Chapter 5 – Flip-Flops and Related Devices

ELEVENTH EDITION

Digital Systems

Principles and Applications

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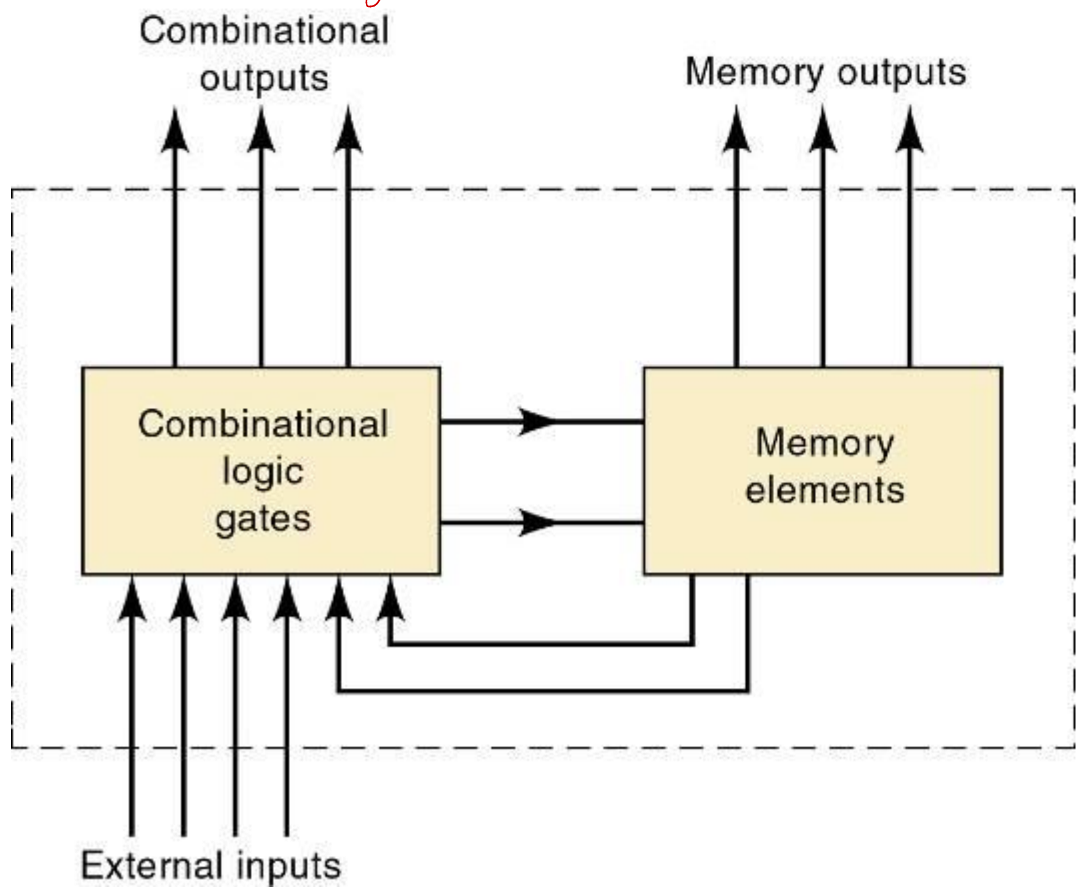
Chapter 5 Objectives

