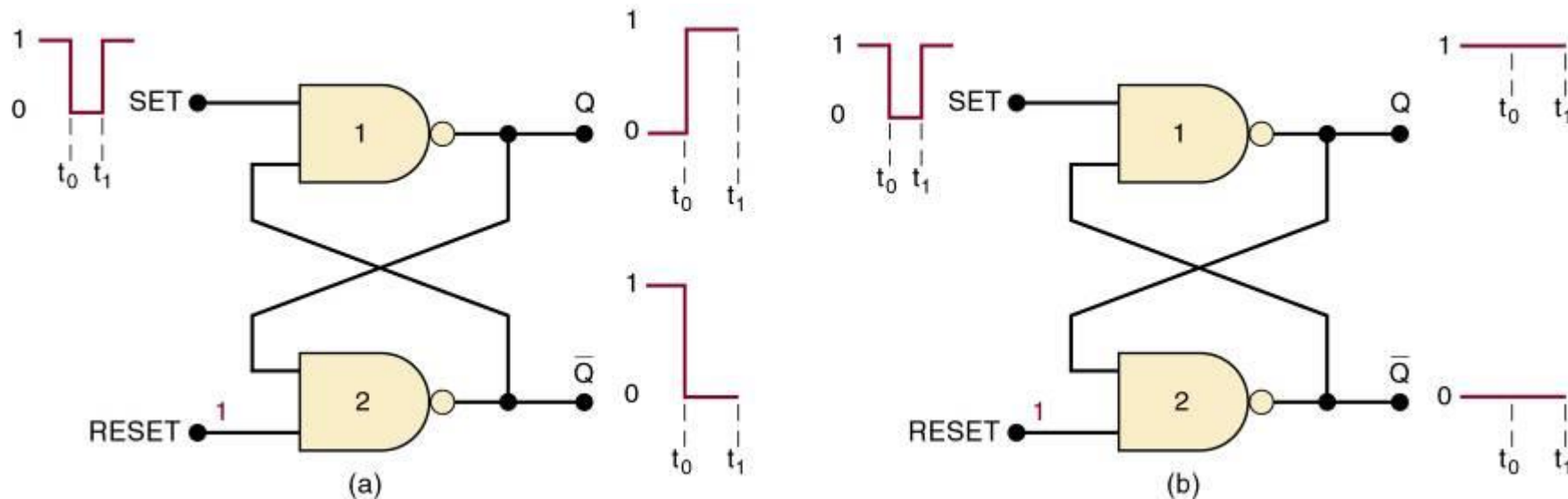
5-1 NAND Gate Latch

- The **NAND** gate latch or simply latch is a basic FF.
 - Inputs are *SET* and *CLEAR (RESET)*.
- Inputs are active-LOW—output will change when the input is pulsed LOW.
 - When the latch is set: $Q = 1$ and $\bar{Q} = 0$
 - When the latch is clear or reset: $Q = 0$ and $\bar{Q} = 1$



5-1 NAND Gate Latch – Setting the Latch (FF)

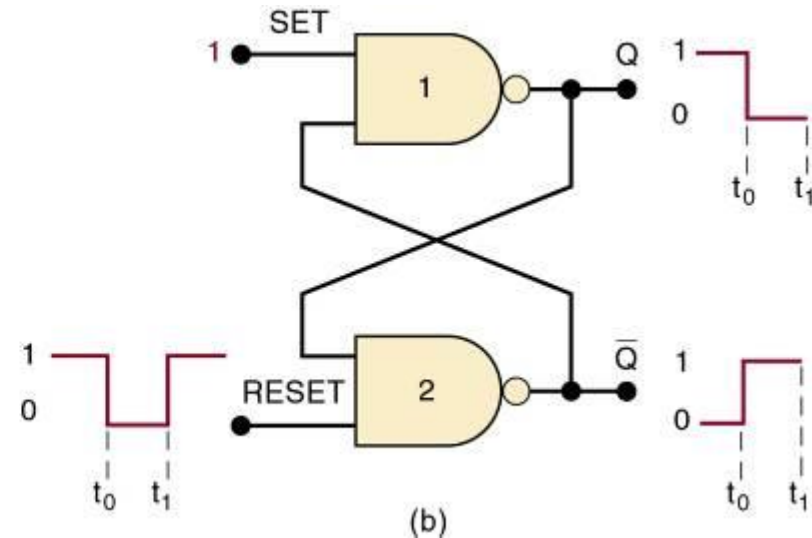
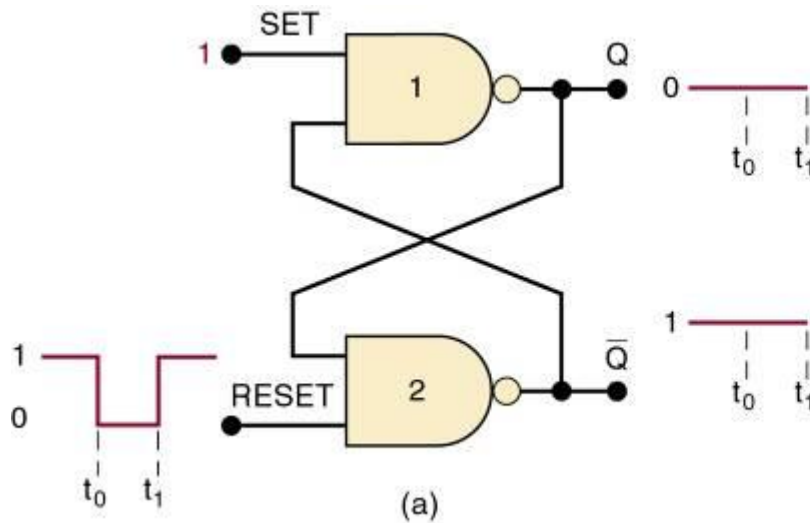
- Pulsing the SET input to the 0 state...
 - (a) $Q = 0$ prior to SET pulse.
 - (b) $Q = 1$ prior to SET pulse.



In both cases, Q ends up HIGH.

5-1 NAND Gate Latch – Resetting the Latch (FF)

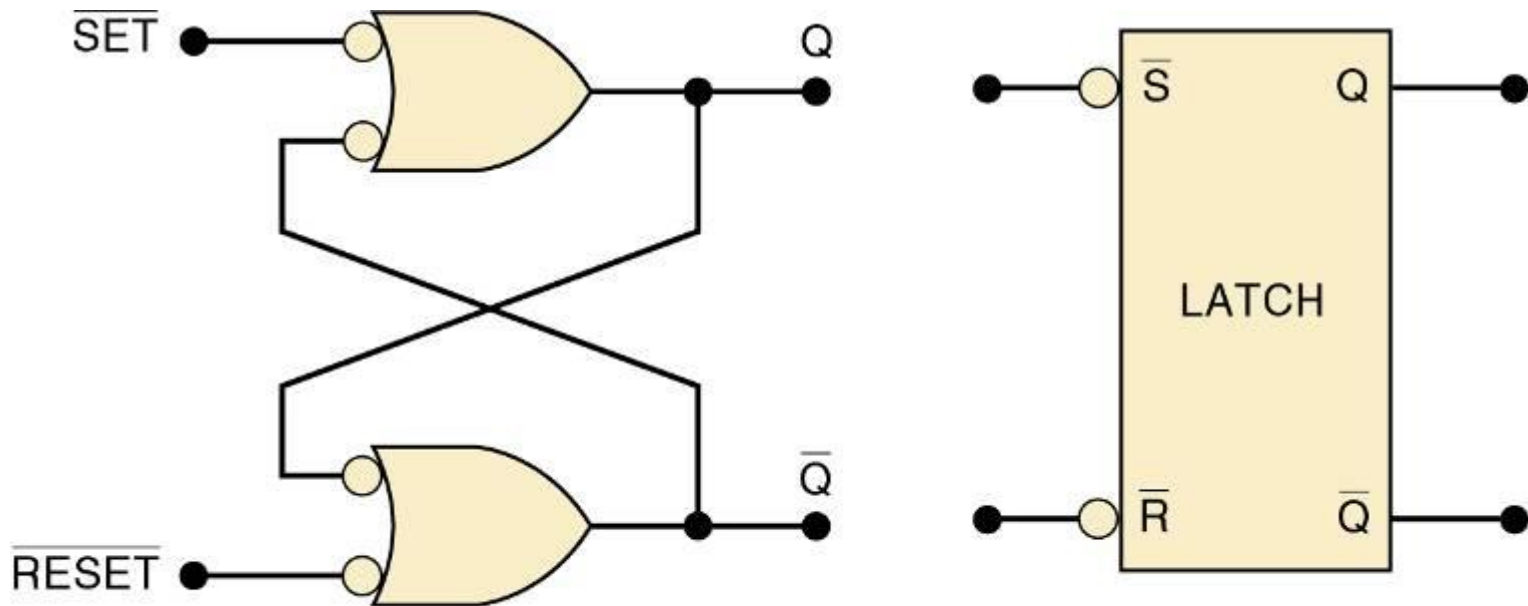
- Pulsing RESET LOW when...
 - (a) $Q = 0$ prior to the RESET pulse.
 - (b) $Q = 1$ prior to the RESET pulse.



In each case, Q ends up LOW.

5-1 NAND Gate Latch – Alternate Representations

NAND latch equivalent representations
and simplified block diagram.

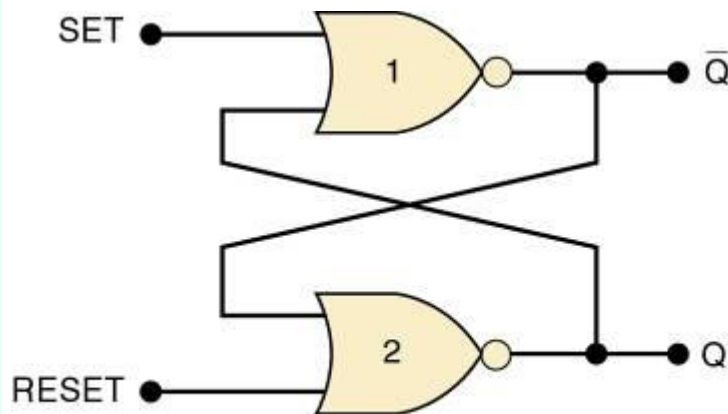


5-1 NAND Gate Latch - Summary

- Summary of the **NAND** latch:
 - **SET = 1, RESET = 1**—Normal resting state, outputs remain in state they were in prior to input.
 - **SET = 0, RESET = 1**—Output will go to $Q = 1$ and remains there, even after SET returns HIGH.
 - Called *setting* the latch.
 - **SET = 0, RESET = 0**—Will produce $Q = 0$ LOW and remains there, even after RESET returns HIGH.
 - Called *clearing* or *resetting* the latch.
 - **SET = 0, RESET = 0**—Tries to set and clear the latch at the same time, and produces $Q = \bar{Q} = 1$.
 - Output is unpredictable, and this input condition should not be used.

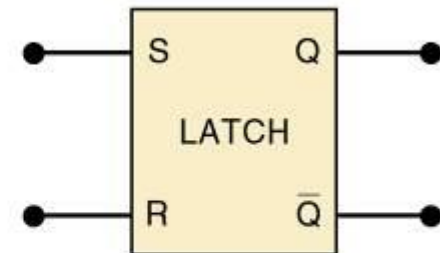
5-2 NOR Gate Latch

- Two cross-coupled **NOR** gates can be used as a **NOR** gate latch—similar to the **NAND** latch.
 - The **Q** and \bar{Q} outputs are reversed.



Set	Reset	Output
0	0	No change
1	0	Q = 1
0	1	Q = 0
1	1	Invalid*

*Produces $Q = \bar{Q} = 0$.



The SET and RESET inputs are active-HIGH.
Output will change when the input is pulsed HIGH.

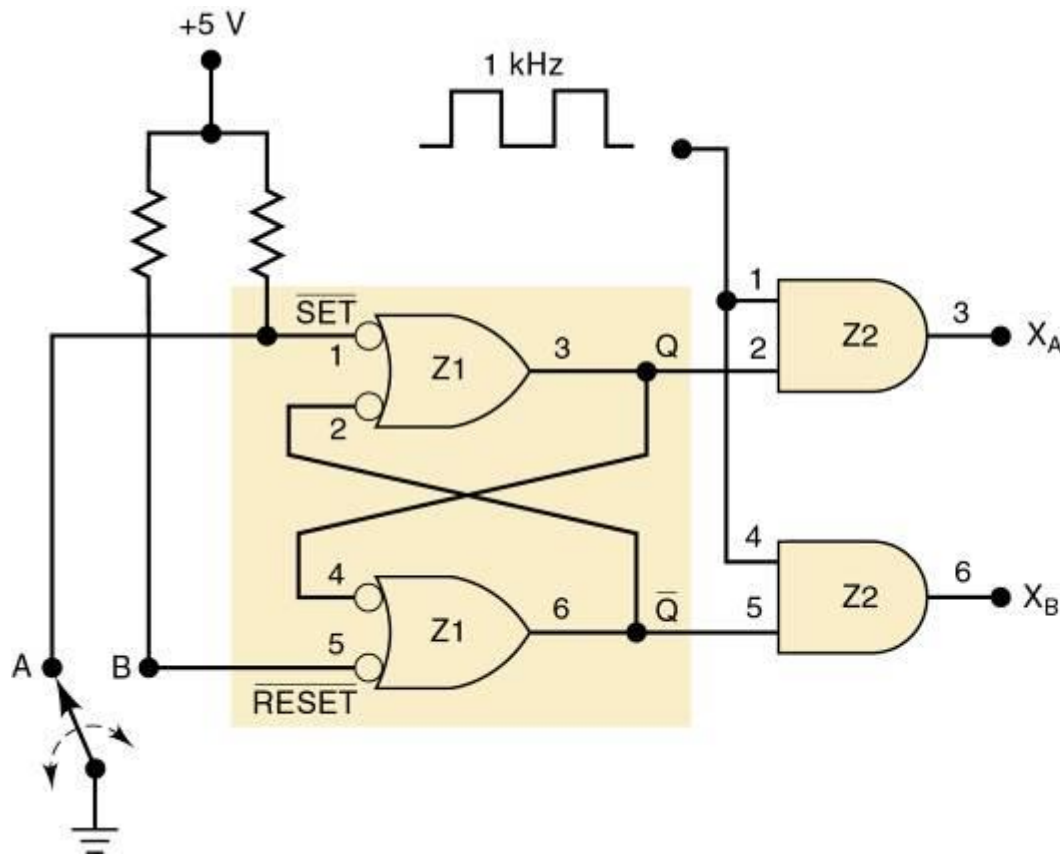
5-1 NOR Gate Latch - Summary

- Summary of the **NOR** latch:
 - **SET = 0, RESET = 0**—Normal resting state, No effect on output state.
 - **SET = 1, RESET = 0**—will always set $Q = 1$, where it remains even after SET returns to 0.
 - **SET = 0, RESET = 1**—will always clear $Q = 0$, where it remains even after RESET returns to 0.
 - **SET = 1, RESET = 1**—Tries to set and reset the latch at the same time, and produces $Q = \overline{Q} = 0$.
 - Output is unpredictable, and this input condition should not be used.

- When power is applied, it is not possible to predict the starting state of a flip-flop's output.
 - If SET and RESET inputs are in their inactive state.
- To start a latch or FF in a particular state, it must be *placed* in that state by momentarily activating the SET or RESET input, at the start of operation.
 - Often achieved by application of a pulse to the appropriate input.

5-3 Troubleshooting Case Study

Switch Position	$\overline{\text{SET}}$ (Z1-1)	$\overline{\text{RESET}}$ (Z1-5)	Q (Z1-3)	\overline{Q} (Z1-6)	X_A (Z2-3)	X_B (Z2-6)
A	LOW	HIGH	LOW	HIGH	LOW	Pulses
B	HIGH	LOW	LOW	HIGH	LOW	Pulses



Troubleshoot the circuit.

Switch position	X_A	X_B
A	Pulses	LOW
B	LOW	Pulses

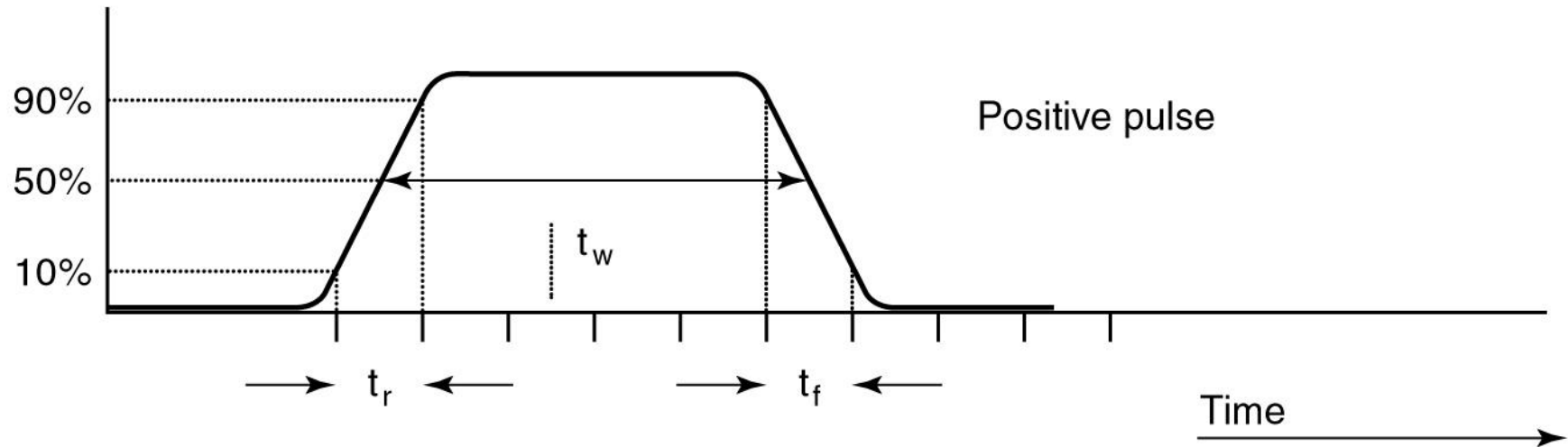
5-3 Troubleshooting Case Study

Switch Position	$\overline{\text{SET}}$ (Z1-1)	$\overline{\text{RESET}}$ (Z1-5)	Q (Z1-3)	\overline{Q} (Z1-6)	X_A (Z2-3)	X_B (Z2-6)
A	LOW	HIGH	LOW	HIGH	LOW	Pulses
B	HIGH	LOW	LOW	HIGH	LOW	Pulses

- There are several possibilities:
 - An internal open connection at Z1-1, which would prevent Q from responding to the input.
 - An internal component failure in NAND gate Z1 that prevents it from responding properly.
 - Q output is stuck LOW, which could be caused by:
 - Z1-3 internally shorted to ground
 - Z1-4 internally shorted to ground
 - Z2-2 internally shorted to ground
 - The Q node externally shorted to ground

5-4 Digital Pulses

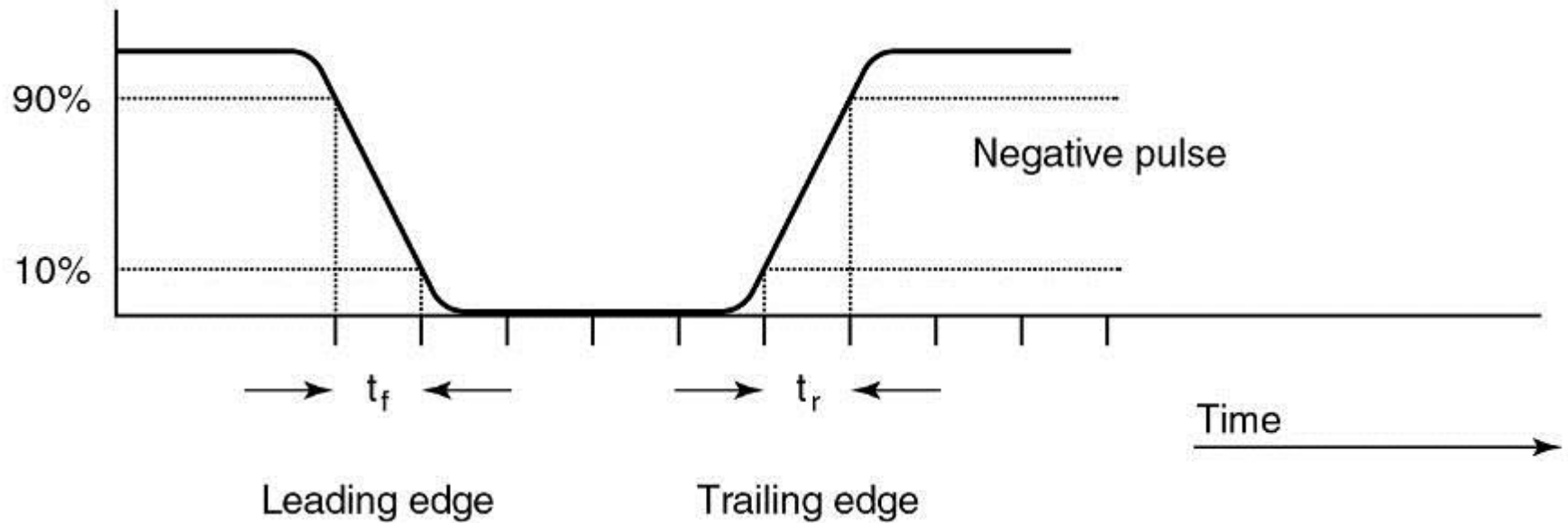
Signals that switch between active and inactive states are called pulse waveforms.



A positive pulse has an active-HIGH level.

5-4 Digital Pulses

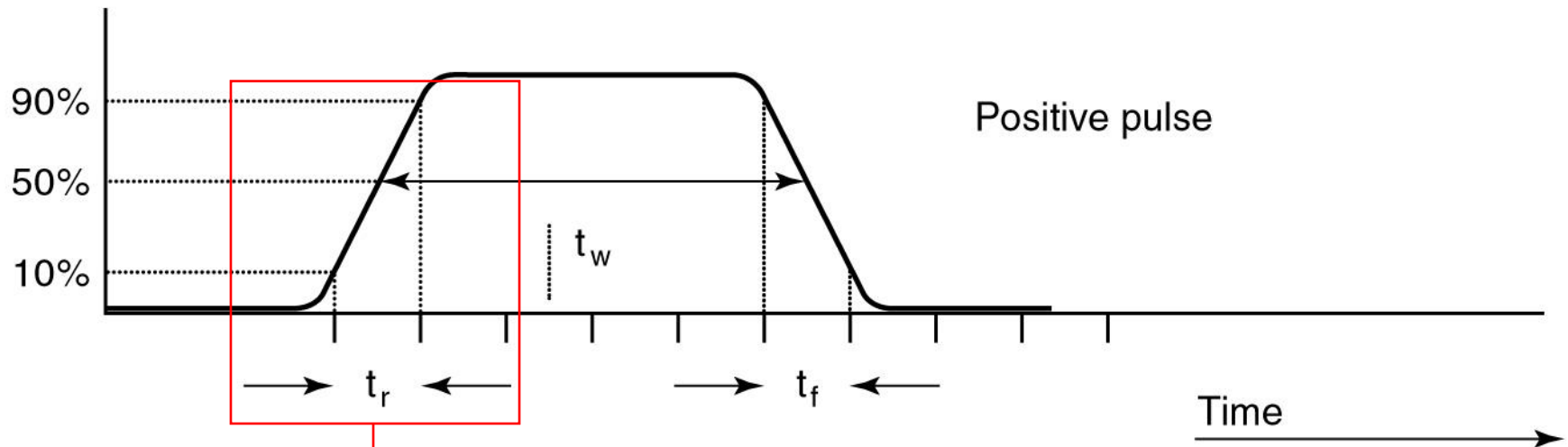
Signals that switch between active and inactive states are called pulse waveforms.



A negative pulse has an active-LOW level.