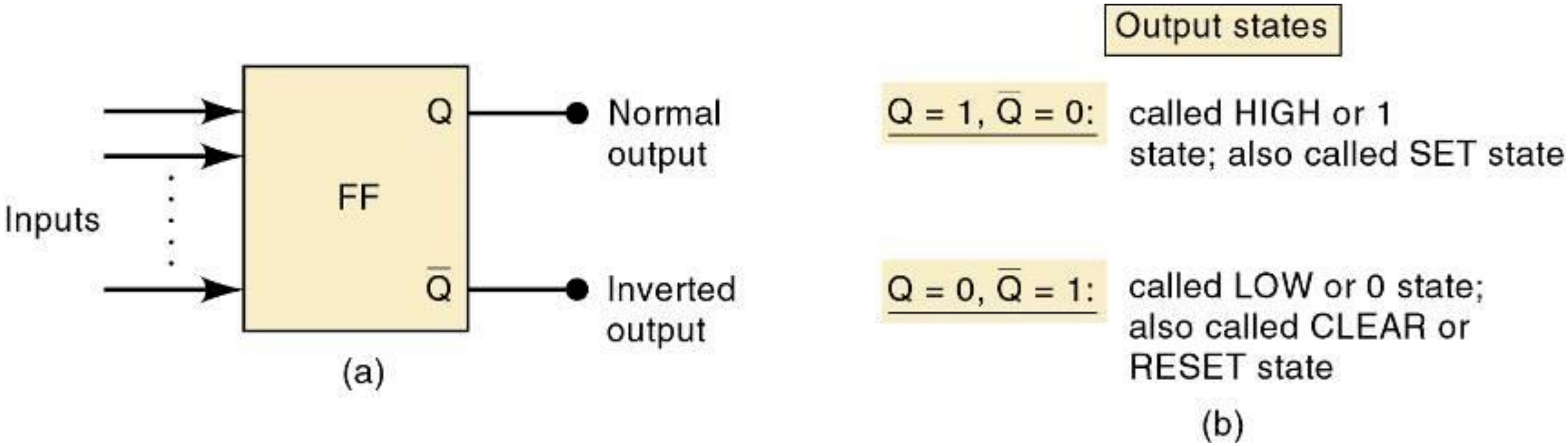
- *Selected areas covered in this chapter*:
  - Constructing/analyzing operation of latch flip-flops made from NAND or NOR gates.
  - Differences of synchronous/asynchronous systems.
  - Major differences between parallel & serial transfers.
  - Operation of edge-triggered flip-flops.
  - Typical characteristics 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.

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

รวม logic gates ไว้กับ memory devices



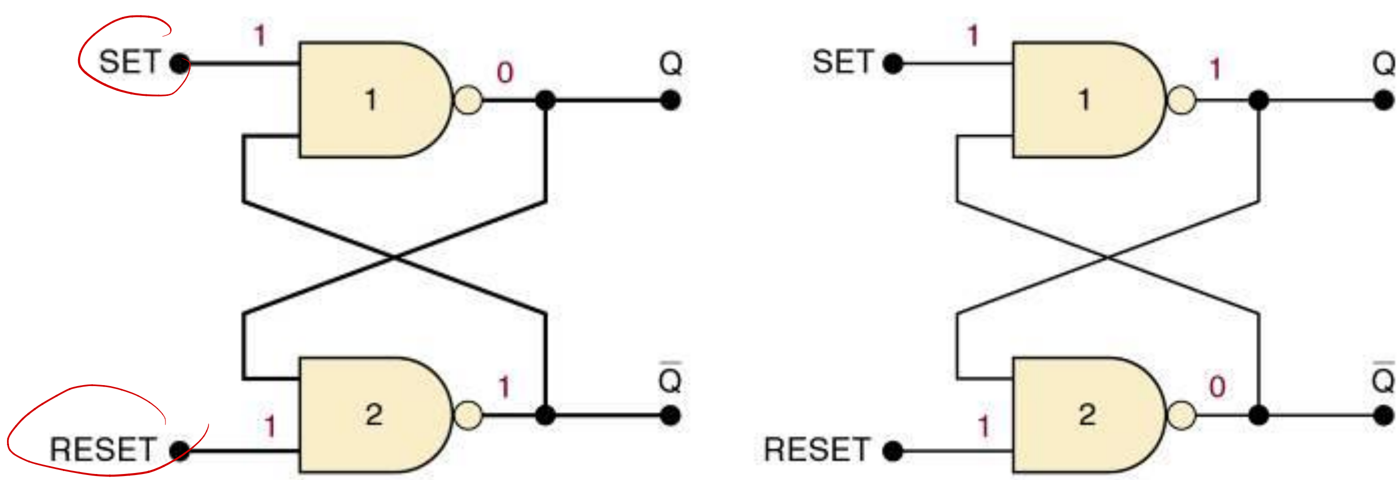
- The most important memory element is the **flip-flop** (FF)—made up of an assembly of logic gates.



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 $\overline{\mathbf{Q}}$ = 0
  - When the latch is clear or reset: **Q** = 0 and $\overline{\mathbf{Q}}$ = 1