5-4 Digital Pulses

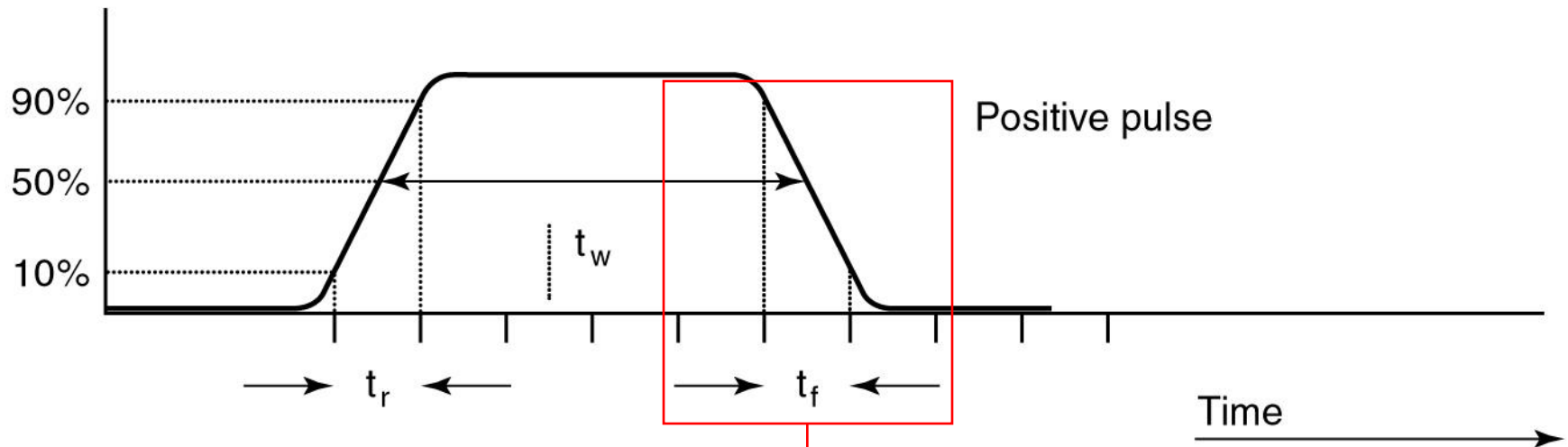
- In actual circuits it takes time for a pulse waveform to change from one level to the other.
 - Transition from LOW to HIGH on a positive pulse is called *rise time* (t_r).



**Measured between the 10% and 90% points
on the *leading edge* of the voltage waveform.**

5-4 Digital Pulses

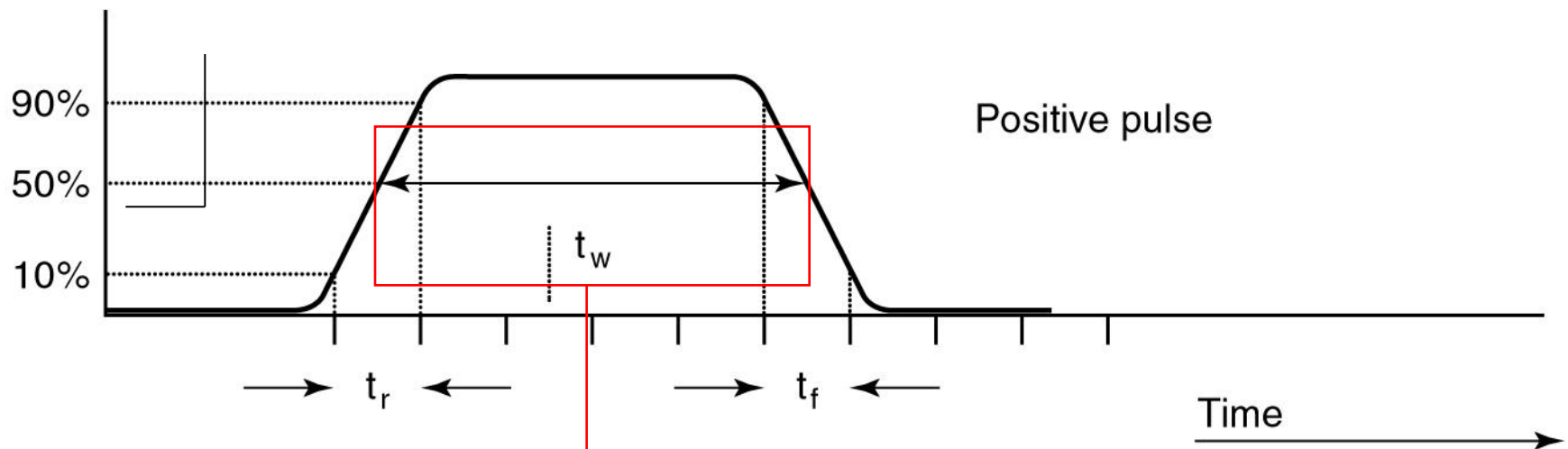
- In actual circuits it takes time for a pulse waveform to change from one level to the other.
 - Transition from HIGH to LOW on a positive pulse is called *fall time* (t_f).



Measured between the 90% and 10% points on the *trailing edge* of the voltage waveform.

5-4 Digital Pulses

- In actual circuits it takes time for a pulse waveform to change from one level to the other.
 - A pulse also has a *duration*—width—(t_w).



The time between the points when the leading and trailing edges are at 50% of the HIGH level voltage.

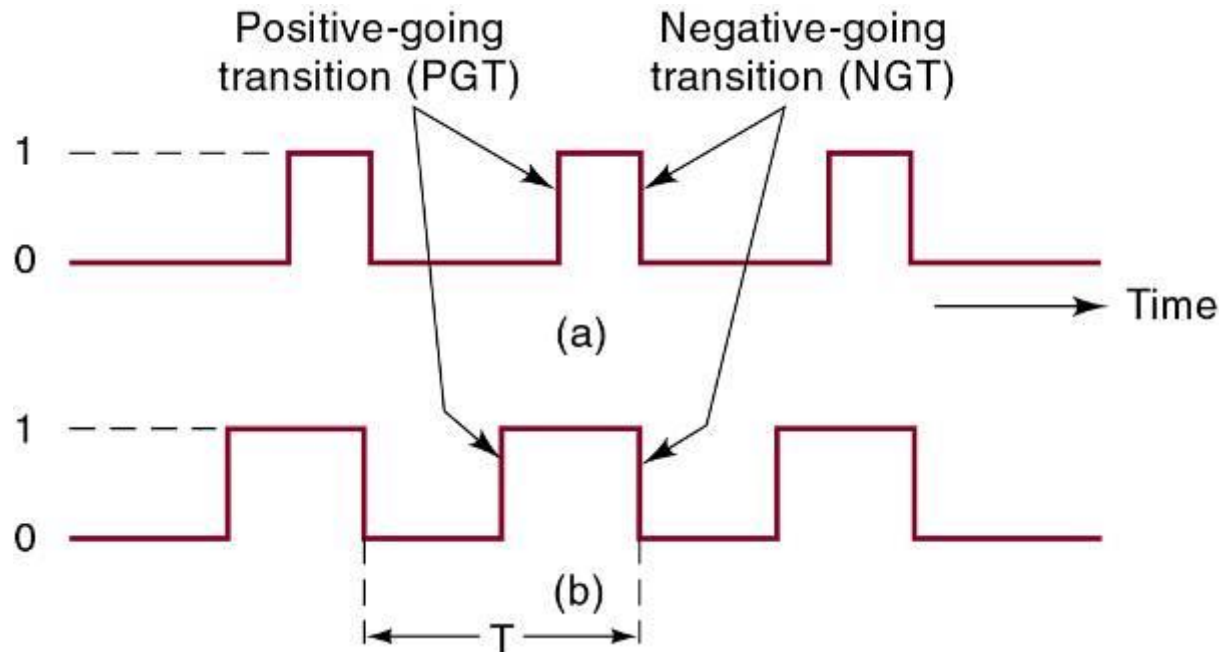
5-5 Clock Signals and Clocked Flip-Flops

- Digital systems can operate either *asynchronously* or *synchronously*.
 - **Asynchronous system**—outputs can change state at any time the input(s) change.
 - **Synchronous system**—output can change state only at a specific time in the clock cycle.

5-5 Clock Signals and Clocked Flip-Flops

- The clock signal is a rectangular pulse train or square wave.
 - Positive going transition (PGT)—clock pulse goes from 0 to 1.
 - Negative going transition (NGT)—clock pulse goes from 1 to 0.

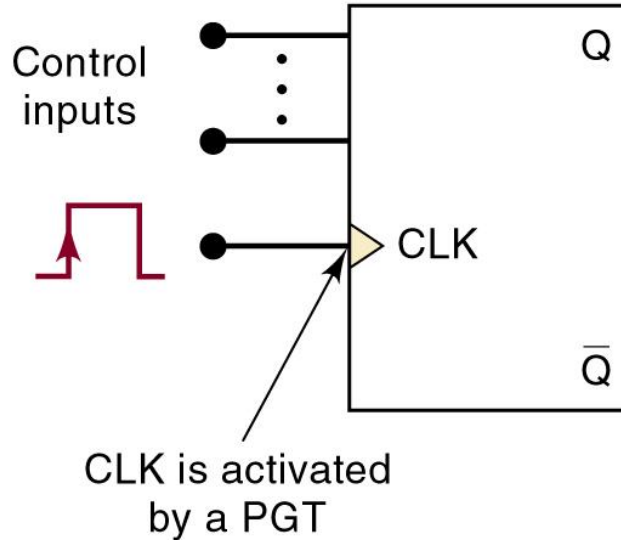
Transitions are also called *edges*.



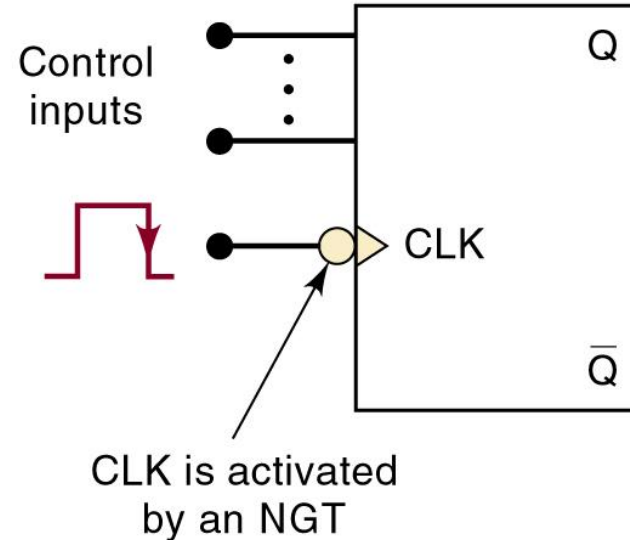
5-5 Clock Signals and Clocked Flip-Flops

- Clocked FFs change state on one or the other clock transitions.
 - Clock inputs are labeled CLK, CK, or CP.

A small triangle at the CLK input indicates that the input is activated with a PGT.

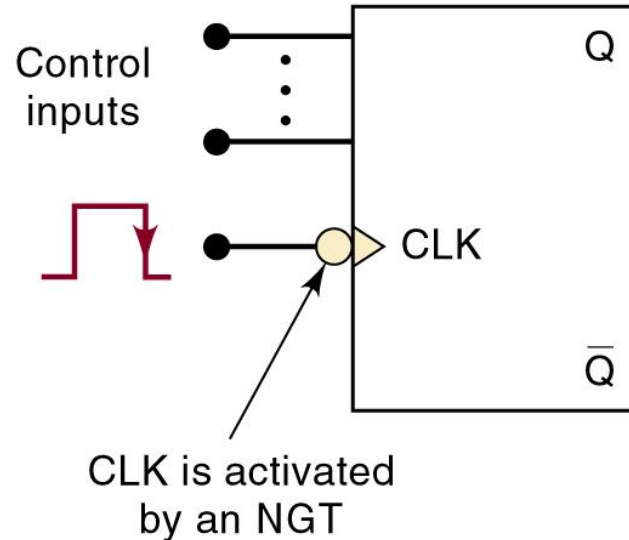
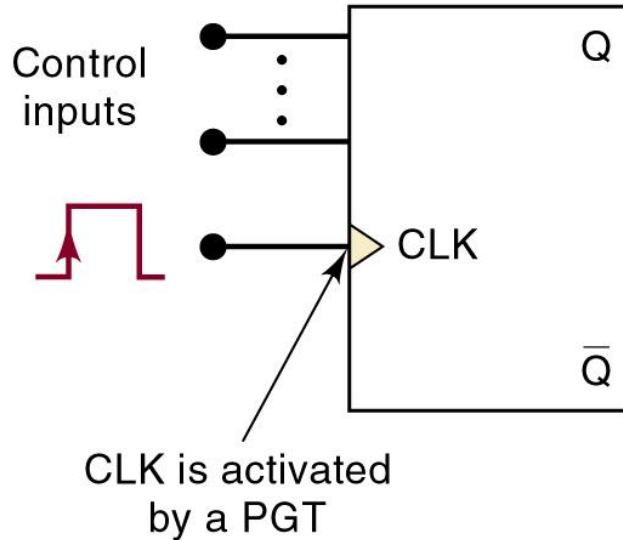


A bubble and a triangle indicates that the CLK input is activated with a NGT.



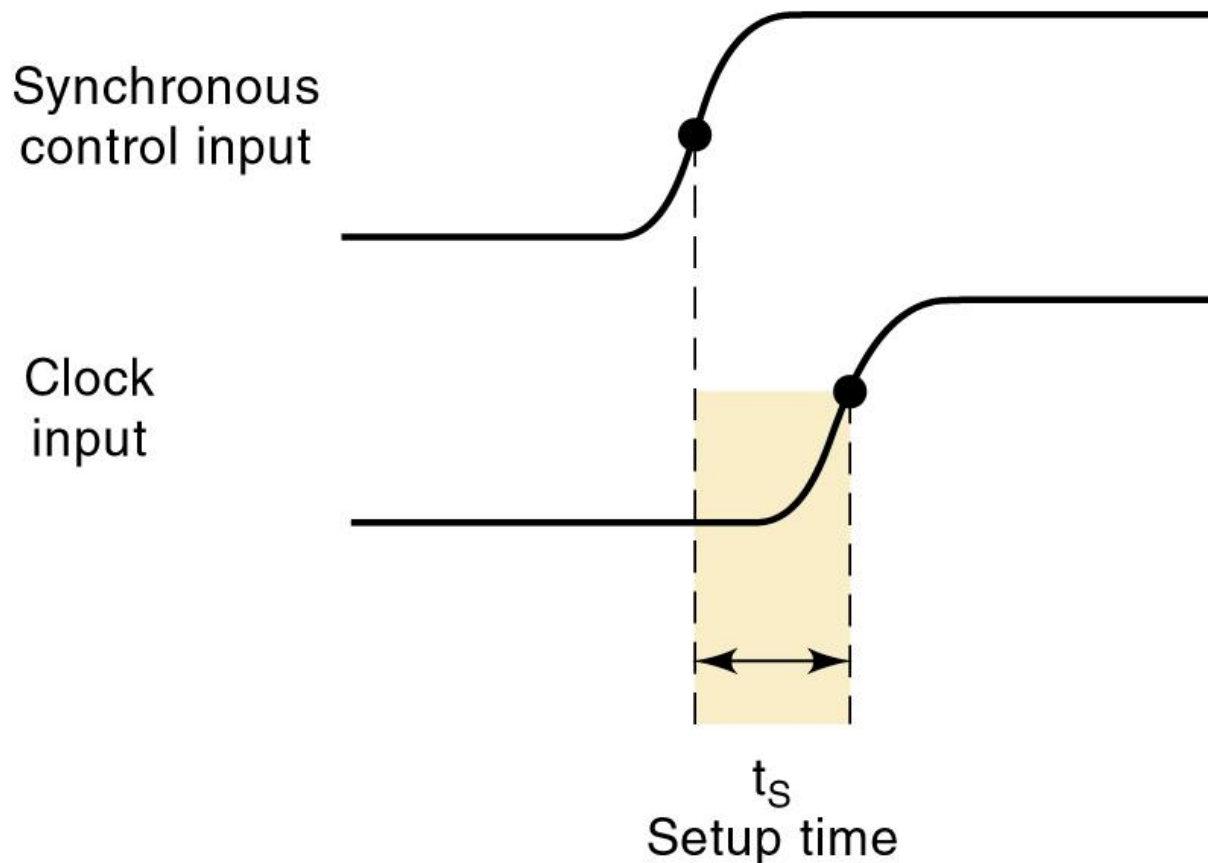
5-5 Clock Signals and Clocked Flip-Flops

- Control inputs have an effect on the output only at the active clock transition (NGT or PGT)—also called synchronous control inputs.
 - The control inputs get the outputs ready to change, but the change is not triggered until the CLK edge.



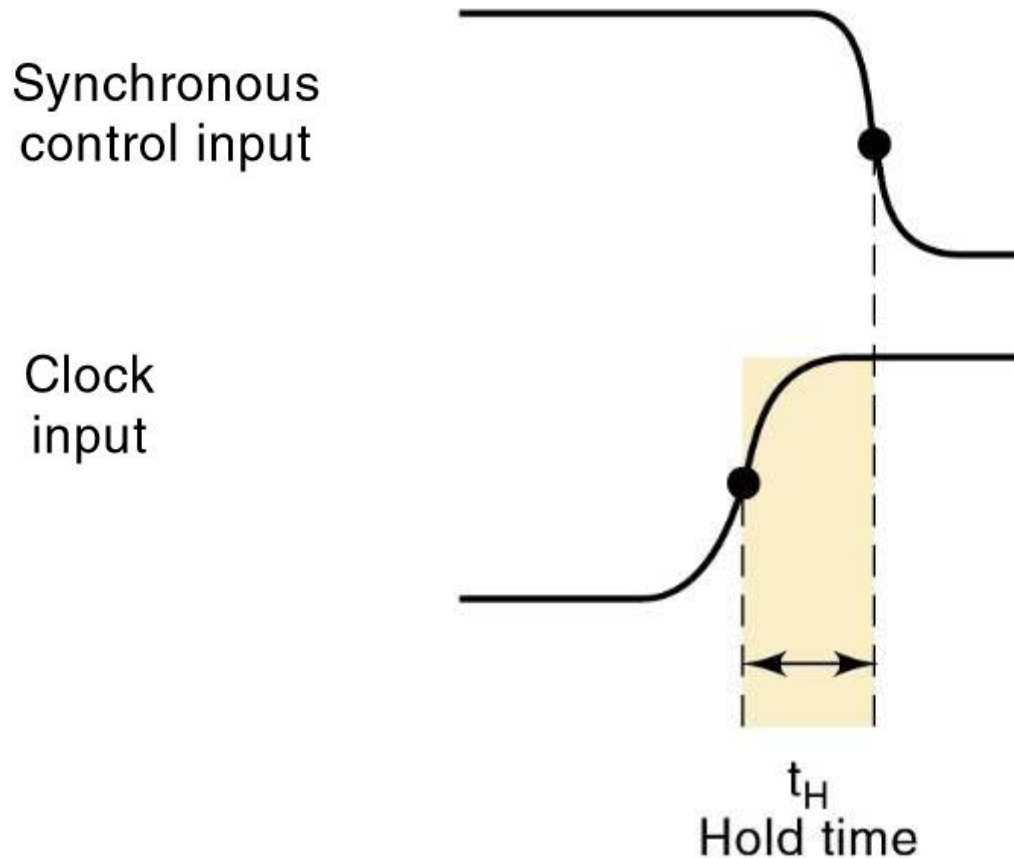
5-5 Clock Signals and Clocked Flip-Flops

- *Setup time* (t_s) is the minimum time interval before the active CLK transition that the control input must be kept at the proper level.



5-5 Clock Signals and Clocked Flip-Flops

- *Hold time* (t_H) is the time following the active transition of the CLK, during which the control input must be kept at the proper level.

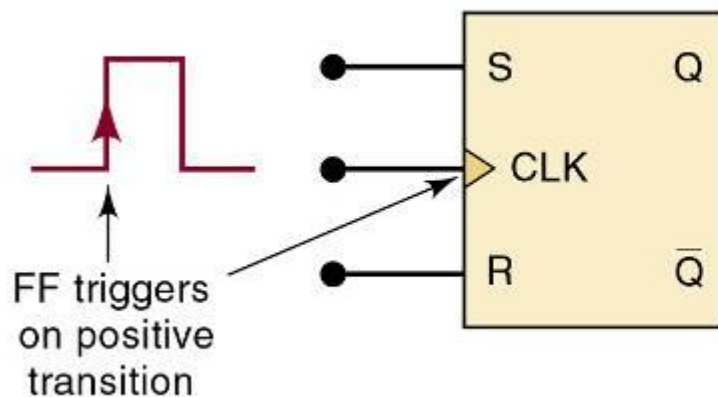


5-6 Clocked S-R Flip-Flop

- The S and R inputs are synchronous *control* inputs, which control the state the FF will go to when the clock pulse occurs.
 - The CLK input is the **trigger** input that causes the FF to change states according to the S and R inputs.
- SET-RESET (or SET-CLEAR) FF will change states at positive- or negative-going clock edges.

5-6 Clocked S-R Flip-Flop

A clocked S-R flip-flop triggered by the positive-going edge of the clock signal.



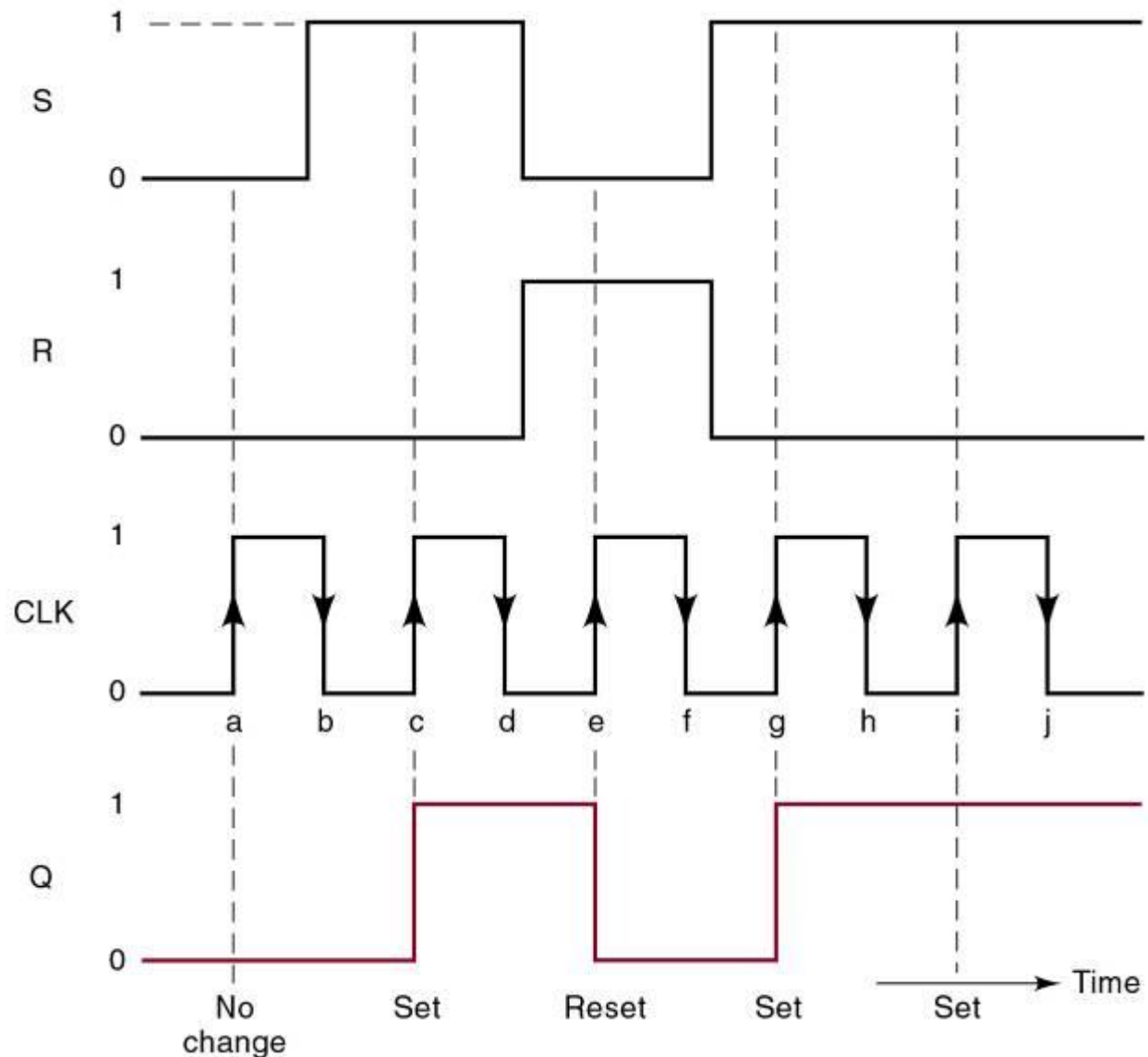
Inputs			Output
S	R	CLK	Q
0	0	↑	Q_0 (no change)
1	0	↑	1
0	1	↑	0
1	1	↑	Ambiguous

Q_0 is output level prior to ↑ of CLK.
↓ of CLK produces no change in Q.

The S and R inputs control the state of the FF in the same manner as described earlier for the NOR gate latch, but the FF does *not* respond to these inputs *until* the occurrence of the PGT of the clock signal.