Sync
অন্য Clock

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

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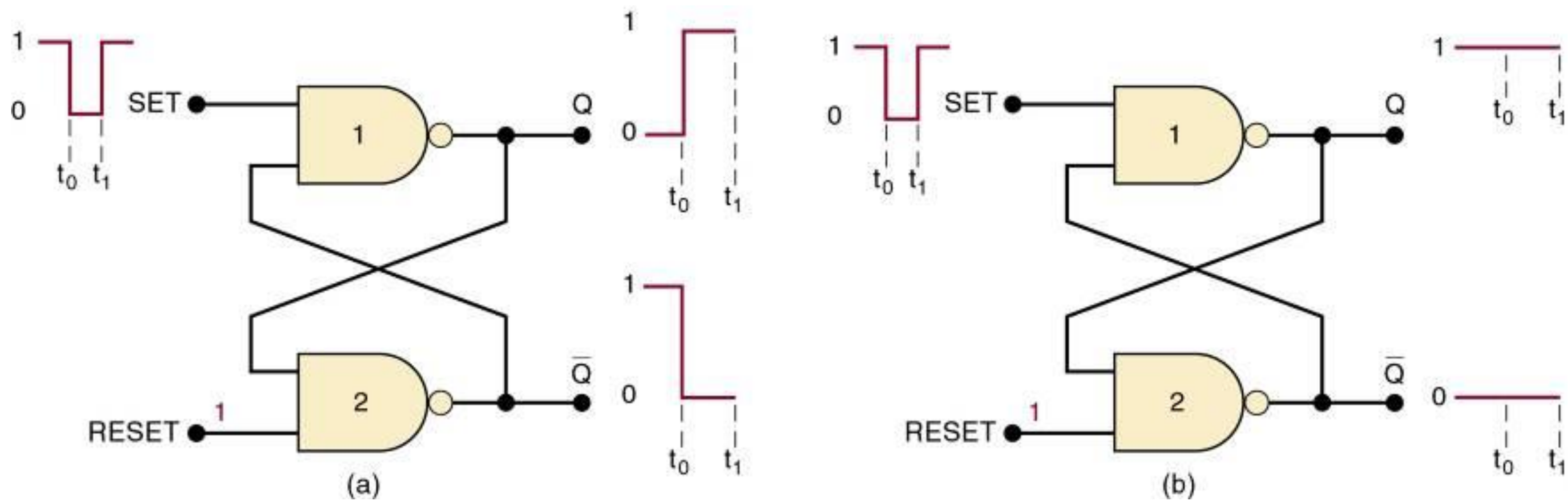
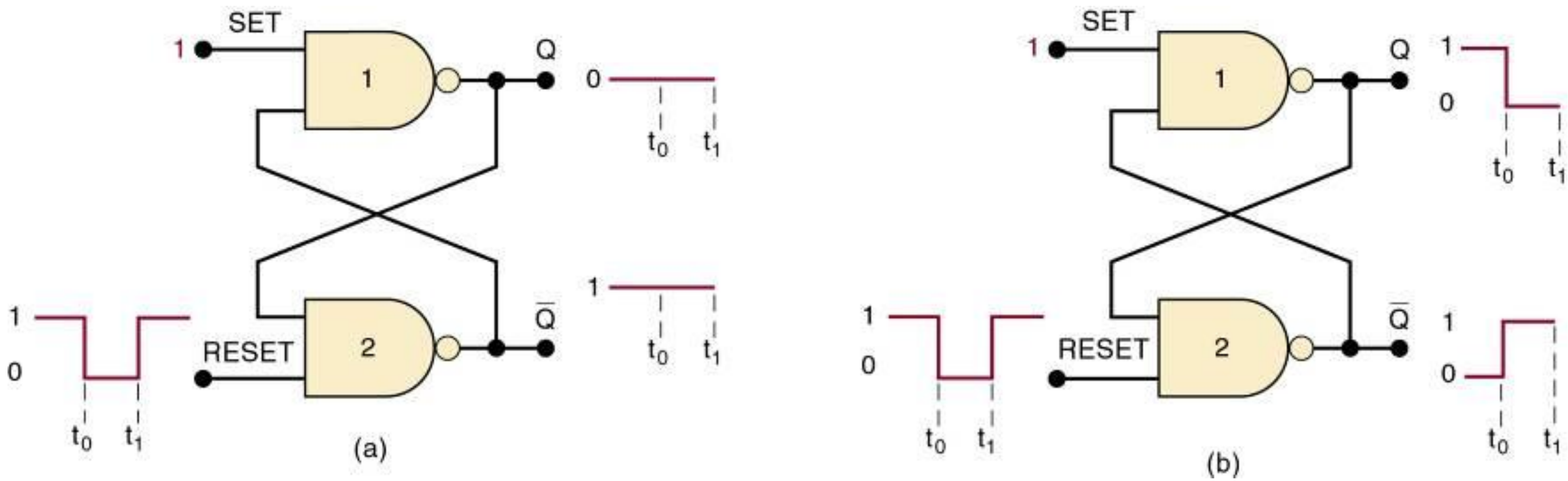


In both cases, *Q* ends up HIGH.

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.

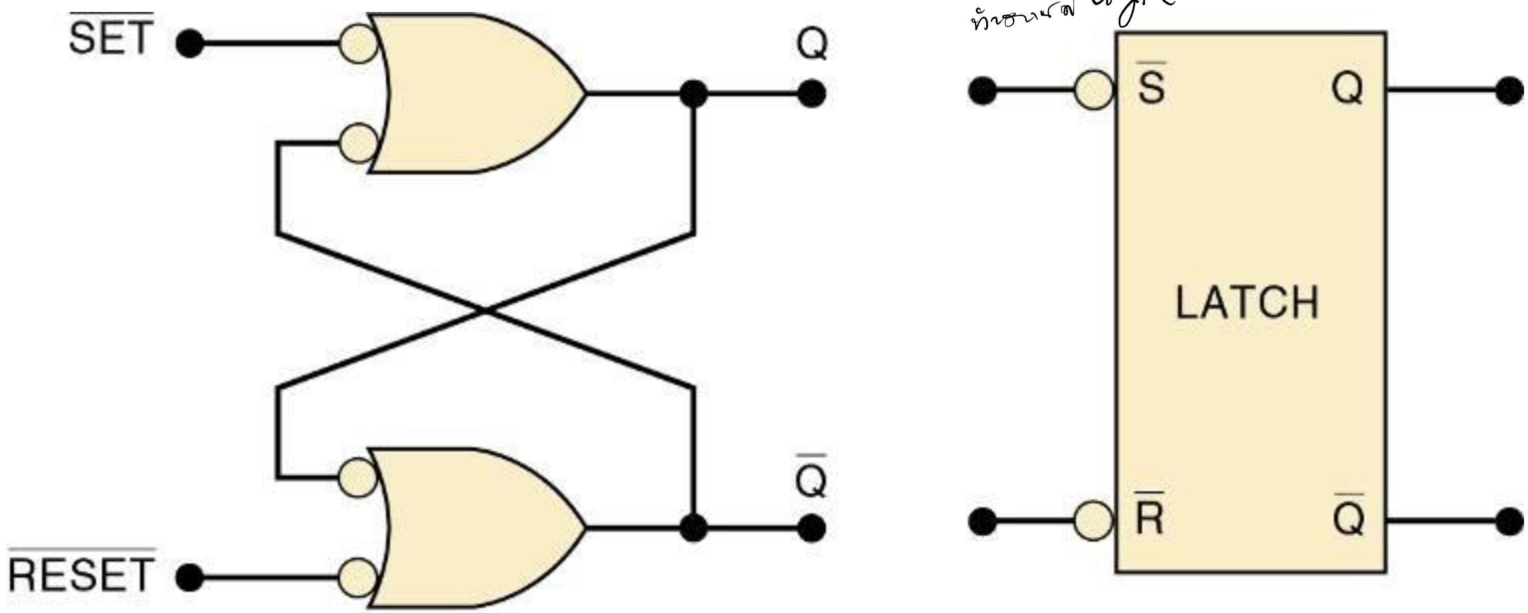


In each case, *Q* ends up LOW.

5-1 NAND Gate Latch – Alternate Representations

NAND latch equivalent representations and simplified block diagram.

ทำงานที่ logic 0

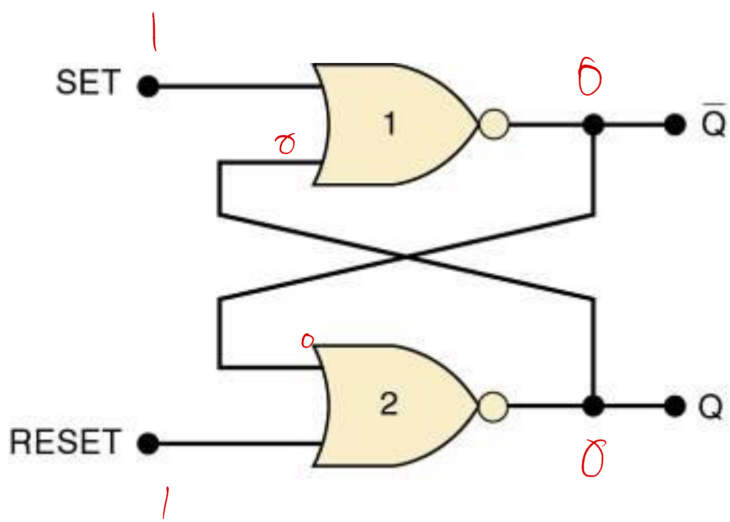


- Summary of the **NAND** latch:
  - **SET = 1, RESET = 1**—Normal resting state, outputs remain in state they were in prior to input.
  - **SET = 0, RESET = 1**—Output will go to Q = 1 and remains there, even after SET returns HIGH.
    - Called *setting* the latch.
  - **SET = 1, RESET = 0**—Will produce 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 $\boxed{Q = \overline{Q} = 1}$. ไม่รู้
    - Output is unpredictable, and this input condition should not be used.