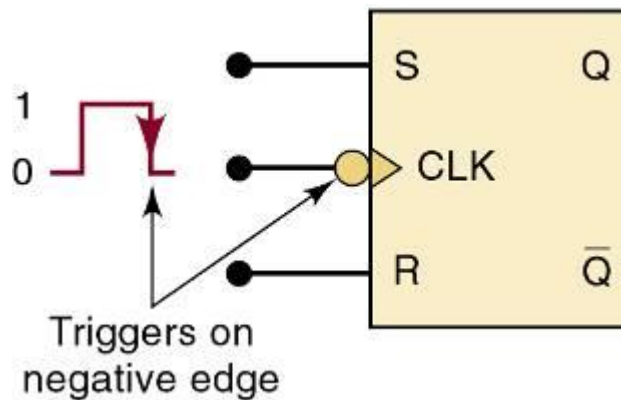
5-6 Clocked S-R Flip-Flop

Waveforms of the operation of a clocked S-R flip-flop triggered by the positive-going edge of a clock pulse.



5-6 Clocked S-R Flip-Flop

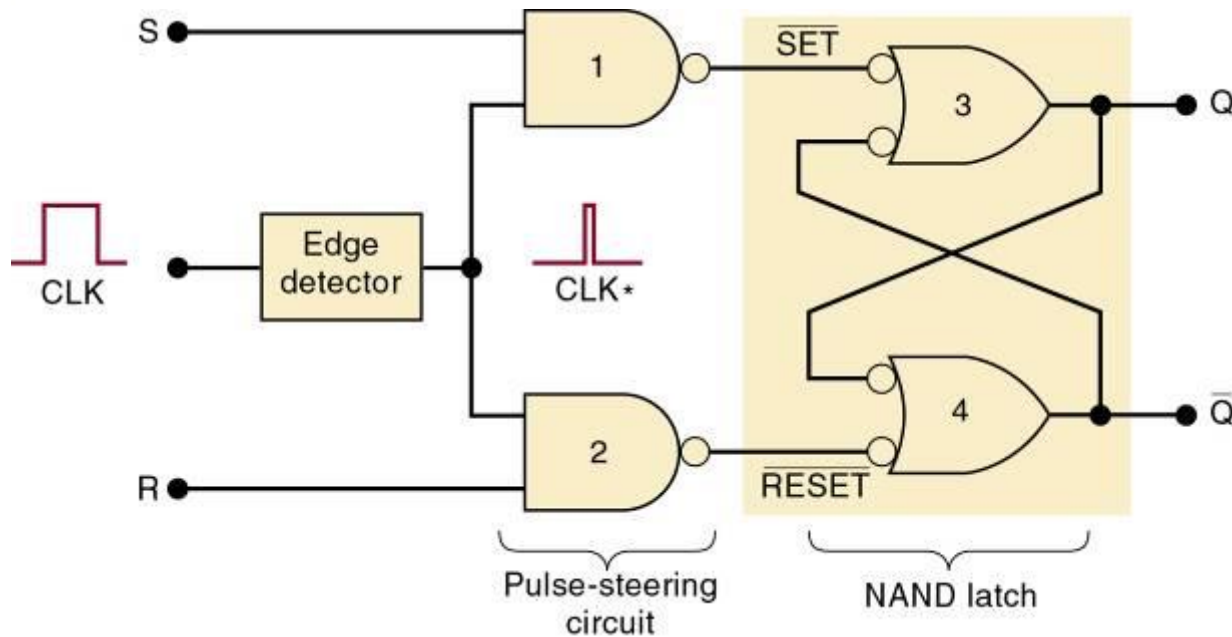
A clocked S-R flip-flop triggered by the negative-going edge of the clock signal.



Inputs			Output
S	R	CLK	Q
0	0	↓	Q_0 (no change)
1	0	↓	1
0	1	↓	0
1	1	↓	Ambiguous

Both positive-edge and negative-edge triggering FFs are used in digital systems.

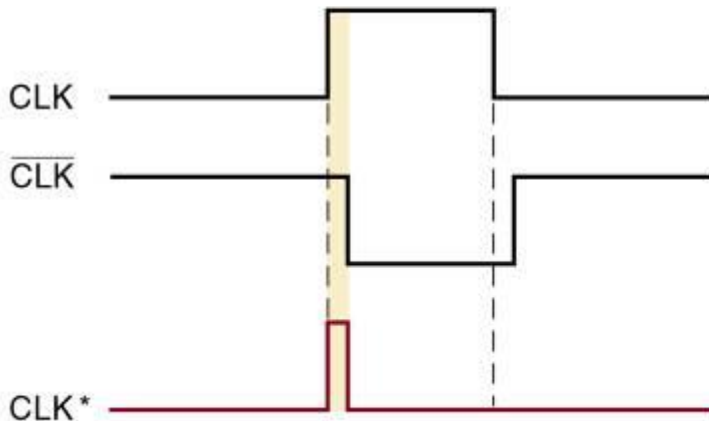
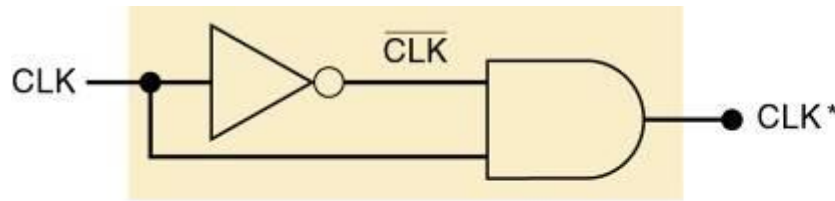
5-6 Clocked S-R Flip-Flop – Internal Circuitry



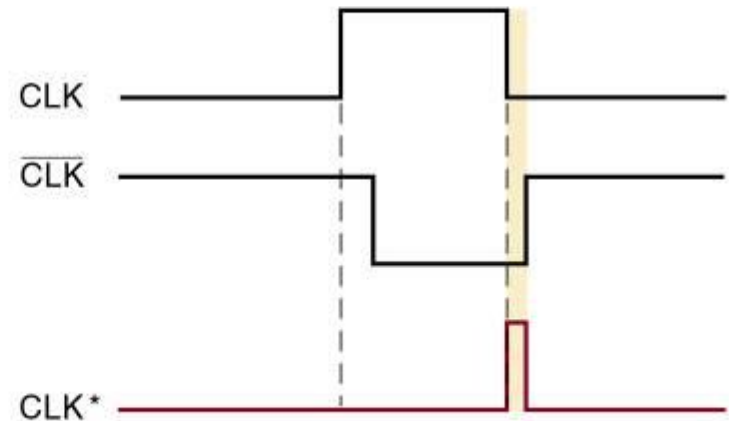
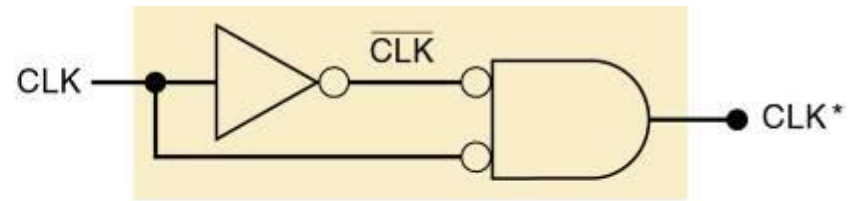
- An edge-triggered S-R flip-flop circuit features:
 - A basic **NAND** gate latch formed by **NAND-3** and **NAND-4**.
 - A **pulse-steering circuit** formed by **NAND-1** and **NAND-2**.
 - An **edge-detector circuit**.

5-6 Clocked S-R Flip-Flop – Internal Circuitry

- Implementation of edge-detector circuits used in edge-triggered flip-flops:
 - (a) PGT; (b) NGT.



(a)



(b)

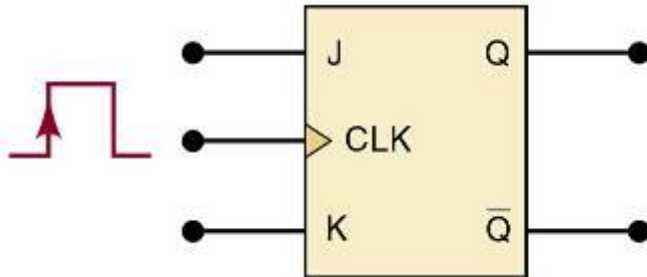
The duration of the CLK^* pulses is typically 2–5 ns.

5-7 Clocked J-K Flip-Flop

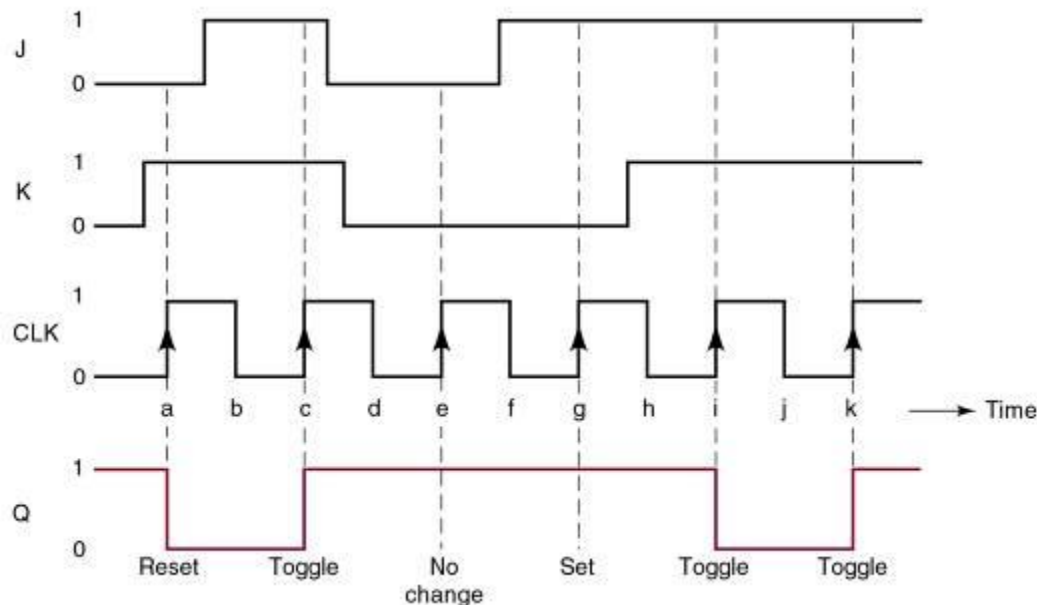
- Operates like the S-R FF.
 - J is SET, K is CLEAR.
- When J and K are both HIGH, output is toggled to the opposite state.
 - May be positive going or negative going clock trigger.
- Much more versatile than the S-R flip-flop, as it has no ambiguous states.
 - Has the ability to do everything the S-R FF does, plus operates in toggle mode.

5-7 Clocked J-K Flip-Flop

Clocked J-K flip-flop that responds only to the positive edge of the clock.

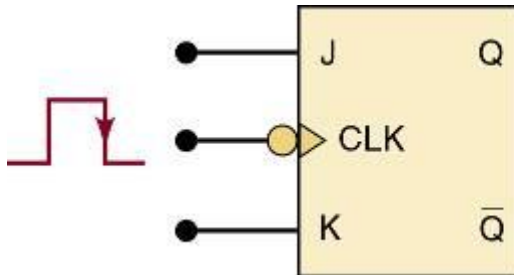


J	K	CLK	Q
0	0	↑	Q_0 (no change)
1	0	↑	1
0	1	↑	0
1	1	↑	$\overline{Q_0}$ (toggles)



5-7 Clocked J-K Flip-Flop

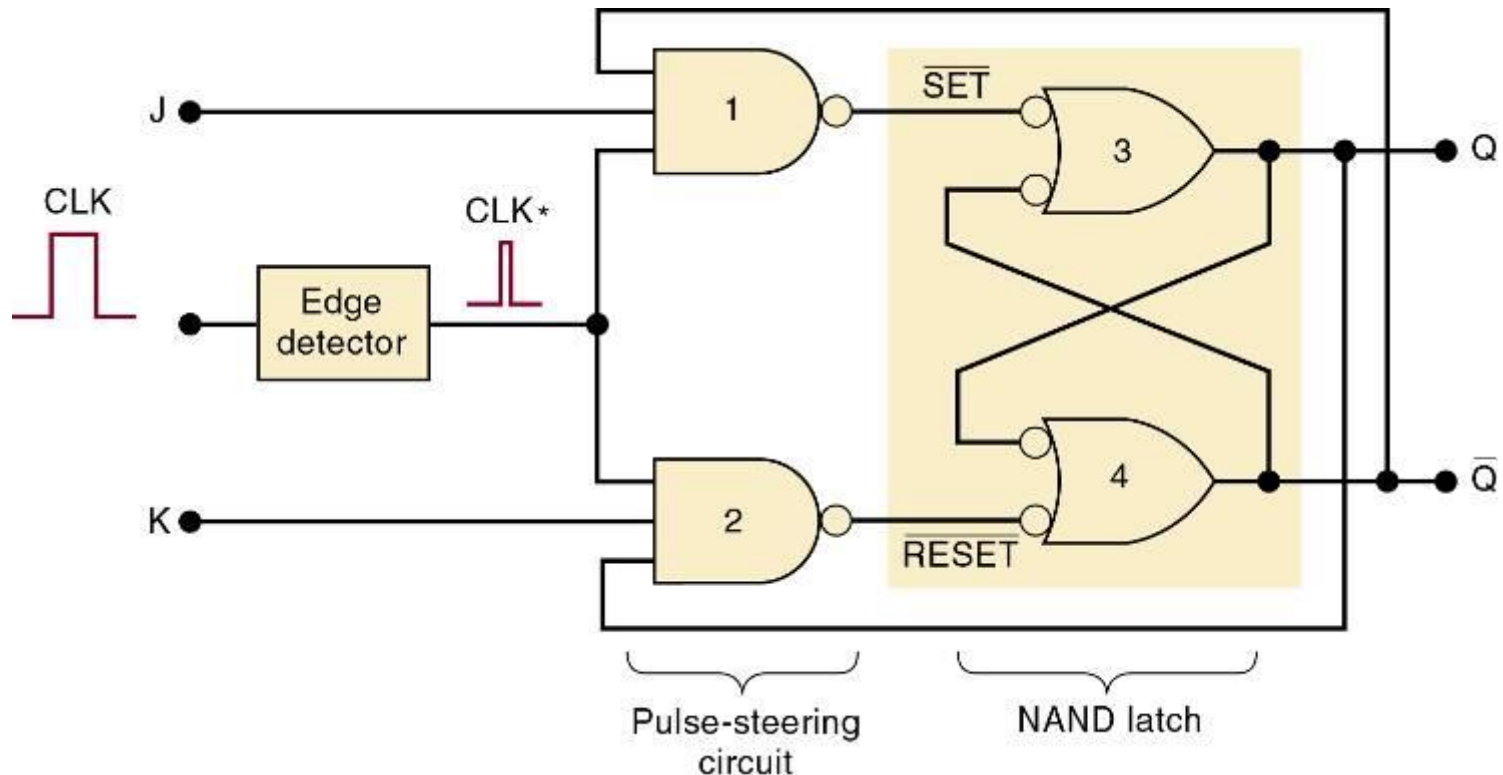
Clocked J-K flip-flop that responds only to the negative edge of the clock.



J	K	CLK	Q
0	0	↓	Q_0 (no change)
1	0	↓	1
0	1	↓	0
1	1	↓	$\overline{Q_0}$ (toggles)

5-7 Clocked J-K Flip-Flop – Internal Circuitry

- The internal circuitry of an edge-triggered J-K flip-flop contains the same three sections as the edge-triggered S-R flip-flop.

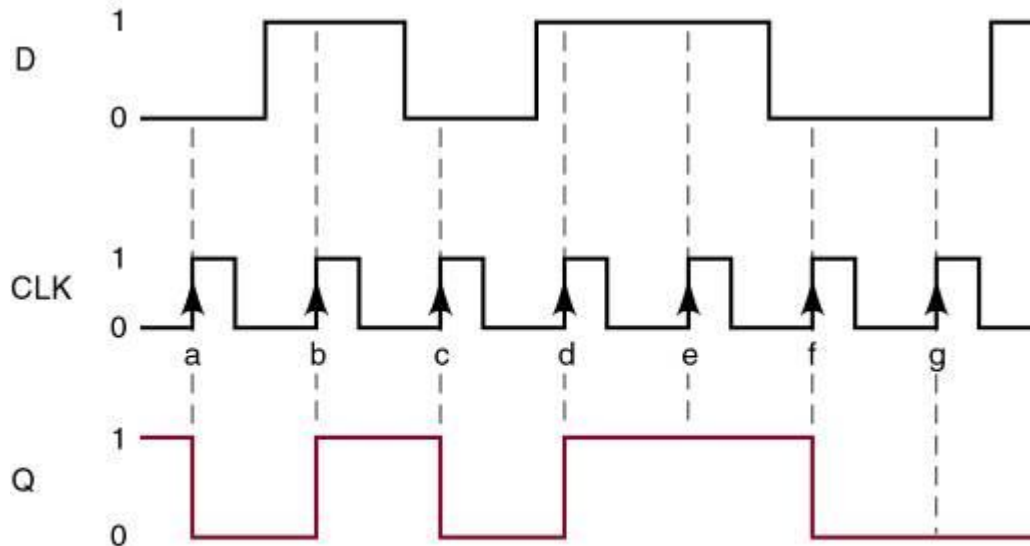
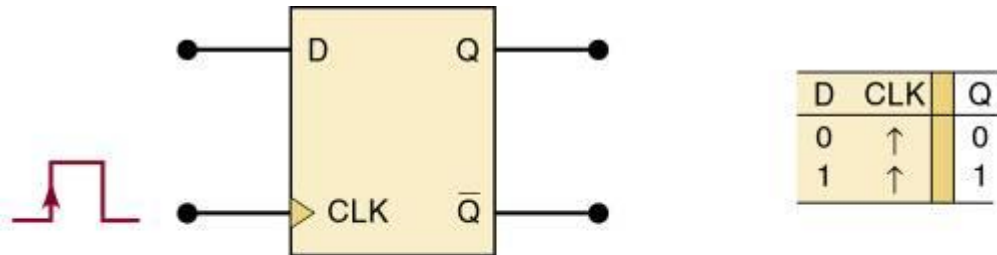


5-8 Clocked D Flip-Flop

- One data input—output changes to the value of the input at either the positive- or negative-going clock trigger.
- May be implemented with a J-K FF by tying the J input to the K input through an inverter.
- Useful for parallel data transfer.

5-8 Clocked D Flip-Flop

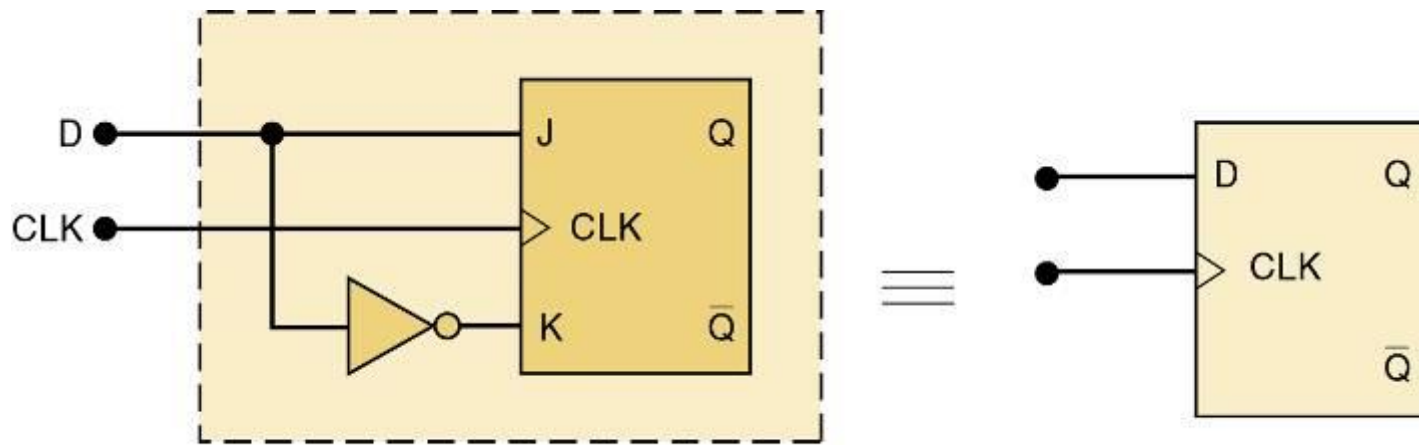
D flip-flop that triggers only on positive-going transitions.



5-8 Clocked D Flip-Flop - Implementation

- An edge-triggered D flip-flop is implemented by adding a single INVERTER to the edge-triggered J-K flip-flop.
 - The same can be done to convert a S-R flip-flop to a D flip-flop.

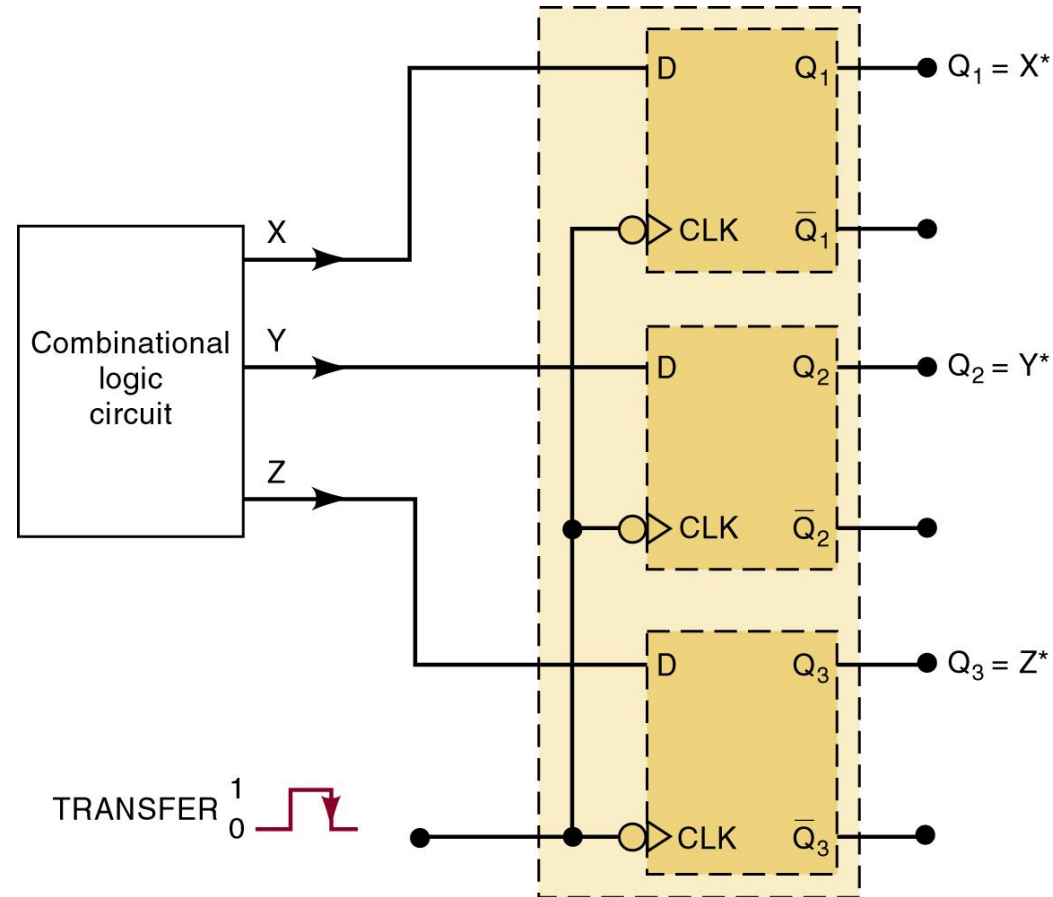
Edge-triggered D flip-flop implementation from a J-K flip-flop.



5-8 Clocked D Flip-Flop – Parallel Data Transfer

Outputs X , Y , Z are to be transferred to FFs Q_1 , Q_2 , and Q_3 for storage.

Using D flip-flops, levels present at X , Y & Z will be transferred to Q_1 , Q_2 & Q_3 , upon application of a TRANSFER pulse to the common CLK inputs.