SET	RESET	Q	$\overline{Q}$	
0	0	1	1	ไม่รู้
0	1	1	0	
1	0	0	1	
1	1			ไม่เปลี่ยน

5-2 NOR Gate Latch

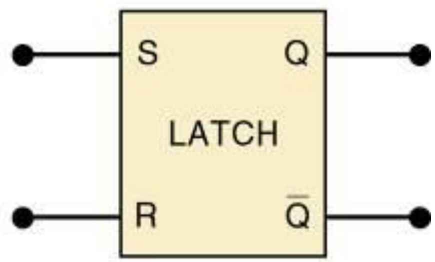
- Two cross-coupled **NOR** gates can be used as a **NOR** gate latch—similar to the **NAND** latch.
  - The **Q** and $\overline{\mathbf{Q}}$ outputs are reversed.



$\overline{Q} \neq Q$

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

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



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

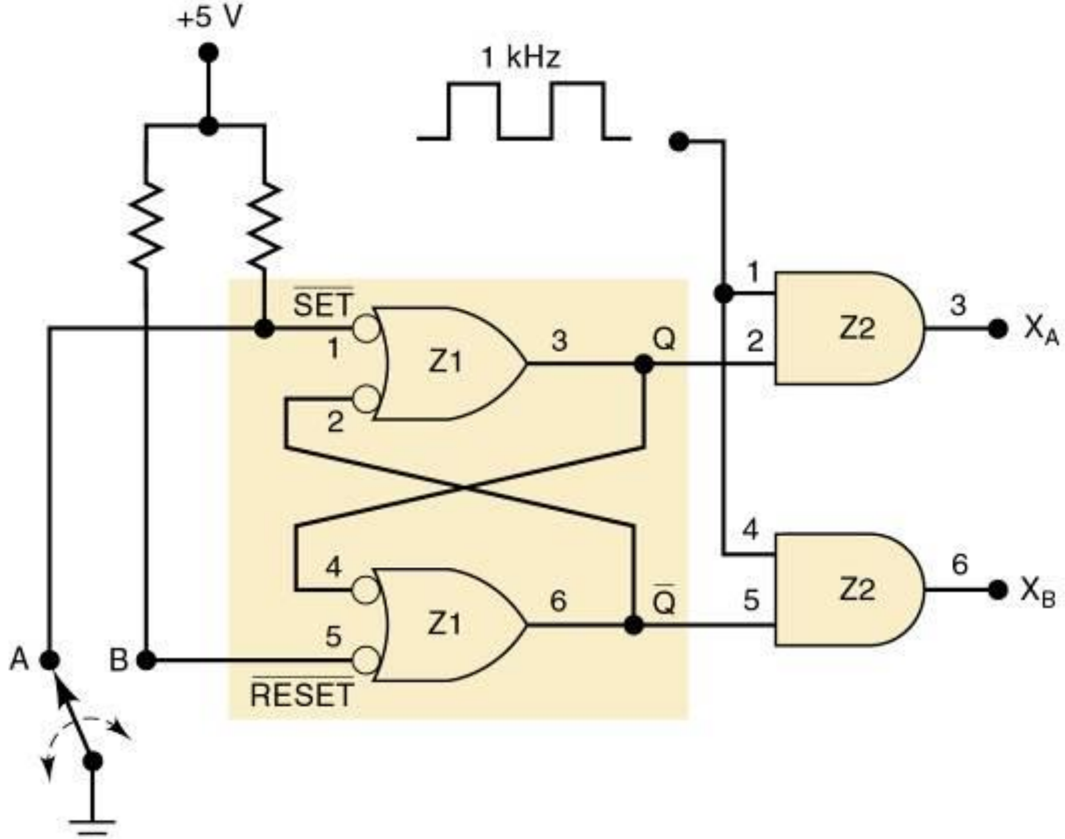
5-1 NOR Gate Latch - Summary

- 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	$\overline{SET}$ (Z1-1)	$\overline{RESET}$ (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.

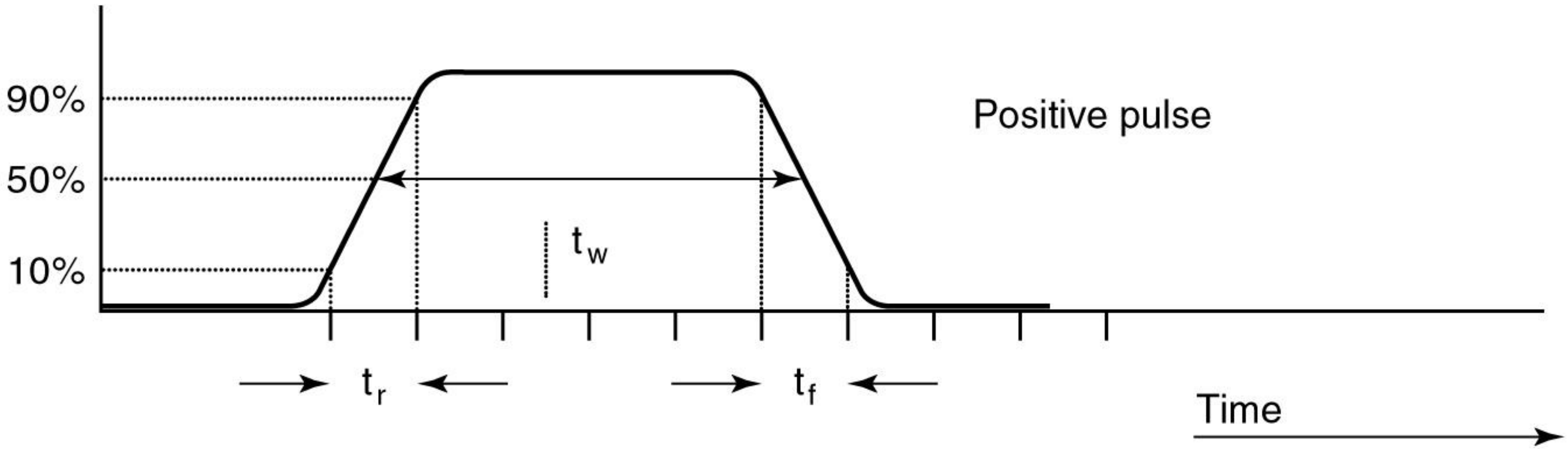
Switch position	X_A	X_B
A	Pulses	LOW
B	LOW	Pulses

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

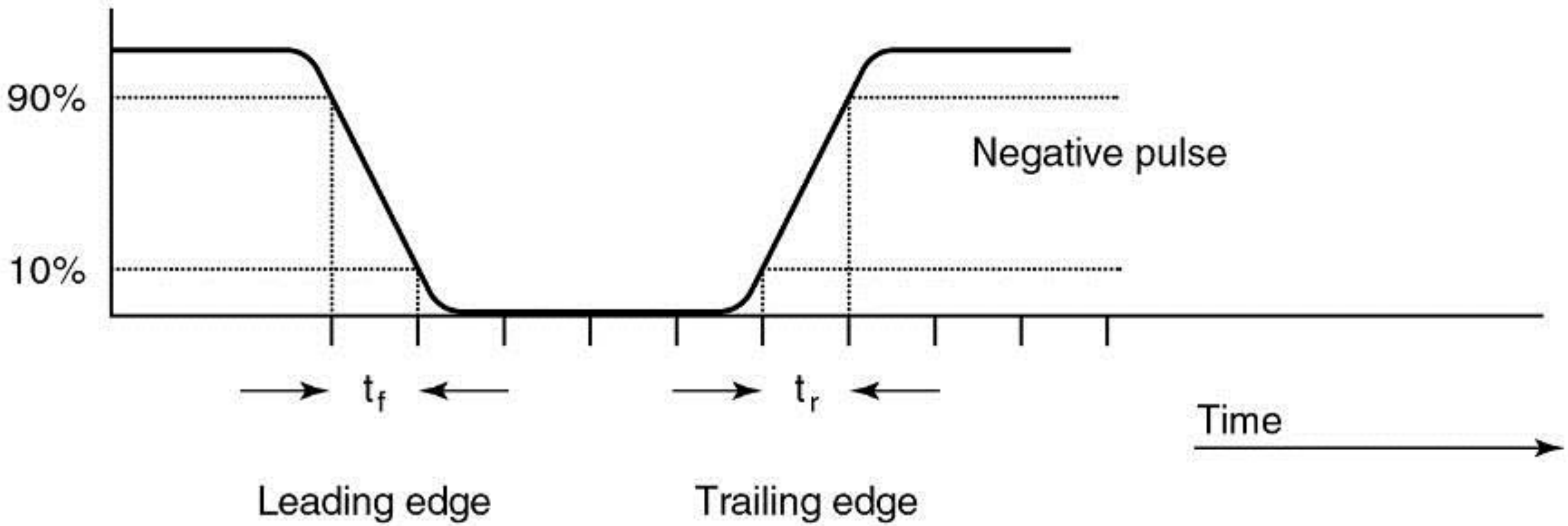
Signals that switch between active and inactive states are called pulse waveforms.