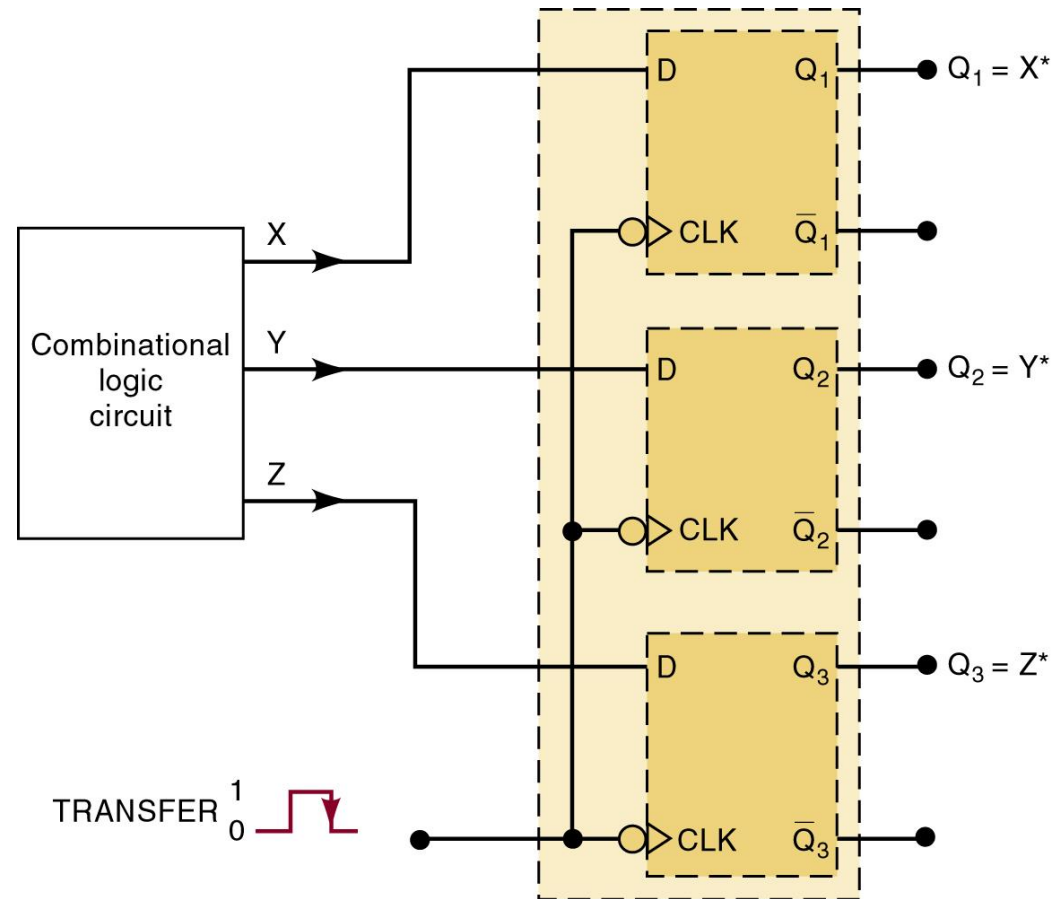


*After occurrence of NGT

5-8 Clocked D Flip-Flop – Parallel Data Transfer

Outputs X , Y , Z are to be transferred to FFs Q_1 , Q_2 , and Q_3 for storage.

This is an example of **parallel data transfer** of binary data—the three bits X , Y & Z are transferred *simultaneously*.



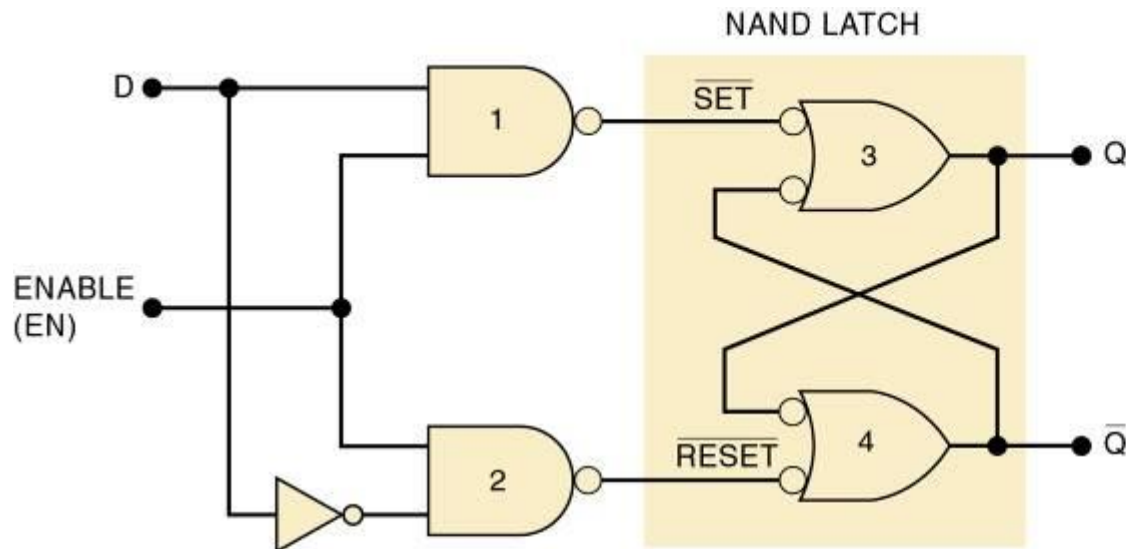
*After occurrence of NGT

5-9 D Latch (Transparent Latch)

- The edge-triggered D flip-flop uses an edge-detector circuit to ensure the output responds to the *D* input *only* on active transition of the clock.
 - If this edge detector is not used, the resultant circuit operates as a **D latch**.

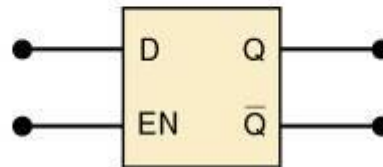
5-9 D Latch (Transparent Latch)

D latch structure, function table, logic symbol.



Inputs		Output
EN	D	Q
0	X	Q ₀ (no change)
1	0	0
1	1	1

"X" indicates "don't care."
Q₀ is state Q just prior to EN going LOW.



5-9 D Latch (Transparent Latch)

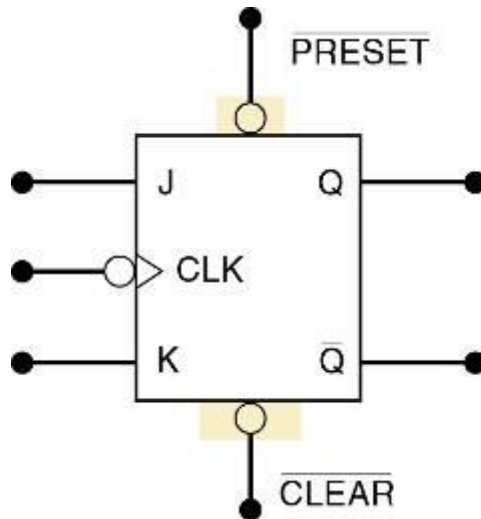
- The circuit contains the **NAND** latch and the steering **NAND** gates 1 and 2 *without* the edge-detector circuit.
- The common input to the steering gates is called an *enable* input (abbreviated *EN*)—rather than a clock input.
 - Its effect on the Q and \bar{Q} outputs is not restricted to occurring only on its transitions

5-10 Asynchronous Inputs

- Inputs that depend on the clock are synchronous.
- Most clocked FFs have asynchronous inputs that do not depend on the clock.
 - Labels PRE & CLR are used for asynchronous inputs.
- Active-LOW asynchronous inputs will have a bar over the labels and inversion bubbles.
- If the asynchronous inputs are not used they will be tied to their inactive state.

5-10 Asynchronous Inputs

Clocked J-K flip-flop with asynchronous inputs.



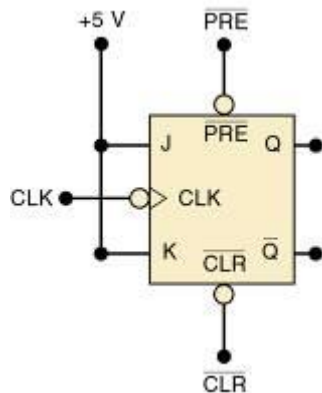
J	K	Clk	$\overline{\text{PRE}}$	$\overline{\text{CLR}}$	Q
0	0	↓	1	1	Q (no change)
0	1	↓	1	1	0 (Synch reset)
1	0	↓	1	1	1 (Synch set)
1	1	↓	1	1	\bar{Q} (Synch toggle)
x	x	x	1	1	Q (no change)
x	x	x	1	0	0 (asynch clear)
x	x	x	0	1	1 (asynch preset)
x	x	x	0	0	(Invalid)

5-10 Asynchronous Inputs - Designations

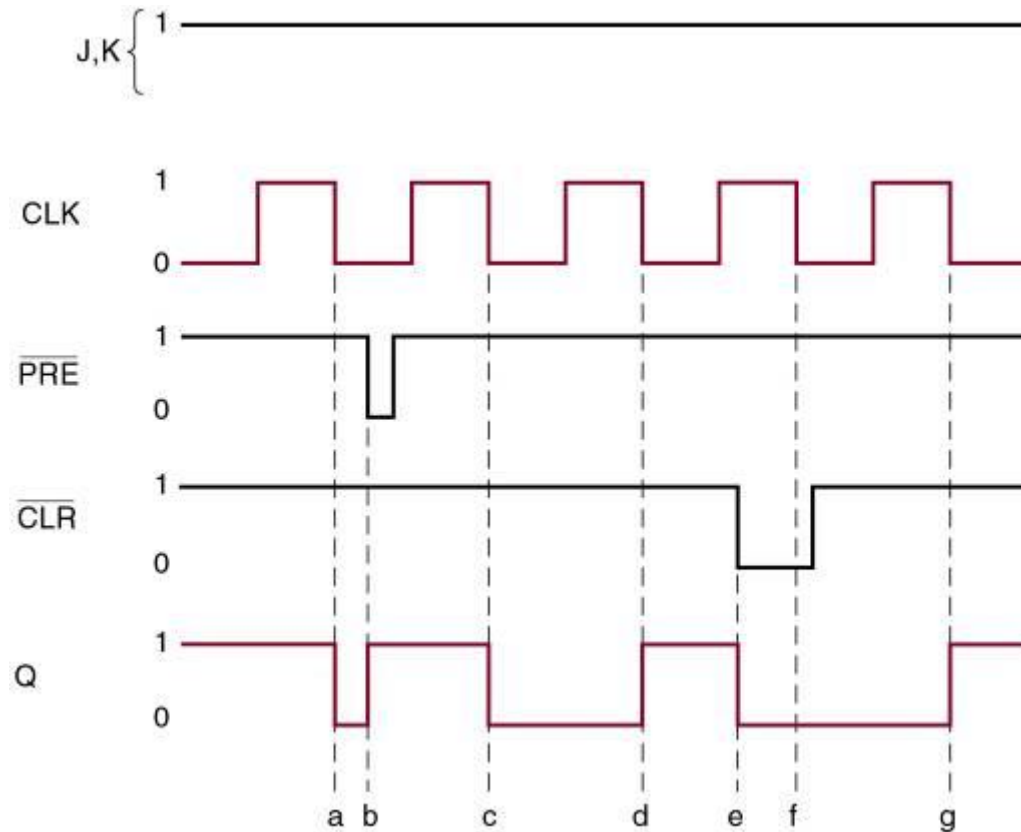
- IC manufacturers do not agree on nomenclature for asynchronous inputs.
 - The most common designations are *PRE* (PRESET) and *CLR* (CLEAR).
 - Clearly distinguished from synchronous SET & RESET.
 - Labels such as *S-D* (direct SET) and *R-D* (direct RESET) are also used.

5-10 Asynchronous Inputs

A J-K FF that responds to a NGT on its clock input and has active-LOW asynchronous inputs.



Point	Operation
a	Synchronous toggle on NGT of CLK
b	Asynchronous set on $\overline{PRE} = 0$
c	Synchronous toggle
d	Synchronous toggle
e	Asynchronous clear on $\overline{CLR} = 0$
f	\overline{CLR} overrides the NGT of CLK
g	Synchronous toggle

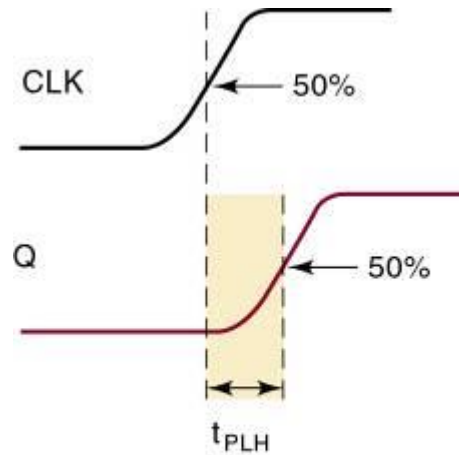


5-11 Flip-Flop Timing Considerations - Parameters

- Important timing parameters:
 - Setup and hold times
 - **Propagation delay**—time for a signal at the input to be shown at the output. (t_{PLH} and t_{PHL})
 - **Maximum clocking frequency**—Highest clock frequency that will give a reliable output. (f_{MAX})
 - **Clock pulse HIGH and LOW times**—minimum clock-time between HIGH/LOW changes. ($t_w(L)$; $t_w(H)$)
 - **Asynchronous Active Pulse Width**—time the clock must HIGH before going LOW, and LOW before going HIGH.
 - **Clock transition times**—maximum time for clock transitions,
 - Less than 50 ns for TTL ; 200 ns for CMOS

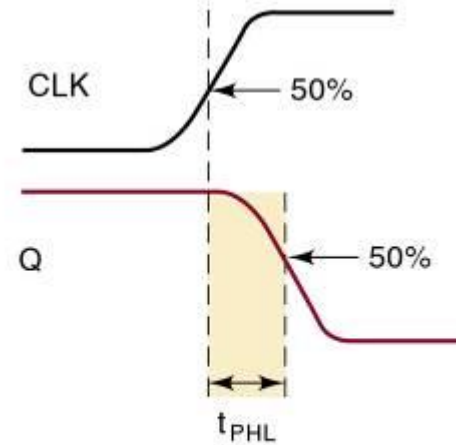
5-11 Flip-Flop Timing Considerations - Parameters

FF propagation delays.



Delay going from
LOW to HIGH

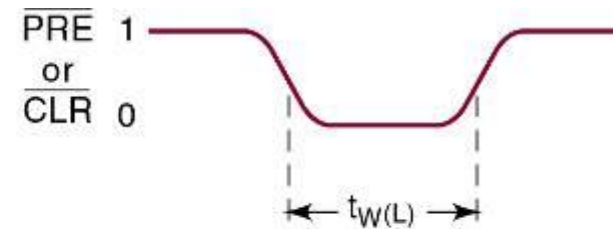
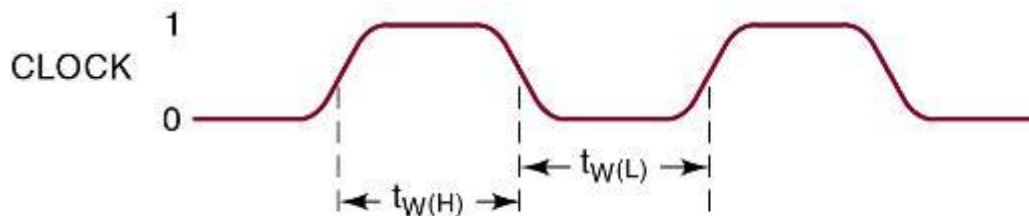
(a)



Delay going from
HIGH to LOW

(b)

Clock Pulse HIGH and LOW and Asynch pulse width.



5-11 Flip-Flop Timing Considerations – Actual IC Values

7474	Dual edge-triggered D flip-flop (standard TTL)
74LS112	Dual edge-triggered J-K flip-flop (low-power Schottky TTL)
74C74	Dual edge-triggered D flip-flop (metal-gate CMOS)
74HC112	Dual edge-triggered J-K flip-flop (high-speed CMOS)

Timing values for FFs from manufacturer data books.

All of the listed values are *minimum* values, except propagation delays, which are *maximum* values.

		TTL		CMOS	
		7474	74LS112	74C74	74HC112
t_S		20 ns	20 ns	60 ns	25 ns
t_H		5	0	0	0
t_{PHL}	from <i>CLK</i> to <i>Q</i>	40	24	200	31
t_{PLH}	from <i>CLK</i> to <i>Q</i>	25	16	200	31
t_{PHL}	from <i>CLR</i> to <i>Q</i>	40	24	225	41
t_{PLH}	from <i>PRE</i> to <i>Q</i>	25	16	225	41
$t_{W(L)}$	<i>CLK</i> LOW time	37	15	100	25
$t_{W(H)}$	<i>CLK</i> HIGH time	30	20	100	25
$t_{W(L)}$	at <i>PRE</i> or <i>CLR</i>	30	15	60	25
f_{MAX}	in MHz	15	30	5	20

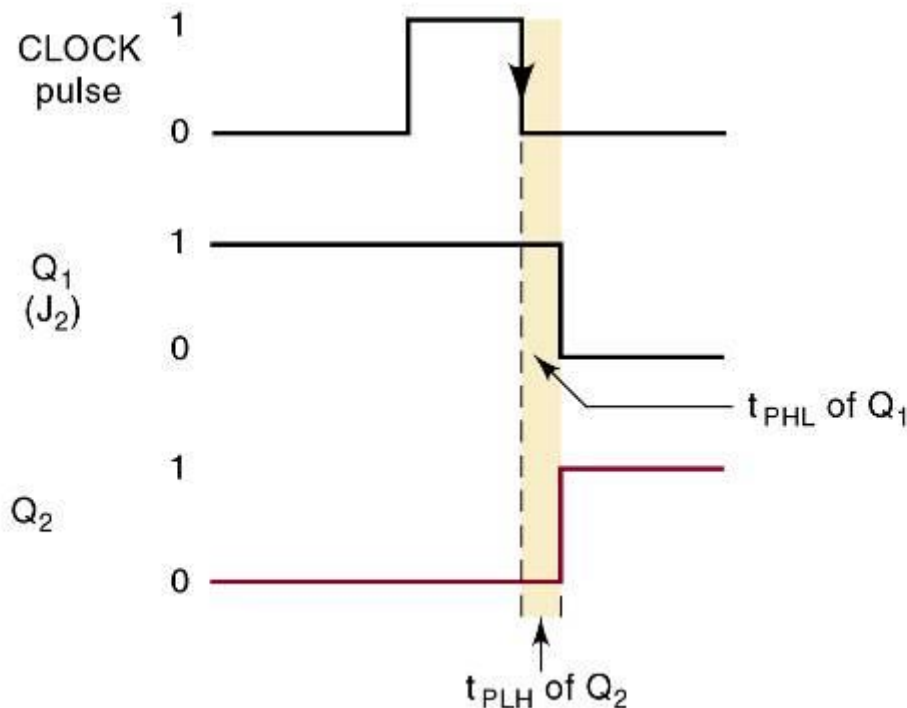
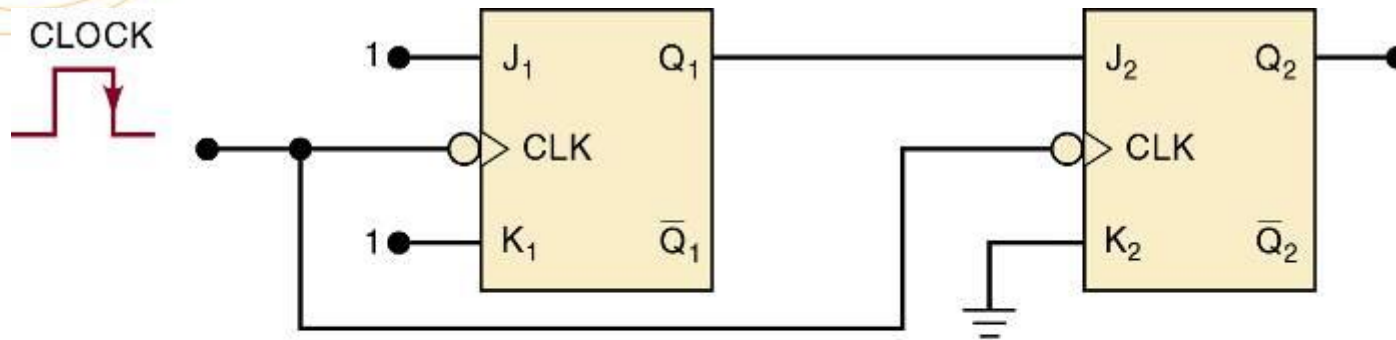
5-12 Potential Timing Problems in FF Circuits

- When the output of one FF is connected to the input of another FF and both are triggered by the same clock, there is a *potential* timing problem.
 - Propagation delay may cause unpredictable outputs.
- Edge-triggered FFs have hold time requirements 5 ns or less—most have $t_H = 0$.
 - They have *no* hold time requirement.

Assume the FF hold time requirement is short enough to respond reliably according to the following rule:

Flip-Flop output will go to a state determined by logic levels present at its synchronous control inputs just prior to the active clock transition.

5-12 Potential Timing Problems in FF Circuits



Q₂ will respond properly to the level present at Q₁ prior to NGT of CLK—*provided* Q₂'s hold time requirement, t_H , is *less* than Q₁'s propagation delay.

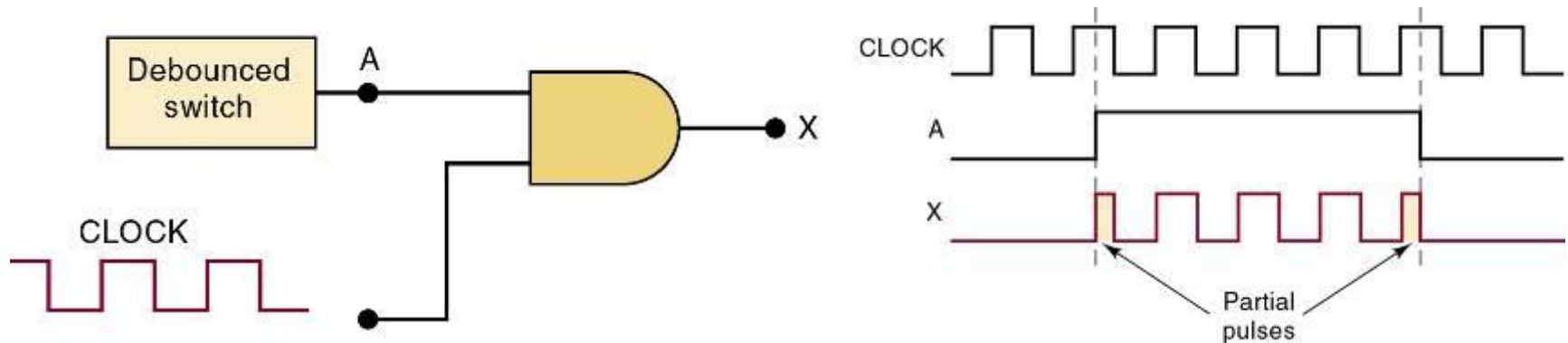
5-13 Flip-Flop Applications

- Examples of applications:
 - Counting; Storing binary data
 - Transferring binary data between locations
- Many FF applications are categorized sequential.
 - Output follows a predetermined sequence of states.

5-14 Flip-Flop Synchronization

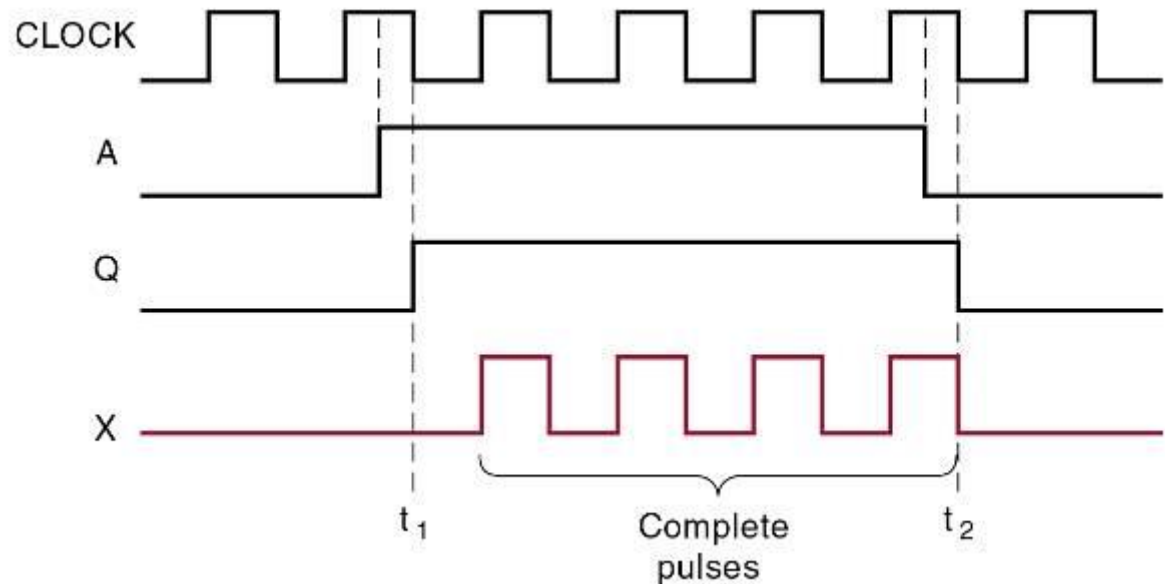
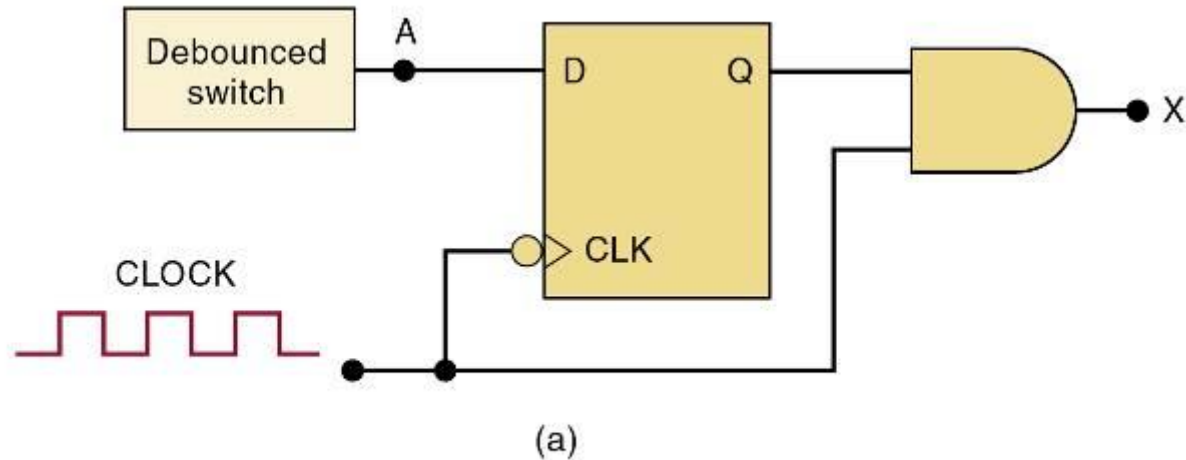
- Most systems are primarily synchronous in operation—in that changes depend on the clock.
- Asynchronous and synchronous operations are often combined—frequently through human input.
 - The random nature of asynchronous inputs *can* result in unpredictable results.

The asynchronous signal *A* can produce partial pulses at *X*.



5-14 Flip-Flop Synchronization

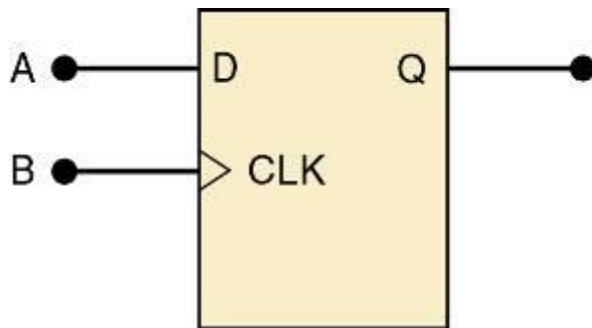
An edge-triggered D flip-flop synchronizes the enabling of the **AND** gate to the NGTs of the clock.



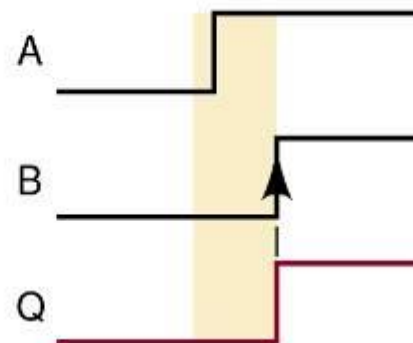
5-15 Detecting an Input Sequence

- FFs provide features pure combinational logic gates do not—in many situations, output activates *only* when inputs activate in a *certain sequence*
 - This requires the storage characteristic of FFs.

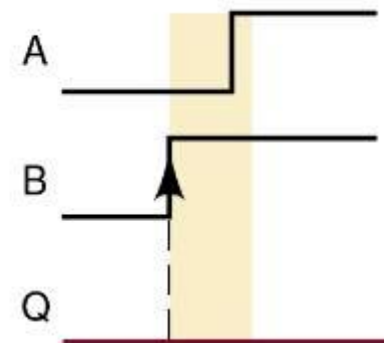
Clocked D flip-flop used to respond to a particular *sequence* of inputs.



To work properly, A must go HIGH, prior to B, by *at least* an amount of time *equal* to FF setup time.



A goes HIGH
before B



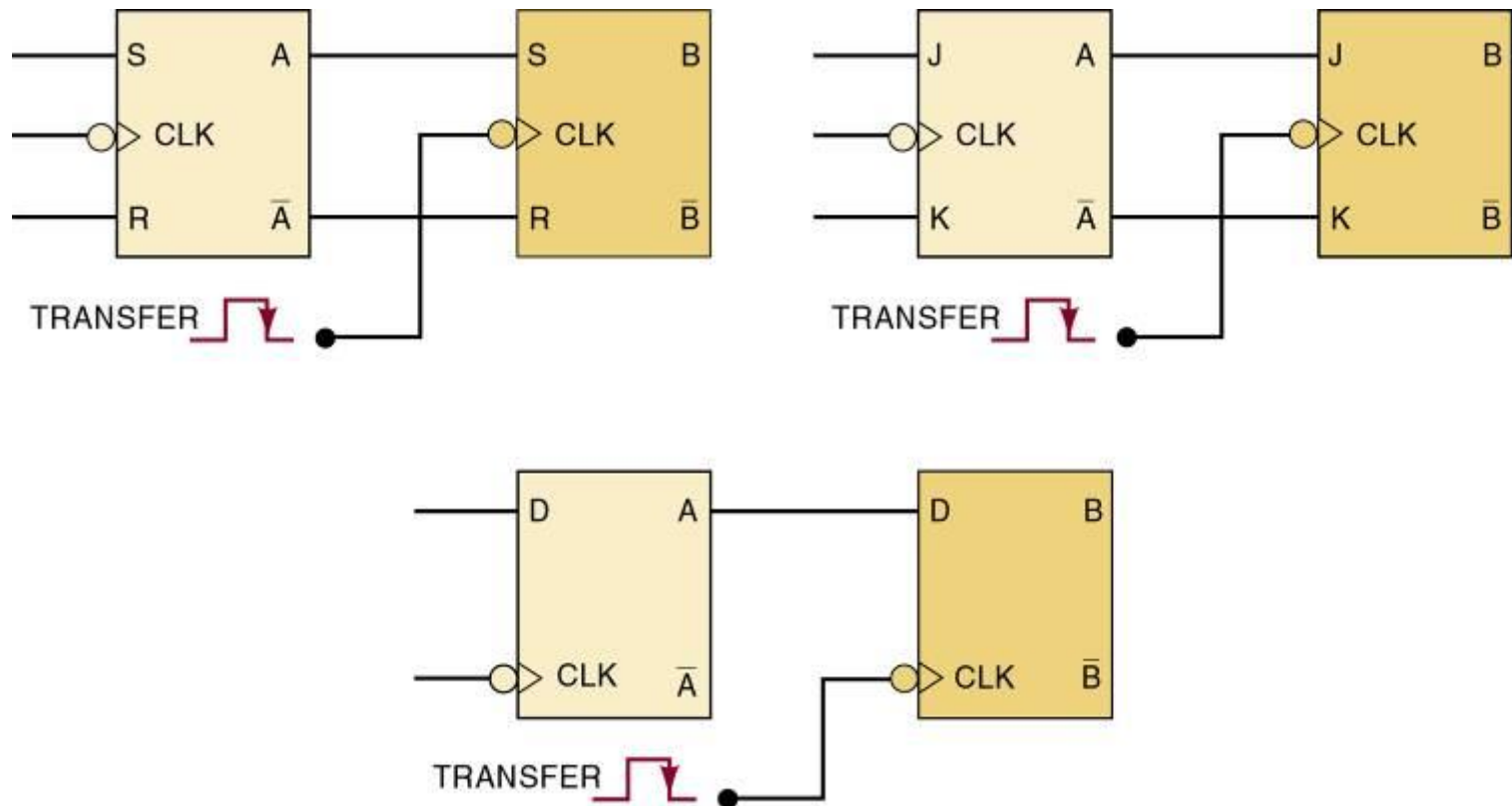
B goes HIGH
before A

5-16 Data Storage and Transfer

- FFs are commonly used for storage and transfer of binary data.
 - Groups used for storage are **registers**.
- Data transfers take place when data is moved between registers or FFs.
 - *Synchronous* transfers take place at clock PGT/NGT.
 - *Asynchronous* transfers are controlled by PRE & CLR.

5-16 Data Storage and Transfer – Synchronous

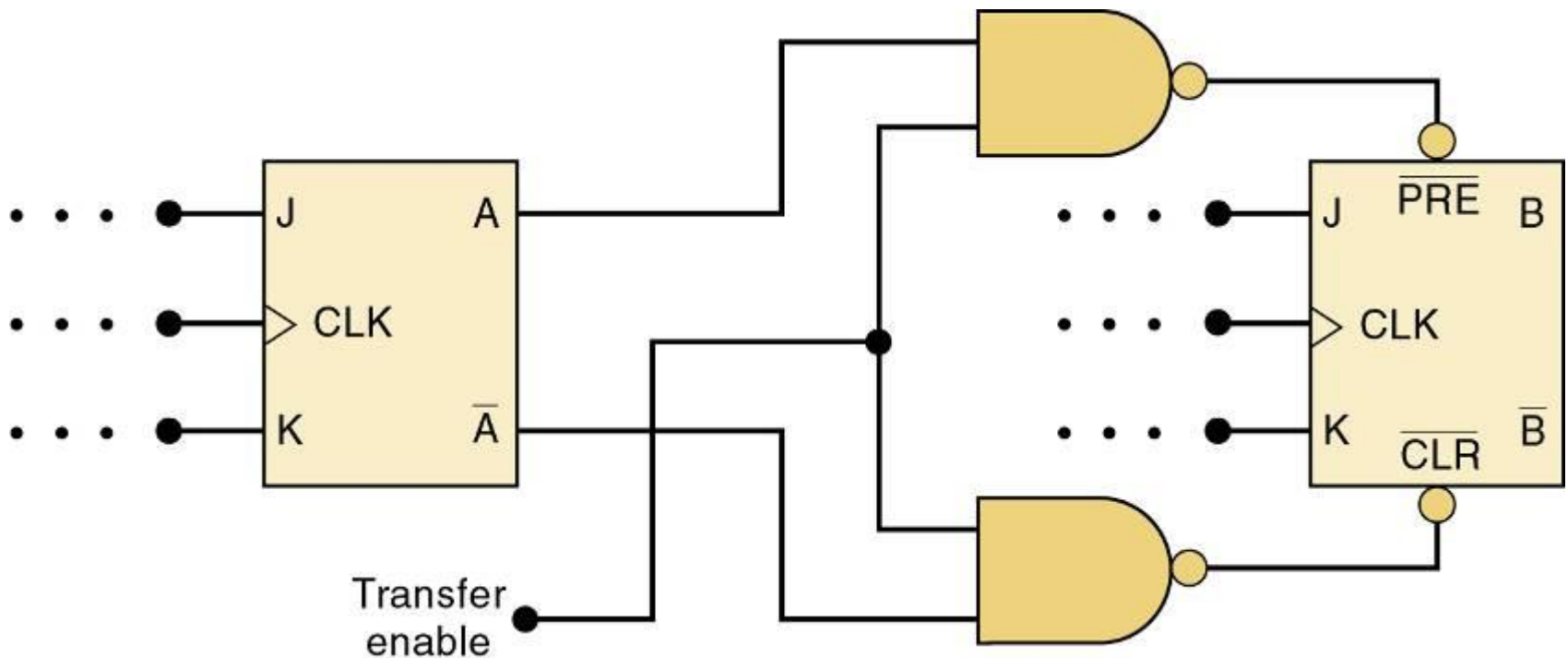
Synchronous data transfer operation by various clocked FFs.



CLK inputs are used to perform the transfer.

5-16 Data Storage and Transfer – Asynchronous

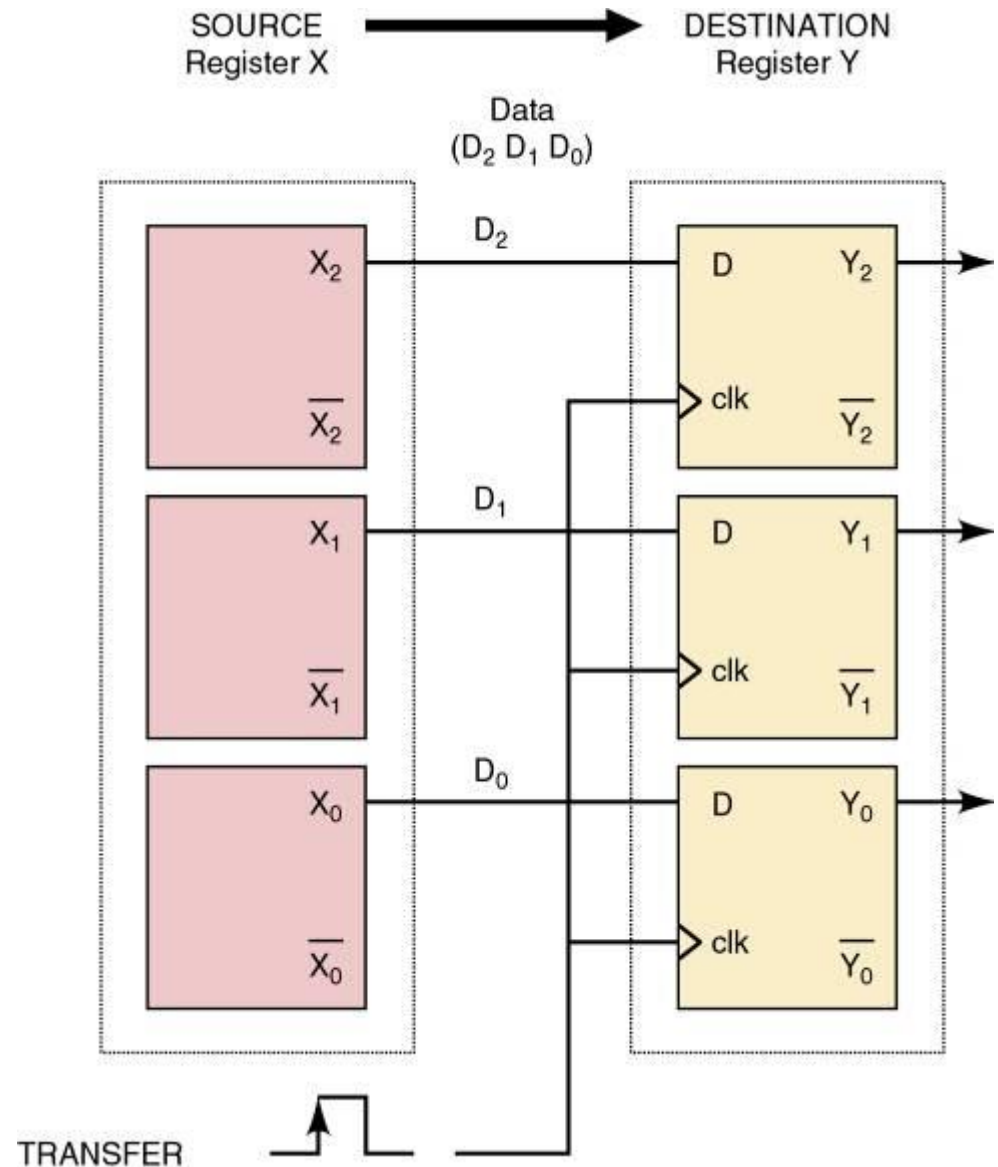
Asynchronous data transfer operation.



PRE and CLR inputs are used to perform the transfer.

5-16 Data Storage and Transfer – Parallel

Transferring the bits of a register *simultaneously* is a *parallel* transfer.

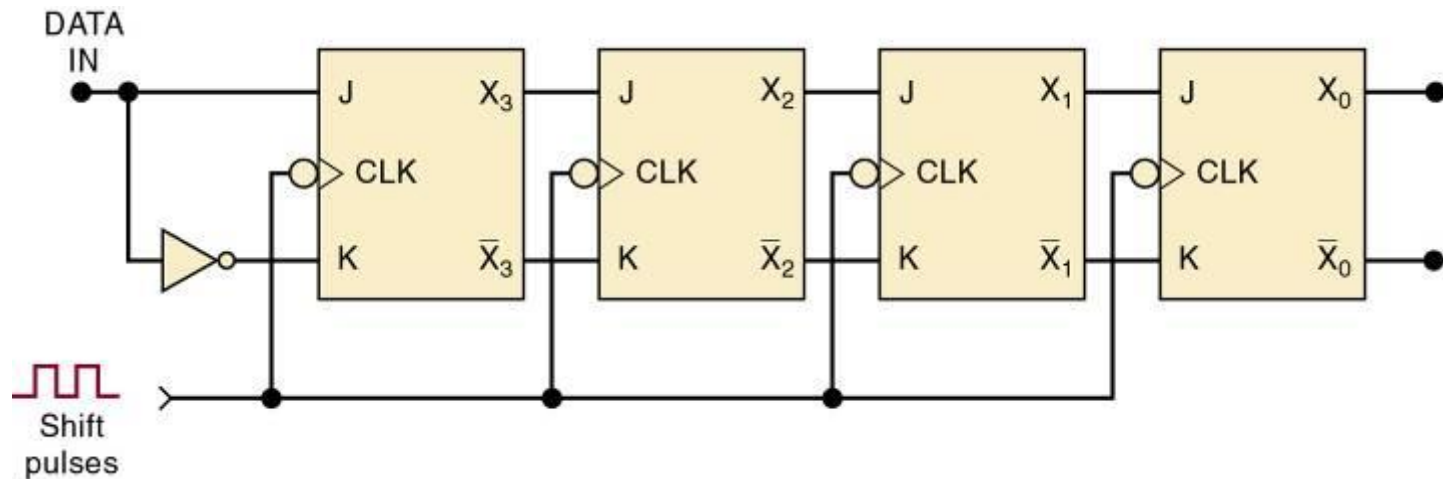


● 5-17 Serial Data Transfer

- Transferring the bits of a register *a bit at a time* is a *serial* transfer.

5-17 Serial Data Transfer – Shift Register

- A **shift register** is a group of FFs arranged so the binary numbers stored in the FFs are shifted from one FF to the next, for every clock pulse.



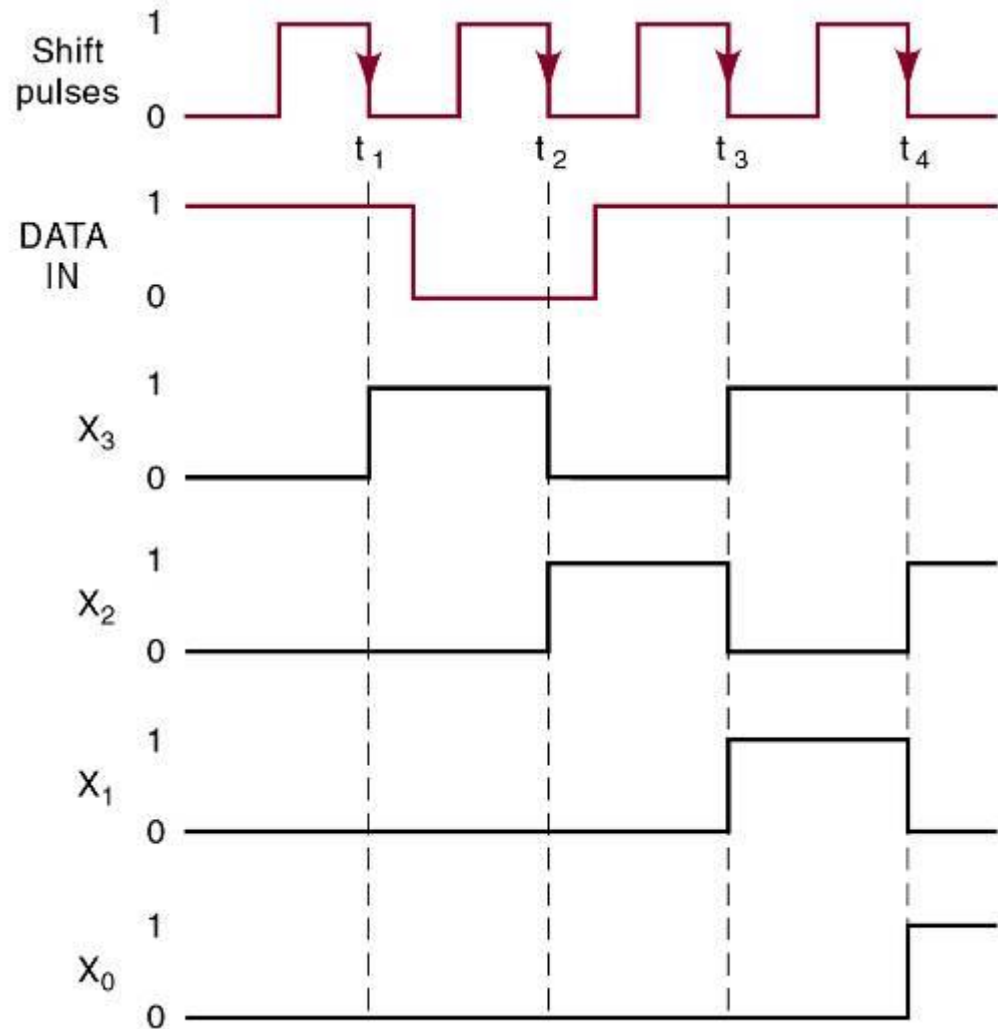
J-K flip-flops operated as a four-bit shift register.

5-17 Serial Data Transfer – Shift Register

Input data are shifted left to right from FF to FF as shift pulses are applied.

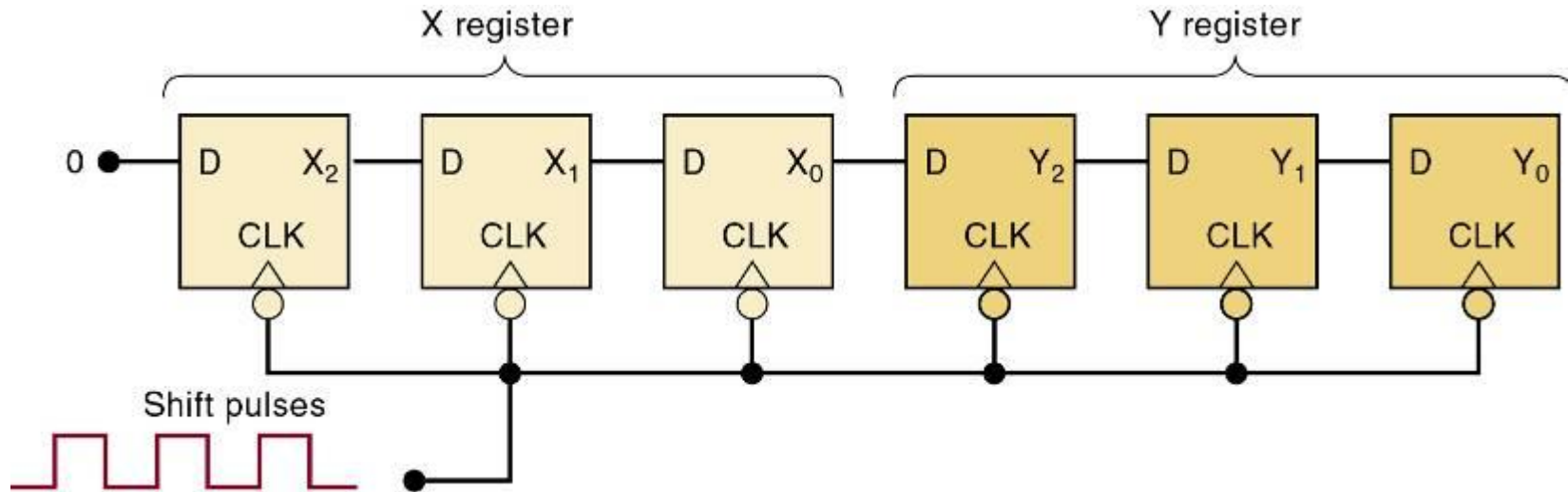
In this shift-register arrangement, it is necessary to have FFs with very small hold time requirements.

There are times when the J , K inputs are changing at about the same time as the CLK transition.



5-17 Serial Data Transfer – Shift Register

Two connected three-bit shift registers.



The contents of the X register will be serially transferred (shifted) into register Y.

The D flip-flops in each shift register require fewer connections than J-K flip-flops.

5-17 Serial Data Transfer – Shift Register

Two connected three-bit shift registers.

The complete transfer of the three bits of data requires three shift pulses.

X_2	X_1	X_0	Y_2	Y_1	Y_0	
1	0	1	0	0	0	← Before pulses applied
0	1	0	1	0	0	
0	0	1	0	1	0	
0	0	0	1	0	1	

5-17 Serial Data Transfer – Shift Register

Two connected three-bit shift registers.