A positive pulse has an active-HIGH level.

5-4 Digital Pulses

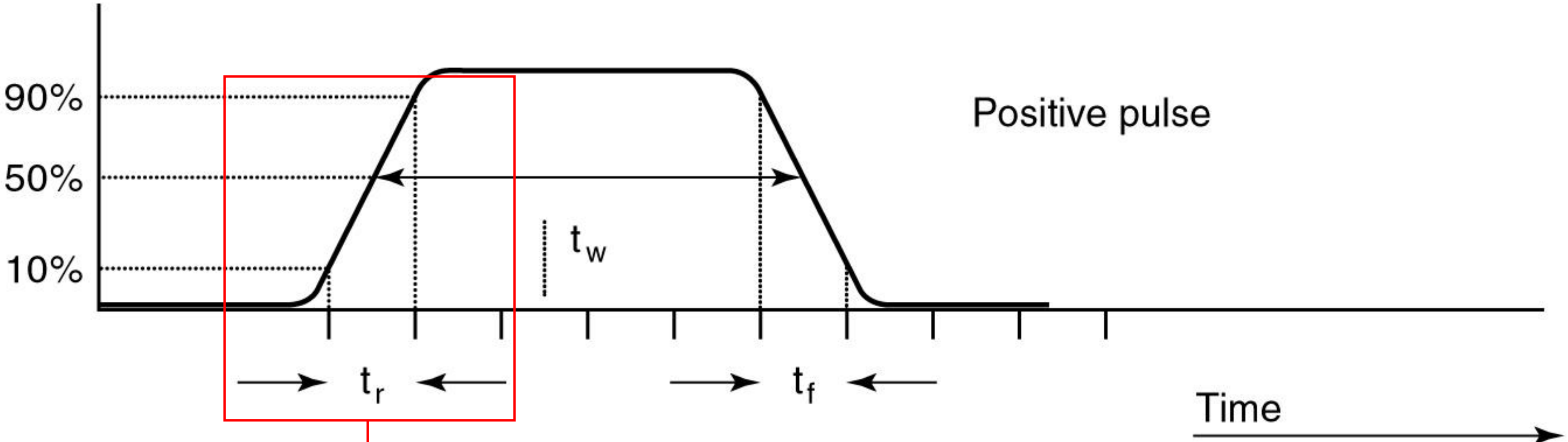
Signals that switch between active and inactive states are called pulse waveforms.



A negative pulse has an active-LOW level.