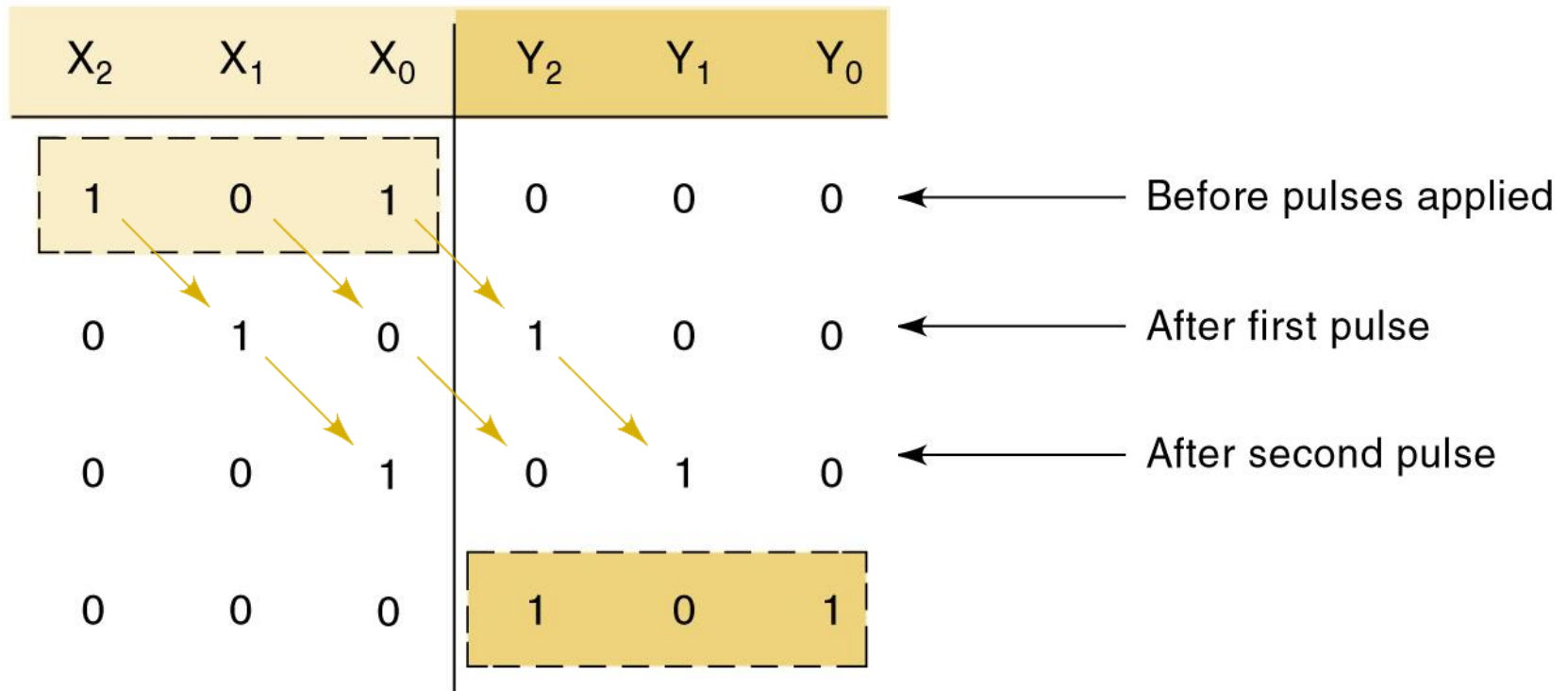
On each pulse NGT, each FF takes on the value stored in the FF on its *left* prior to the pulse.

X_2	X_1	X_0	Y_2	Y_1	Y_0	
1	0	1	0	0	0	← Before pulses applied
0	1	0	1	0	0	← After first pulse
0	0	1	0	1	0	
0	0	0	1	0	1	

5-17 Serial Data Transfer – Shift Register

Two connected three-bit shift registers.

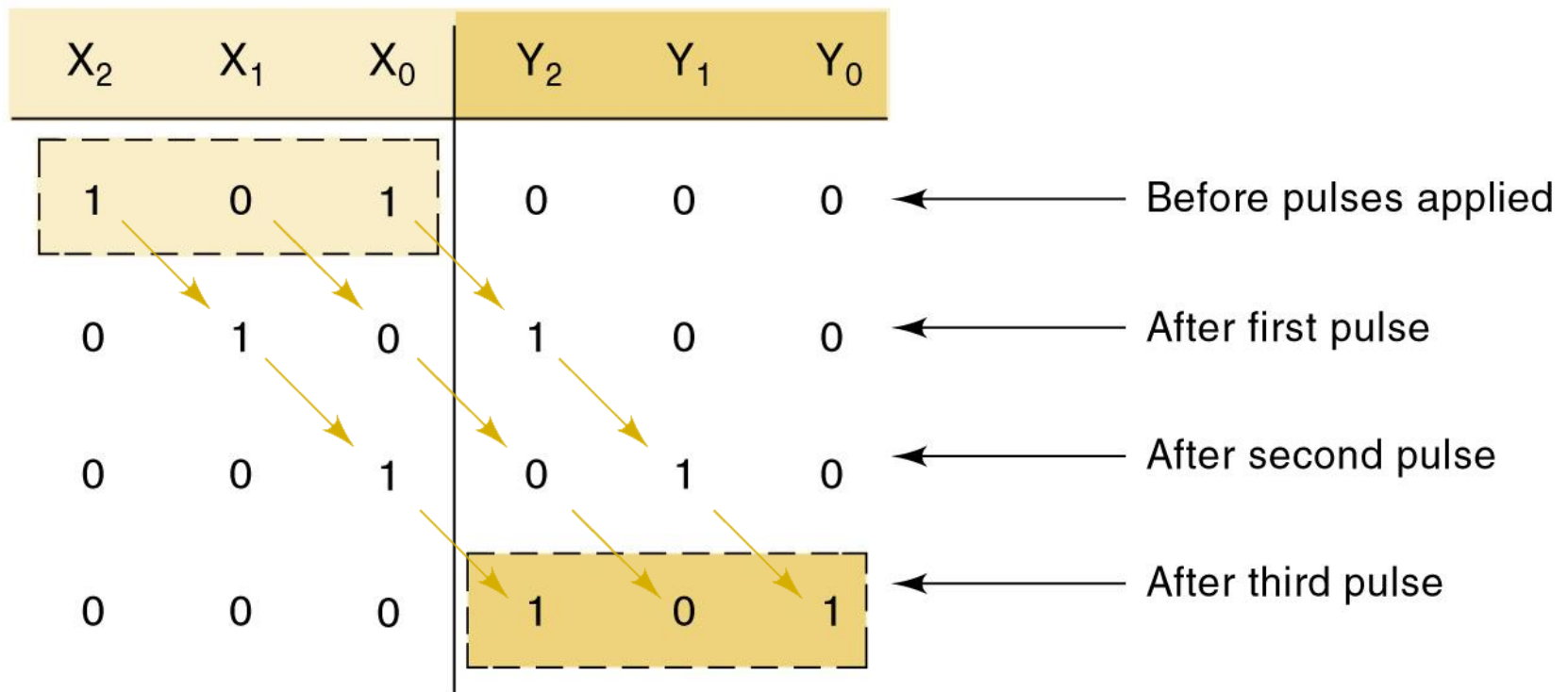
On each pulse NGT, each FF takes on the value stored in the FF on its *left* prior to the pulse.



5-17 Serial Data Transfer – Shift Register

Two connected three-bit shift registers.

On each pulse NGT, each FF takes on the value stored in the FF on its *left* prior to the pulse.



5-17 Serial Data Transfer – Shift Register

Two connected three-bit shift registers.

After three pulses:

- The 1 initially in X_2 is in Y_2 .**
- The 0 initially in X_1 is in Y_1 .**
- The 1 initially in X_0 is in Y_0 .**

X_2	X_1	X_0	Y_2	Y_1	Y_0
1	0	1	0	0	0
0	1	0	1	0	0
0	0	1	0	1	0
0	0	0	1	0	1

The 101 stored in the X register has now been shifted into the Y register.

The X register has lost its original data, and is at 000.

5-17 Serial Data Transfer vs. Parallel

- FFs in can just as easily be connected so that information shifts from *right* to *left*.
 - No general advantage of one direction over another.
 - Often dictated by the nature of the application.
- Parallel transfer requires more interconnections between sending & receiving registers than serial.
 - More critical when a greater number of bits of are being transferred.
- Often, a combination of types is used
 - Taking advantage of parallel transfer *speed* and serial transfer the *economy and simplicity* of serial transfer.

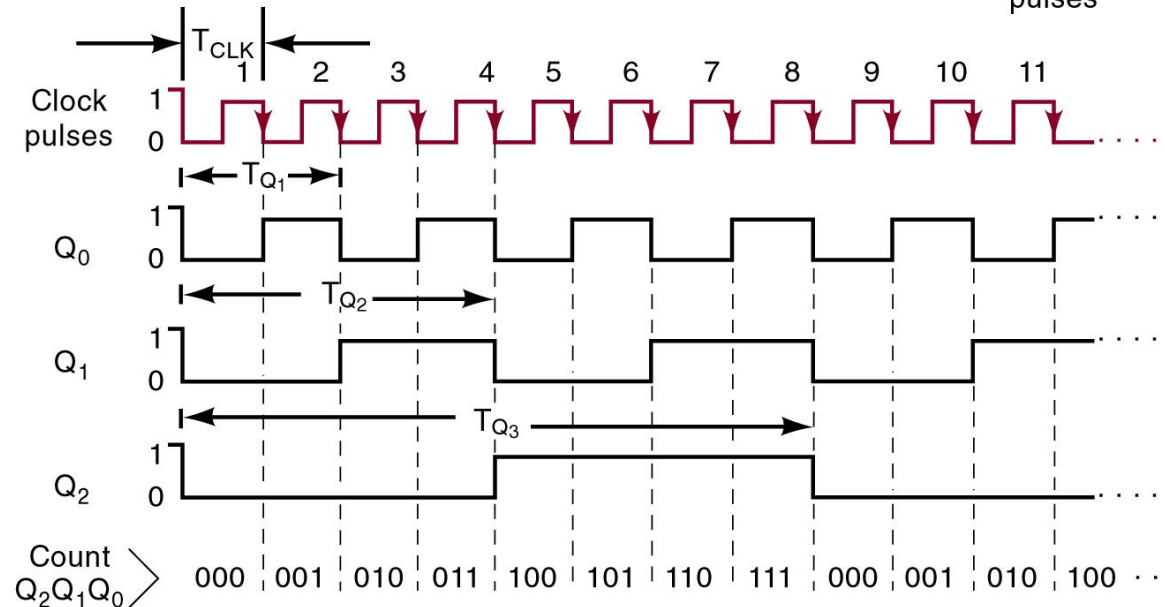
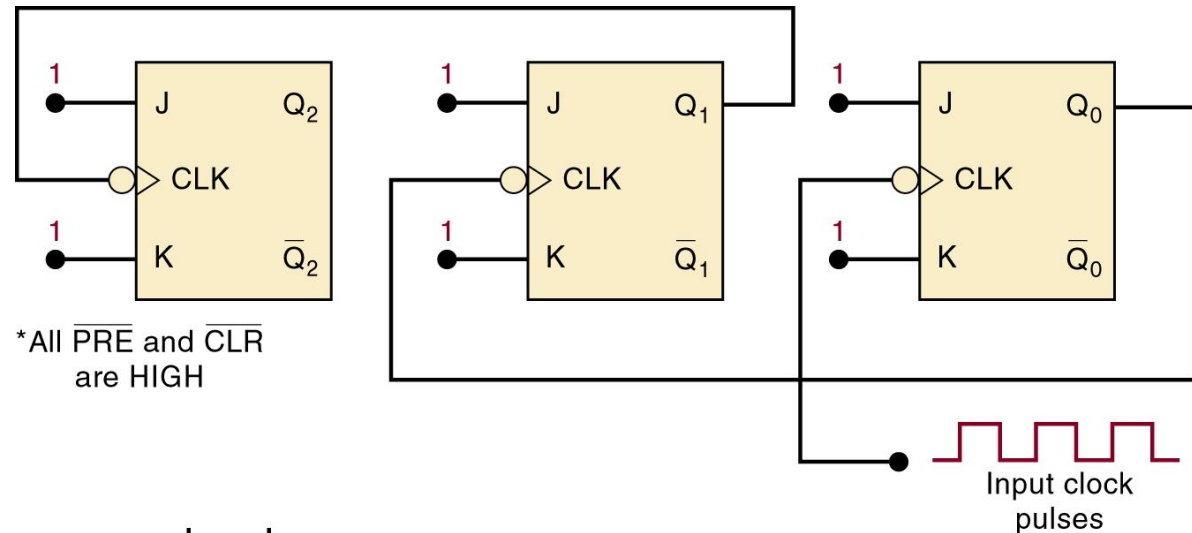
5-18 Frequency Division and Counting

J-K flip-flops wired as a three-bit binary counter (MOD-8).

Each FF divides the input frequency by 2.

Output frequency is 1/8 of the input (clock) frequency.

A fourth FF would make the frequency 1/16 of the clock.



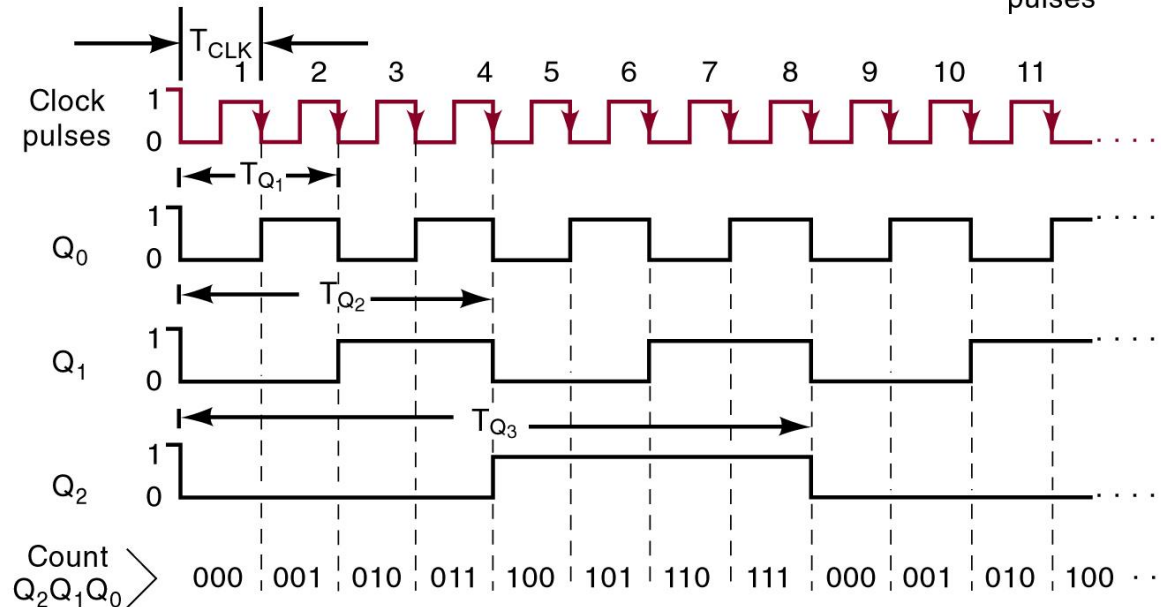
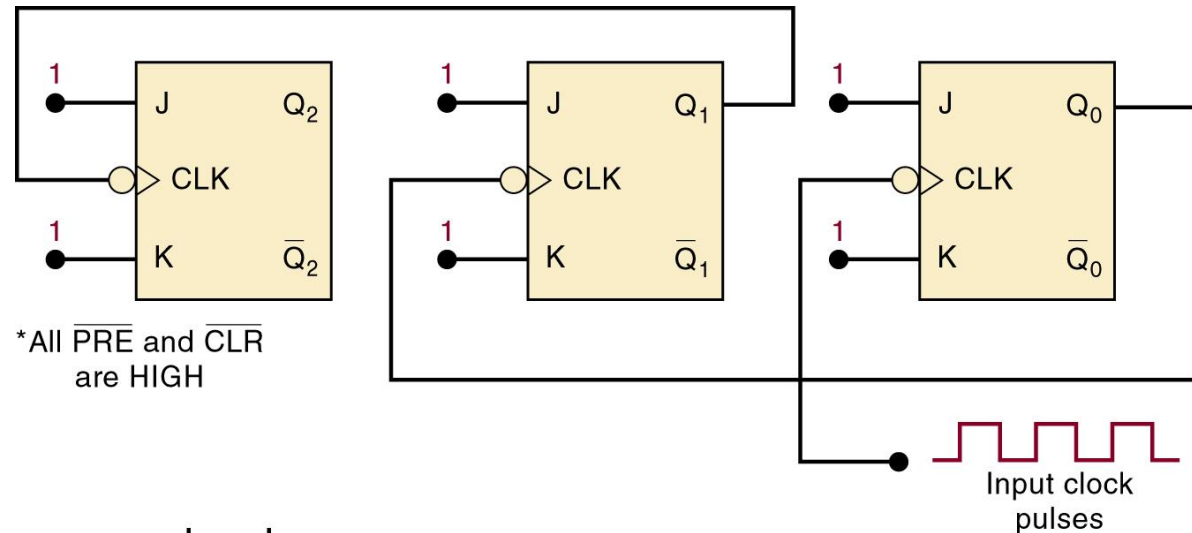
5-18 Frequency Division and Counting

J-K flip-flops wired as a three-bit binary counter (MOD-8).

This circuit also acts as a binary counter.

Outputs will count from 0002 to 1112 or 010 to 710.

The number of states possible in a counter is the modulus or MOD number.

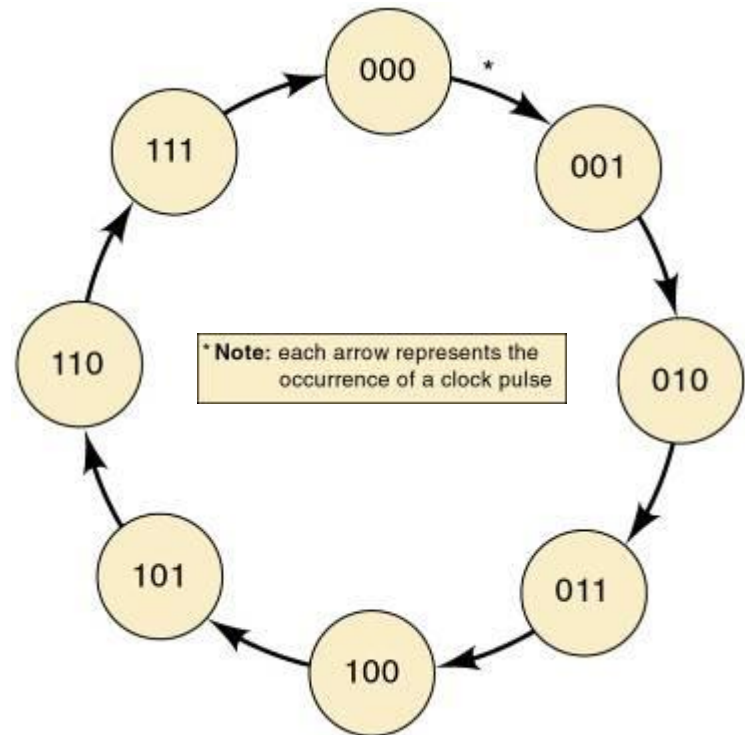


5-18 Frequency Division and Counting

A MOD-8 (2^3) counter.

If another FF is added it would become a MOD-16 (2^4) counter.

2^2	2^1	2^0	
Q_2	Q_1	Q_0	
0	0	0	Before applying clock pulses
0	0	1	After pulse #1
0	1	0	After pulse #2
0	1	1	After pulse #3
1	0	0	After pulse #4
1	0	1	After pulse #5
1	1	0	After pulse #6
1	1	1	After pulse #7
0	0	0	After pulse #8 recycles to 000
0	0	1	After pulse #9
0	1	0	After pulse #10
0	1	1	After pulse #11
.	.	.	.
.	.	.	.
.	.	.	.

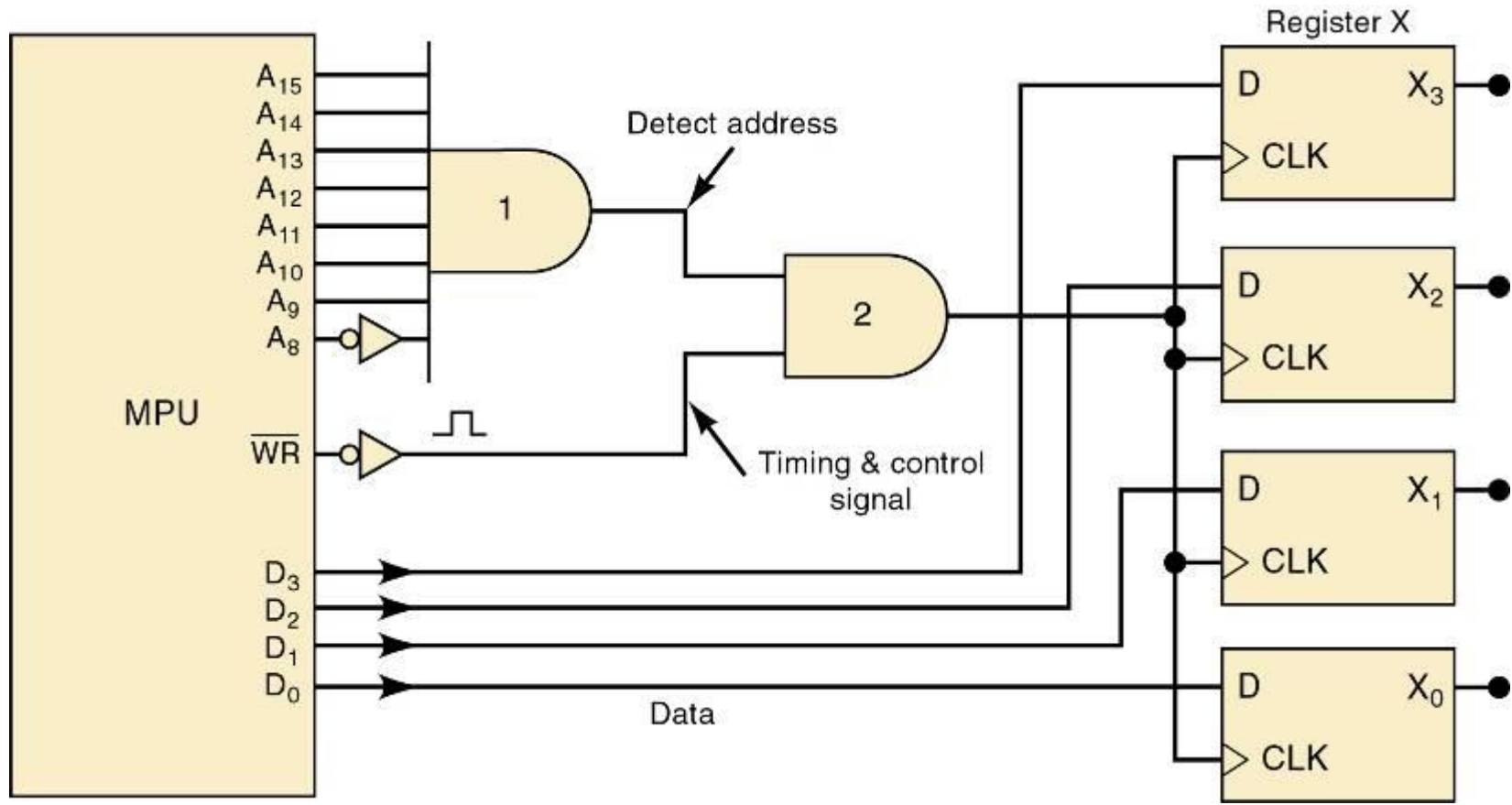


5-19 Microcomputer Application

- Microprocessor units (MPUs) perform many functions involving use of registers for data transfer and storage.
- MPUs may send data to external registers for many purposes, including:
 - Solenoid/relay control; Device positioning.
 - Motor starting & speed controls.

5-19 Microcomputer Application

Microprocessor transferring binary data to an external register.

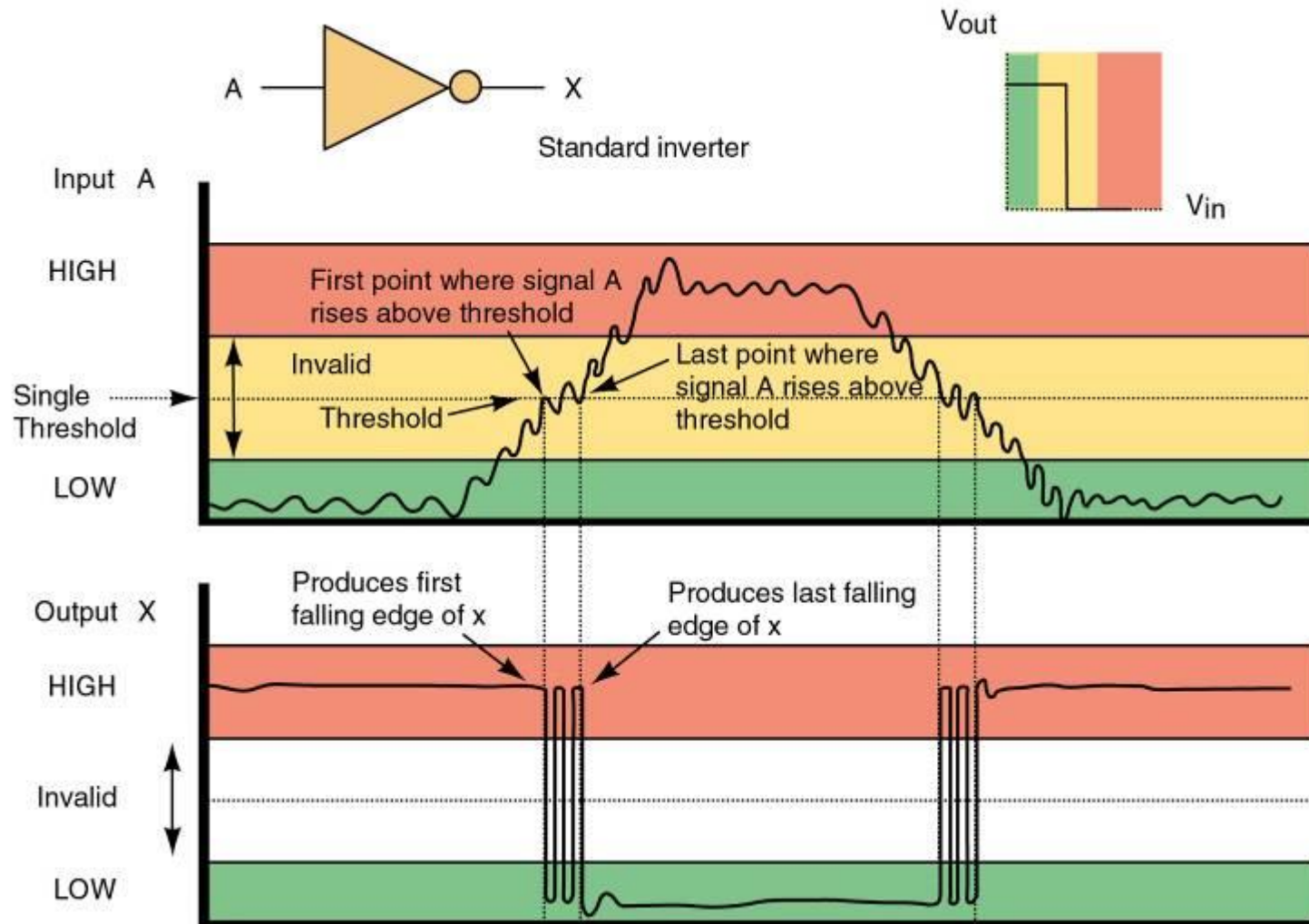


5-20 Schmitt-Trigger Devices

- Not classified as a FF—but has a useful a memory characteristic in certain situations.
- Accepts slow changing signals and produces a signal that transitions quickly, oscillation-free.
- A Schmitt trigger device will not respond to input until it exceeds the positive- (V_{T+}) or negative- (V_{T-}) going threshold.
- Separation between the threshold levels means the device will “remember” the last threshold exceeded.
 - Until the input goes to the opposite threshold.

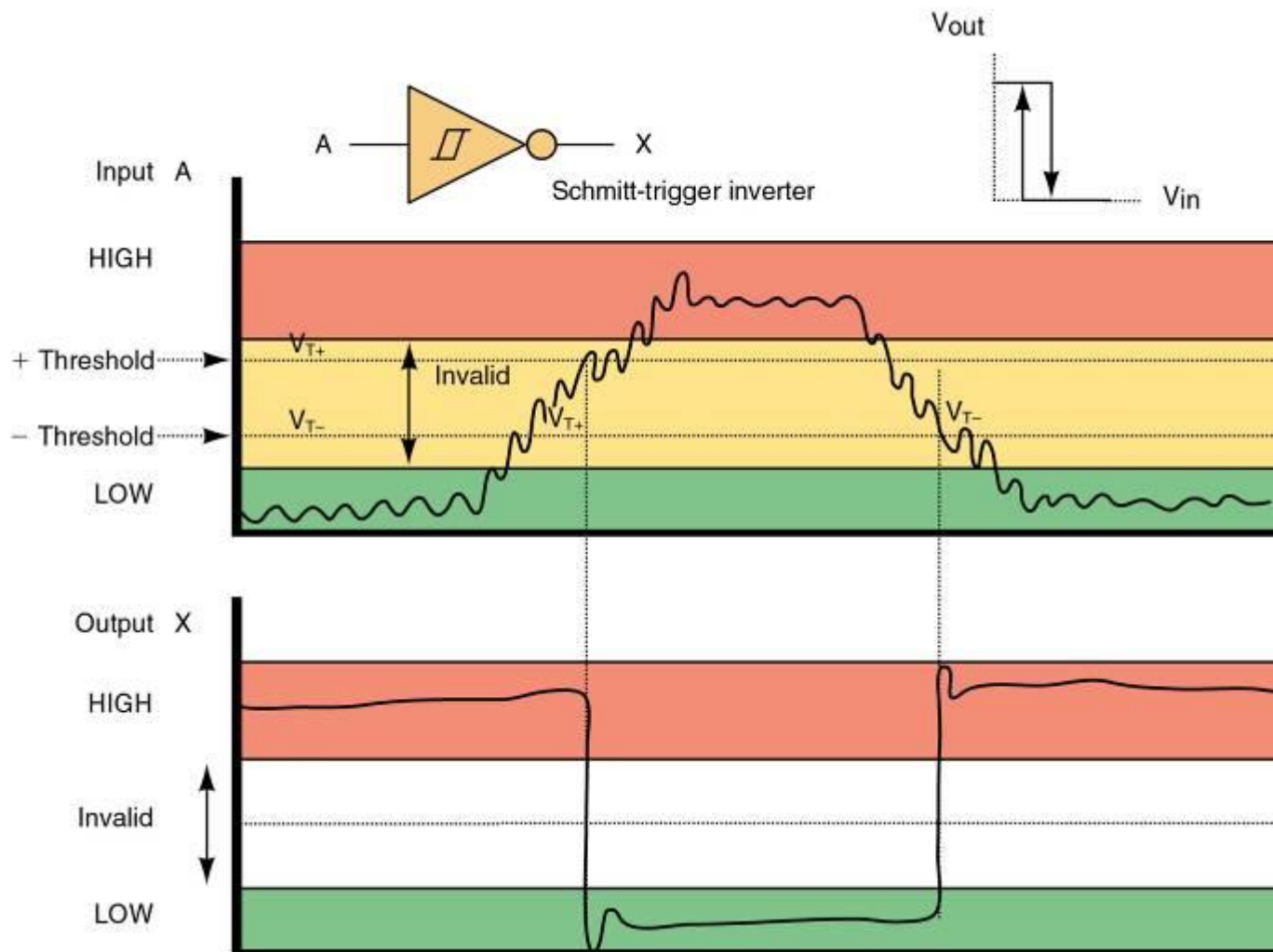
5-20 Schmitt-Trigger Devices

Standard inverter response to slow noisy input.



5-20 Schmitt-Trigger Devices

Schmitt-trigger response to slow noisy input.



5-21 One-shot (Monostable Multivibrator)

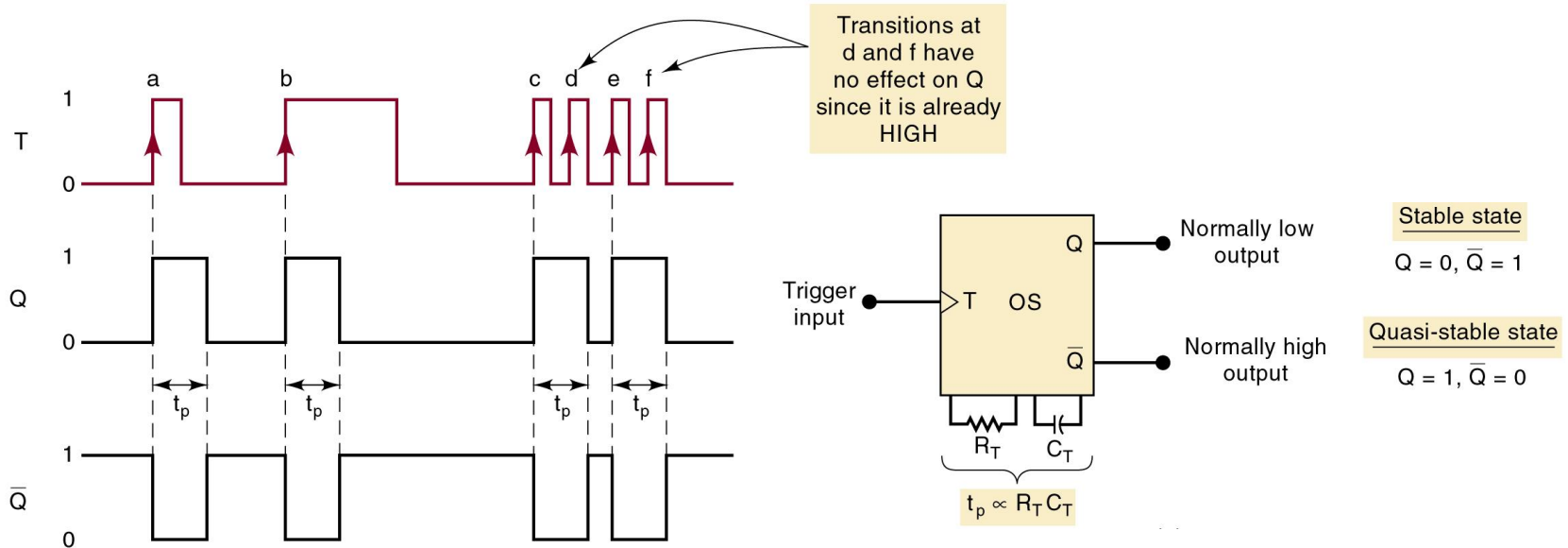
- Like the FF, the OS has two outputs, Q and \bar{Q} .
 - The inverse of each other.
- One shots are called monostable multivibrators because they have only one stable state.
 - Prone to triggering by noise.
- Changes from stable to quasi-stable state for a fixed time-period (t_p).
 - Usually determined by an RC time constant from external components.

● 5-21 One-shot (Monostable Multivibrator)

- **Nonretriggerable** devices trigger & return to stable.
- **Retriggerable** devices can be triggered while in the quasi-stable state, to begin another pulse.

5-21 One-shot (Monostable Multivibrator)

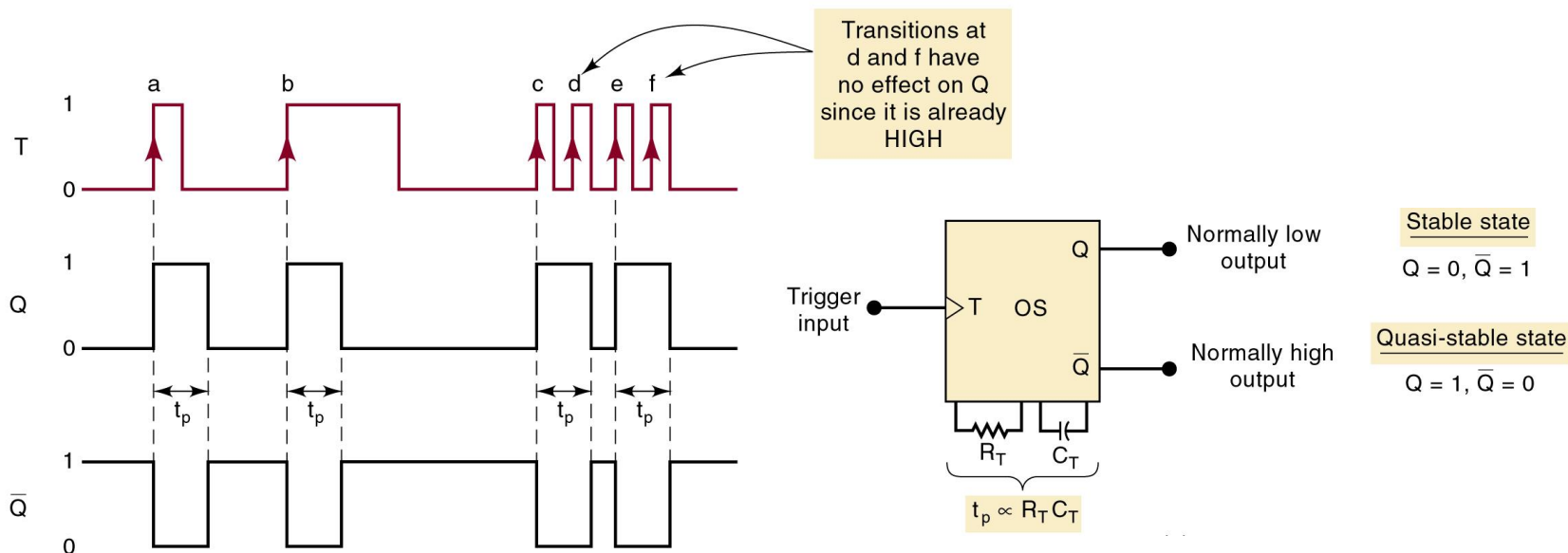
OS symbol and typical waveforms for nonretriggerable operation.



PGTs at points *a*, *b*, *c*, and *e* will trigger the OS to its quasi-stable state for a time t_p . After which it automatically returns to the stable state.

5-21 One-shot (Monostable Multivibrator)

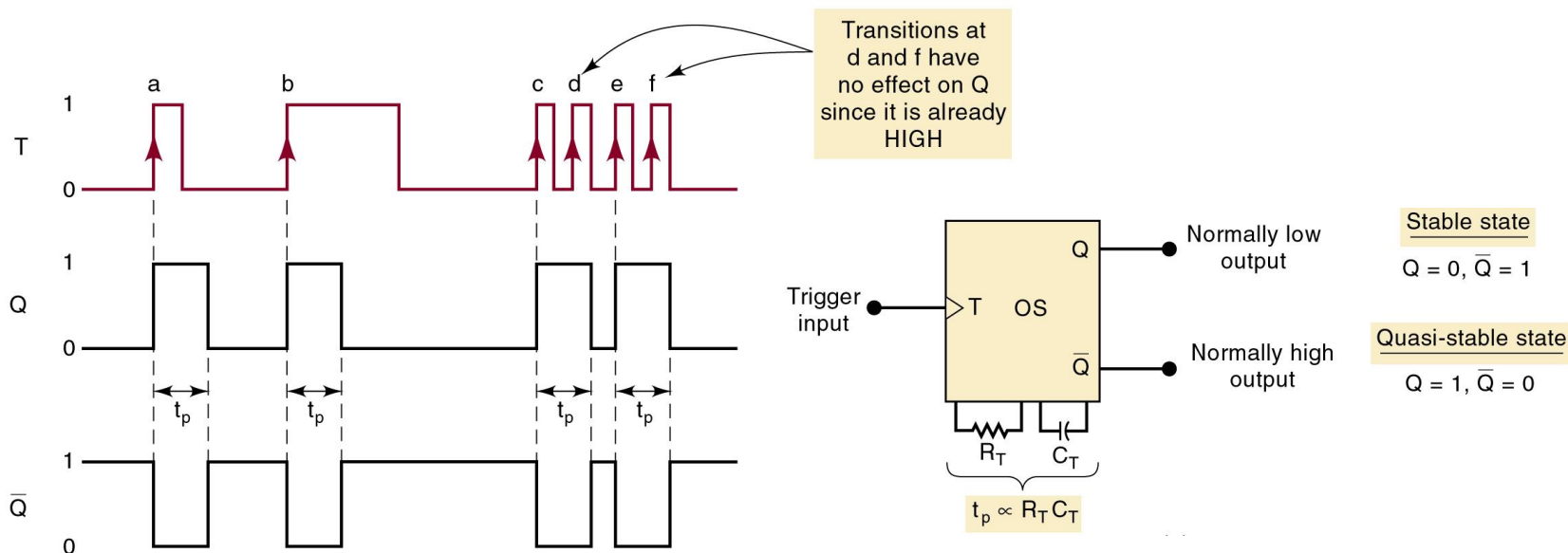
OS symbol and typical waveforms for nonretriggerable operation.



PGTs at points *d* and *f* have no effect on the OS because it has already been triggered quasi-stable. OS must return to the stable before it can be triggered.

5-21 One-shot (Monostable Multivibrator)

OS symbol and typical waveforms for nonretriggerable operation.

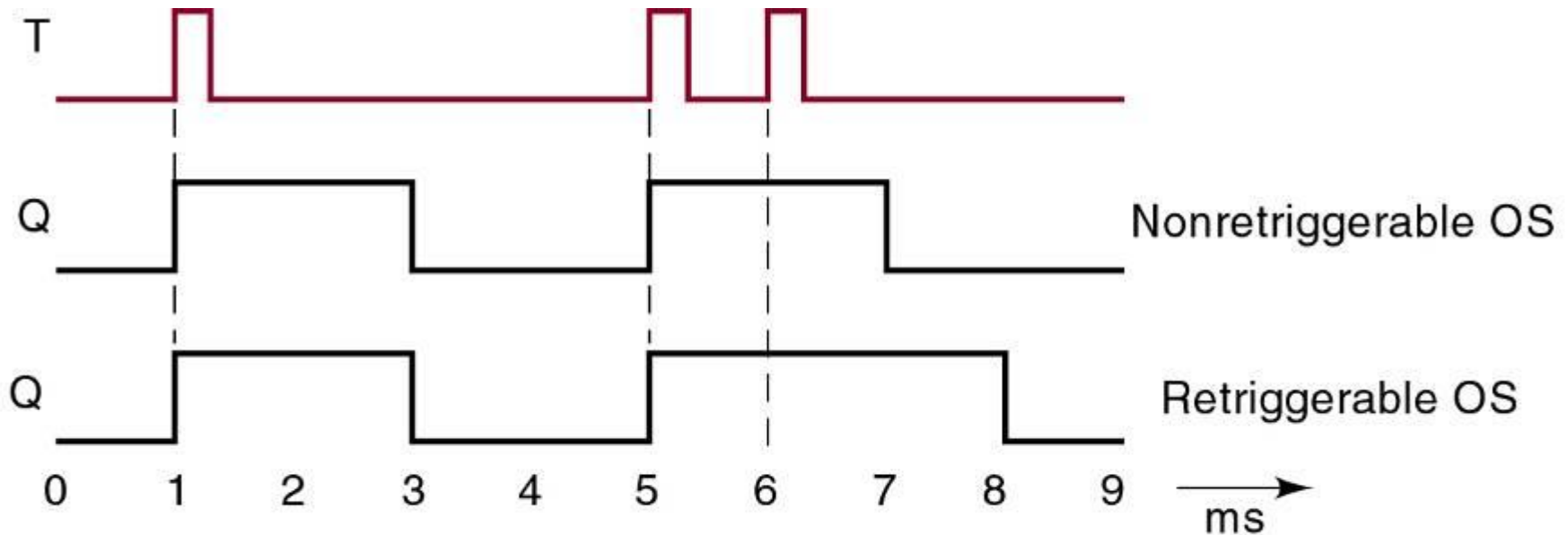


OS output-pulse duration is always the same, regardless of the duration of the input pulses.

Time t_p depends only on R_T , C_T & internal OS circuitry.

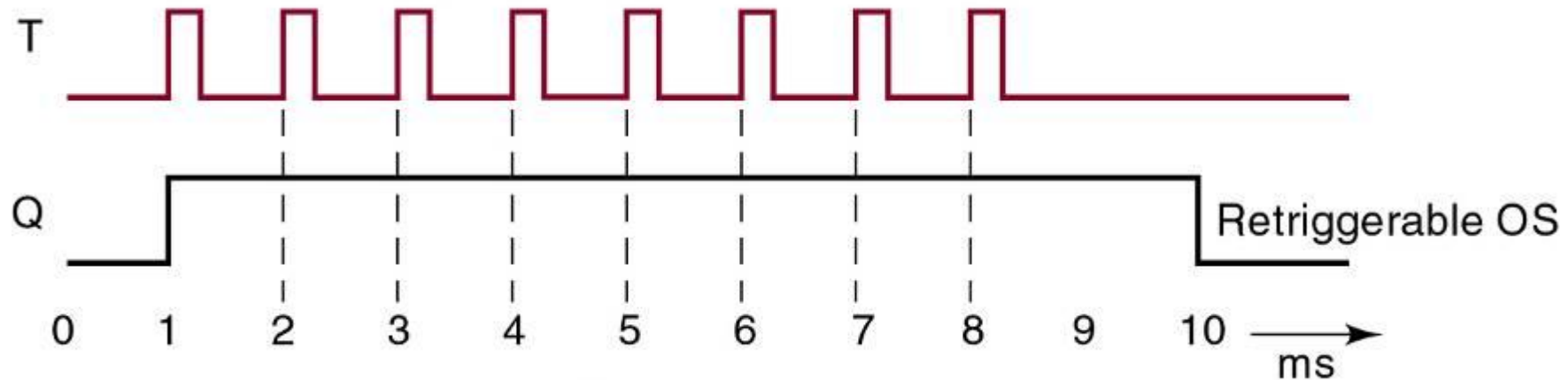
5-21 One-shot (Monostable Multivibrator)

Comparison of nonretriggerable and retriggerable OS responses for $t_p = 2\text{ms}$.



5-21 One-shot (Monostable Multivibrator)

Retriggerable OS begins a new t_p interval each time it receives a trigger pulse.



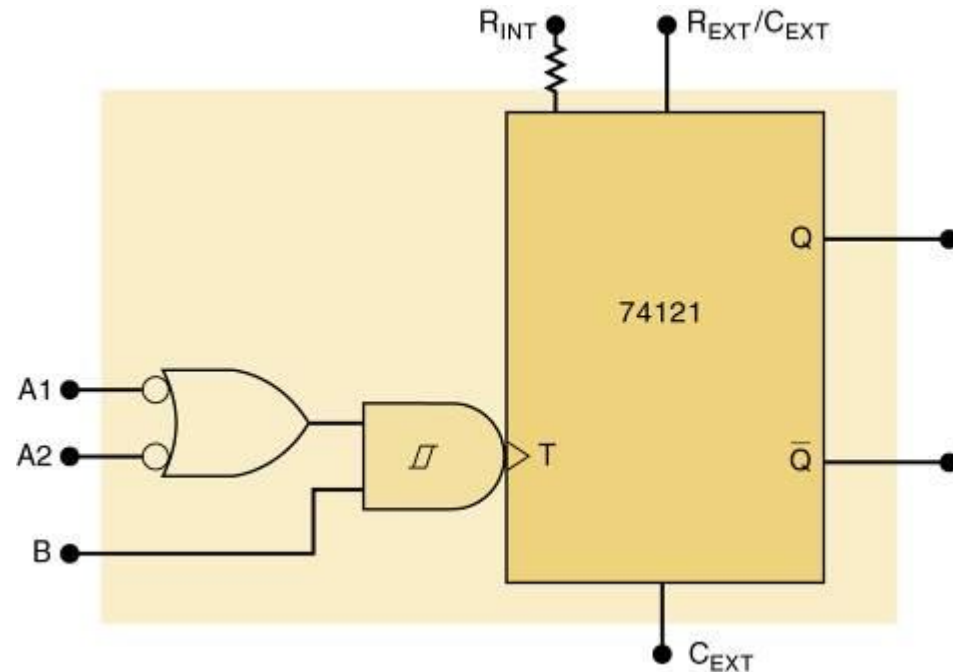
5-21 One-shot (Monostable Multivibrator)

74121 nonretriggerable one-shot IC.

Contains internal logic gates to allow inputs A_1 , A_2 , and B to trigger OS.

Input B is a Schmitt-trigger—allowed to have slow transition times & still reliably trigger OS.

Pins R_{INT} , R_{EXT}/C_{INT} , and C_{EXT} connect to an external resistor & capacitor to achieve desired output pulse duration.

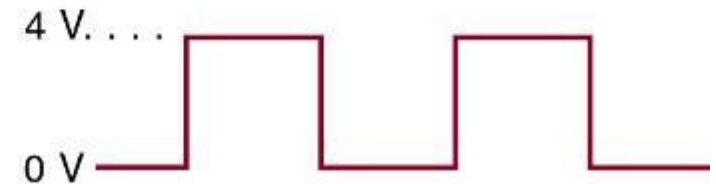
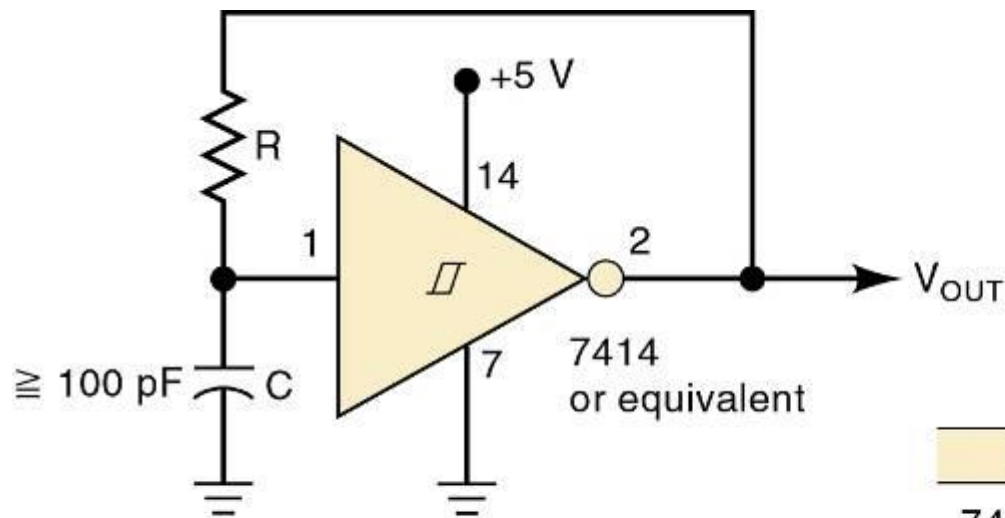


5-22 Clock Generator Circuits

- A third type multivibrator has no stable states—an **astable** or **free-running multivibrator**.
 - Astable or free-running multivibrators switch back and forth between two unstable states.
 - Useful for generating clock signals for synchronous circuits.

5-22 Clock Generator Circuits

Schmitt-trigger oscillator using a 7414 INVERTER.
A 7413 Schmitt-trigger NAND may also be used.



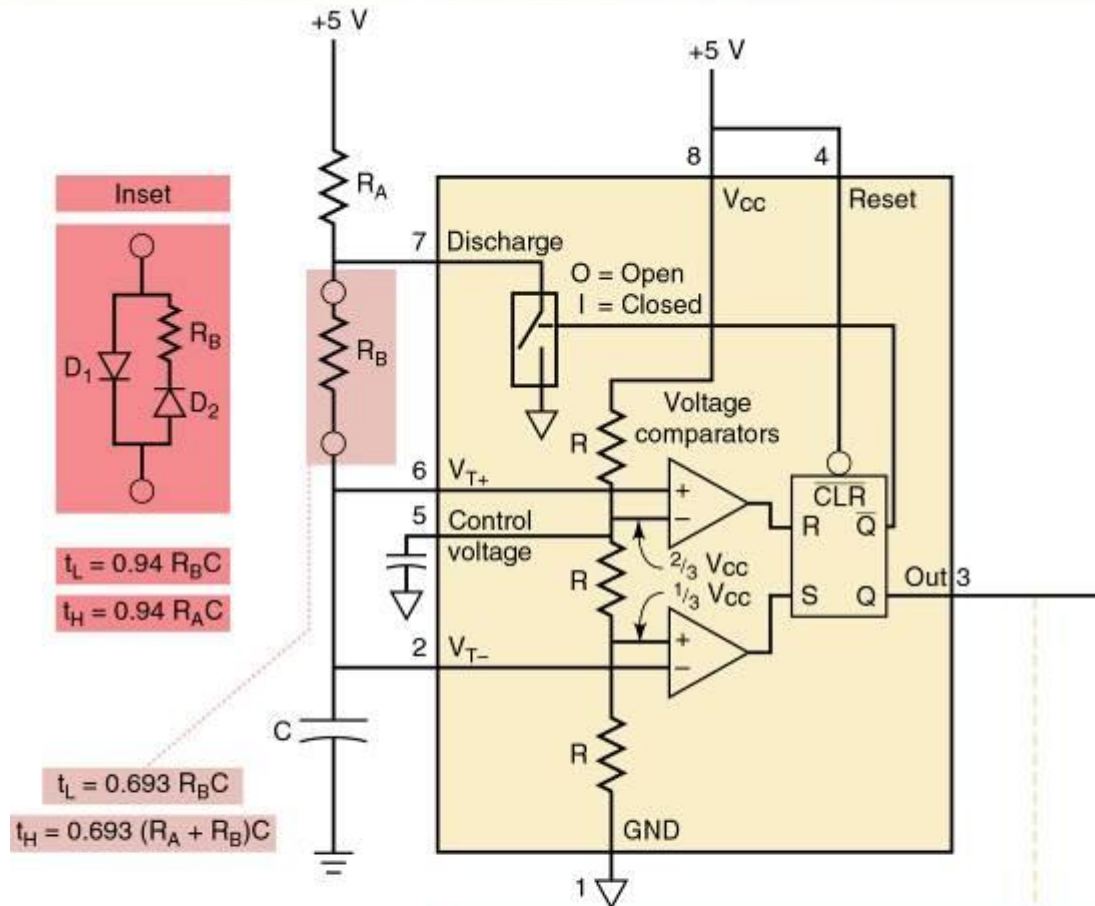
IC	Frequency	
7414	$\approx 0.8/RC$	($R \leq 500 \Omega$)
74LS14	$\approx 0.8/RC$	($R \leq 2 \text{ k}\Omega$)
74HC14	$\approx 1.2/RC$	($R \leq 10 \text{ M}\Omega$)

5-22 Clock Generator Circuits

- The **555 timer** IC is a TTL-compatible device that can operate in several different modes.
 - Output is a repetitive rectangular waveform that switches between two logic levels.
 - The time intervals at each logic level are determined by the R and C values.
- The heart of the 555 timer is two voltage comparators and an S-R latch.
 - The comparators produce a HIGH out when voltage on the (+) input is greater than on the (-) input.

5-22 Clock Generator Circuits

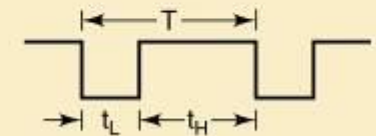
**555 Timer IC used
as an astable
multivibrator.**



$$T = t_L + t_H$$

$$f = \frac{1}{T}$$

$$\text{Duty cycle} = \frac{t_H}{T} \times 100\%$$



5-22 Clock Generator Circuits

- Crystal control may be used if a very stable clock is needed—used in microprocessor systems and microcomputers where accurate timing intervals are essential.

5-23 Troubleshooting Flip-Flop Circuits

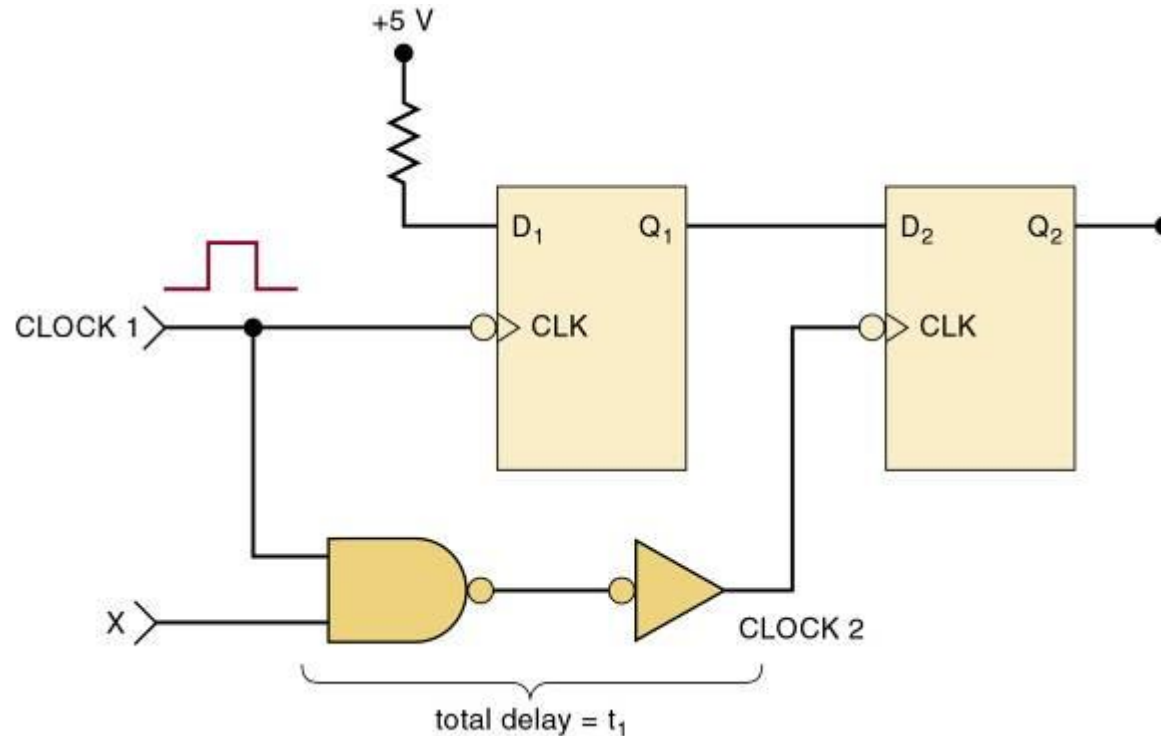
- FFs are subject to the same faults that occur in combinational logic circuits.
 - Timing problems create some faults and symptoms that are not seen in combinational logic circuits.
- Unconnected or floating inputs are particularly susceptible spurious voltage fluctuations—*noise*.
- Given sufficient noise amplitude and duration, logic circuit output may change states in response.
 - In a logic gate, output will return to its original state when the noise signal subsides.
 - In a FF, output will remain in its new state due to its memory characteristic.

● 5-23 Troubleshooting Flip-Flop Circuits

- Clock skew occurs when CLK signals arrive at different FFs at different times.
 - The fault may be seen only intermittently, or may disappear during testing.

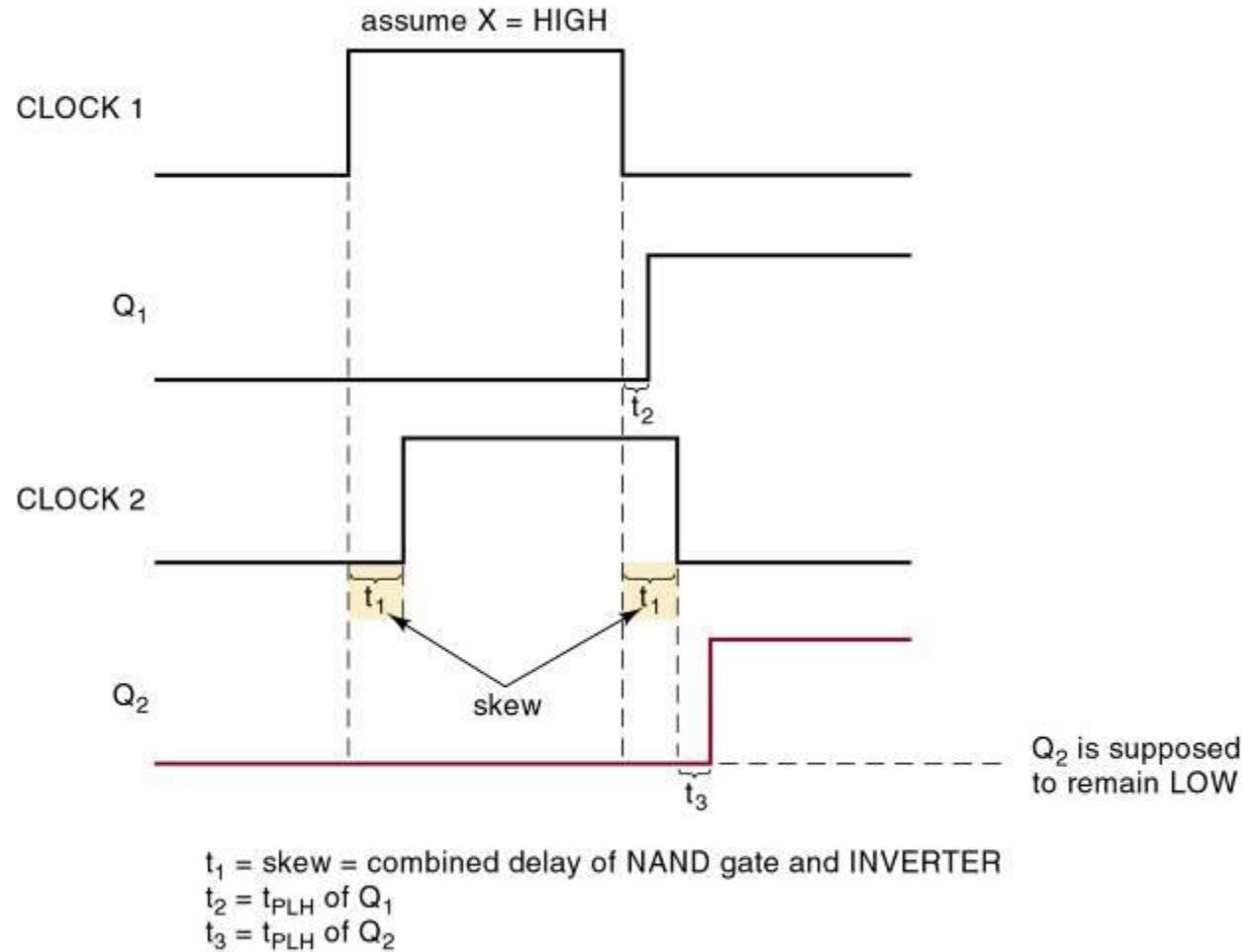
5-23 Troubleshooting Flip-Flop Circuits

Extra gating circuits can cause clock skew.



5-23 Troubleshooting Flip-Flop Circuits

Extra gating circuits can cause clock skew.

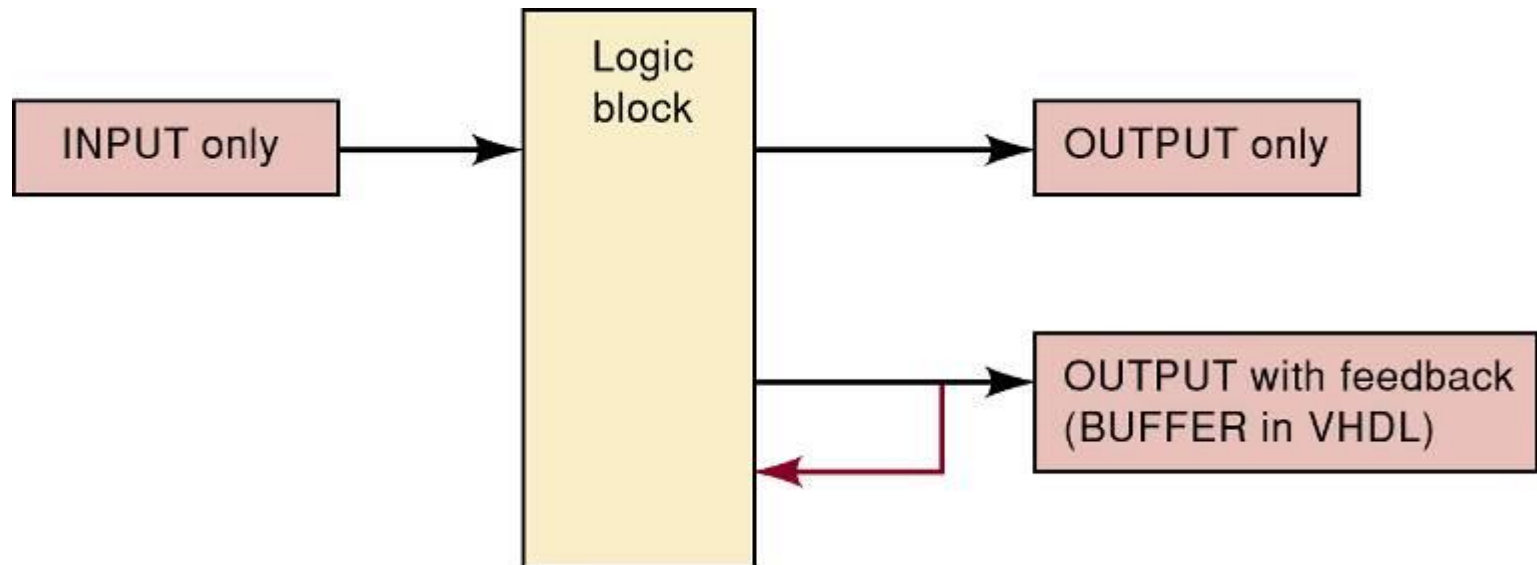


5-24 Sequential Circuits In PLDs Using Schematic Entry

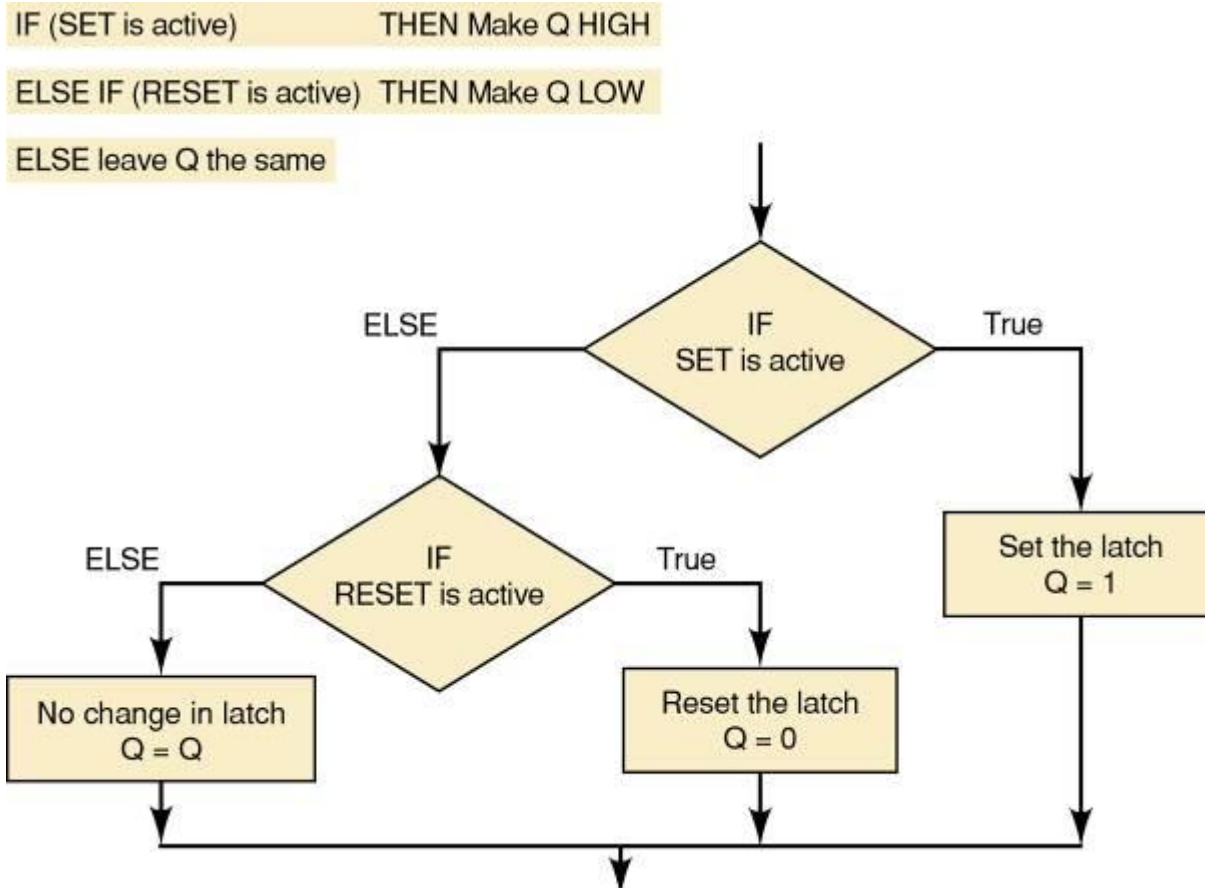
- Altera's Quartus II development system software allows designers to describe the desired circuit using schematics.
 - The megafunction library contains high-level modules that can be used to create logic designs.
- The Quartus II simulator can be used to verify the sequential circuits by schematic capture before you program a PLD.

5-25 Sequential Circuits Using HDL

- Most PLDs have the ability to feed back the output signal to the input circuitry—to accommodate latching action.
 - The port bit is an output with feedback.



The logic of a behavioral description of an S-R latch.



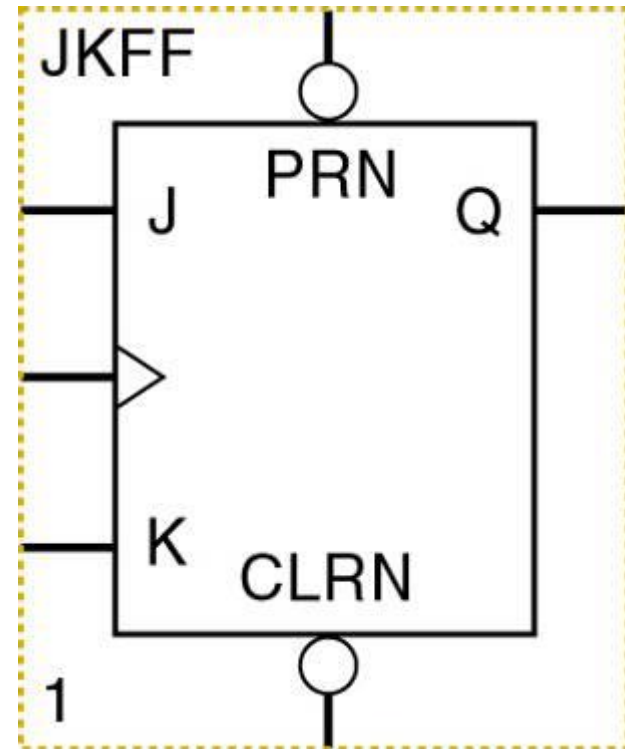
5-25 Sequential Circuits Using HDL

- Sequential circuits that feed output value back to inputs, may possibly create an unstable system.
 - A change in the output state might be fed back to the inputs, which changes the output state again, which feeds back to the inputs, which changes the output back again....
- It is very important to make sure no combination of inputs & outputs can make this undesirable oscillation undesirable happen.

5-26 Edge Triggered Devices

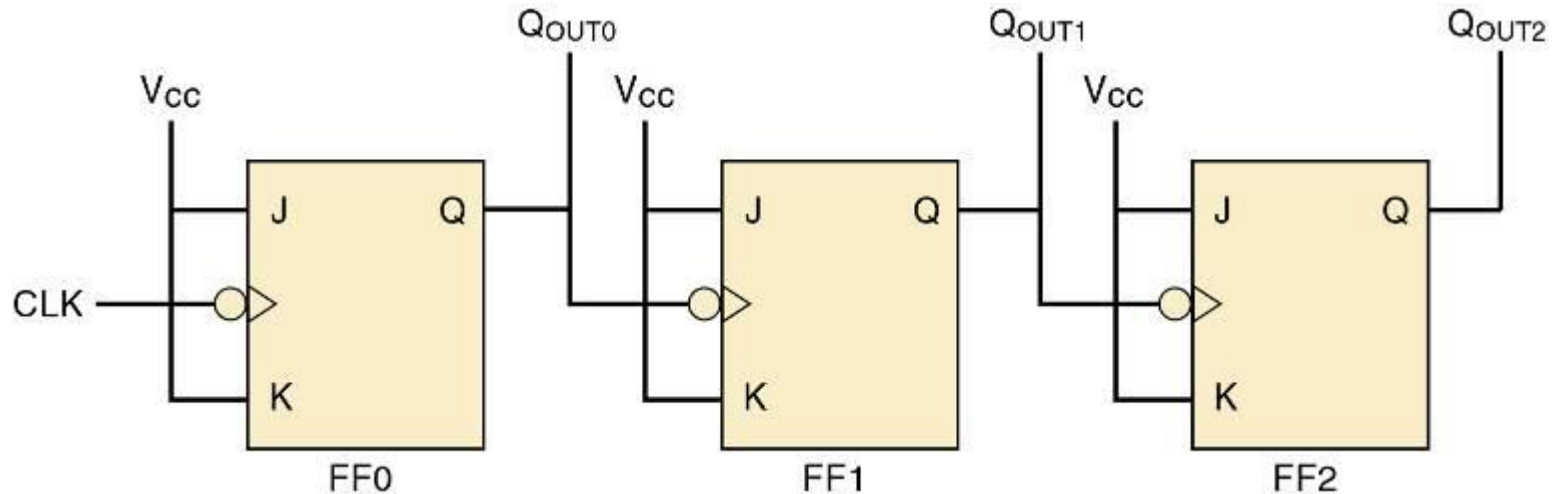
- Edge-triggered device output respond to the inputs when the clock input sees an “edge.”
 - An edge is a transition from HIGH to LOW, or vice versa—and is often referred to as an **event**.

The J-K flip-flop is a standard building block of clocked (sequential) logic circuits known as a **logic primitive**.



5-27 HDL Circuits with Multiple Components

A three-bit binary counter.



**These logic symbols are
negative edge-triggered.**

**These flip-flops do not have
asynchronous inputs prn or clrn.**

END

ELEVENTH EDITION

Digital Systems

Principles and Applications

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