5-4 Digital Pulses

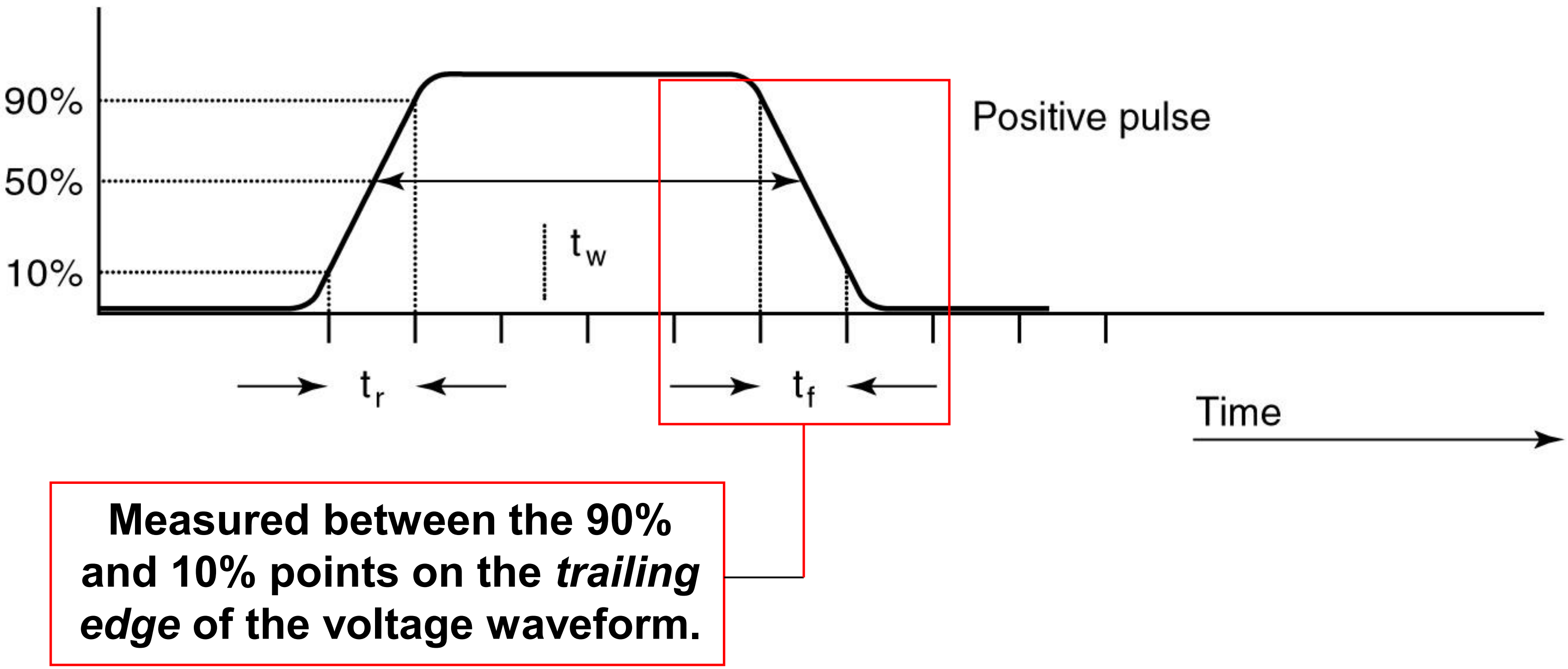
- In actual circuits it takes time for a pulse waveform to change from one level to the other.
  - Transition from LOW to HIGH on a positive pulse is called *rise time* (t_r).



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

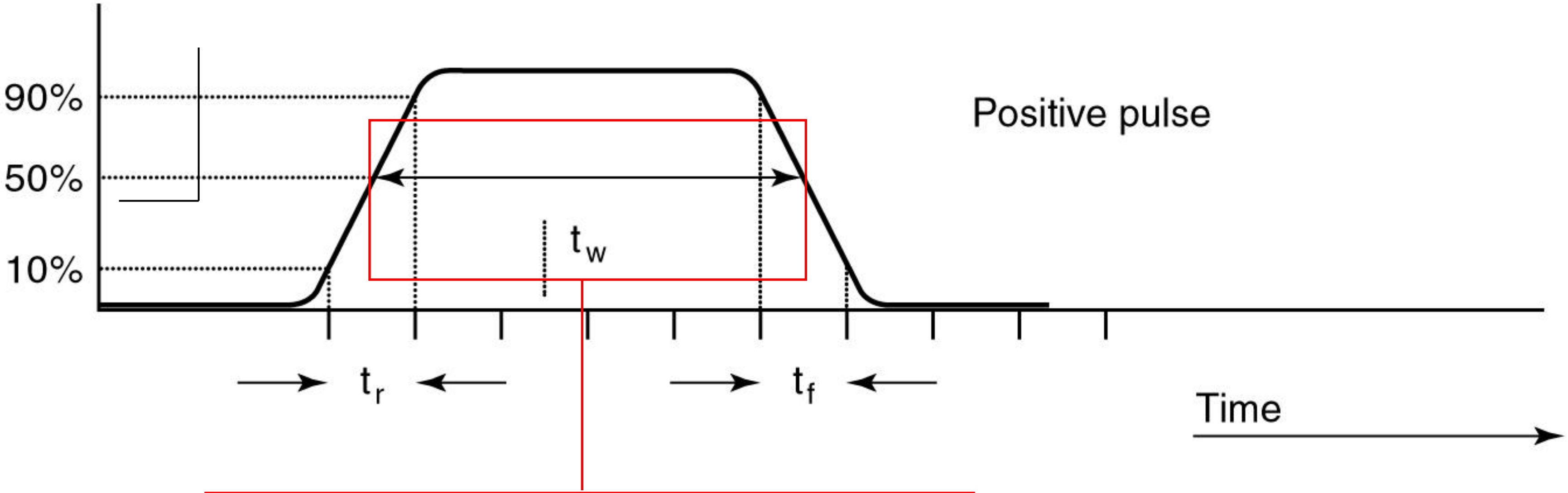
5-4 Digital Pulses

- 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).



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.

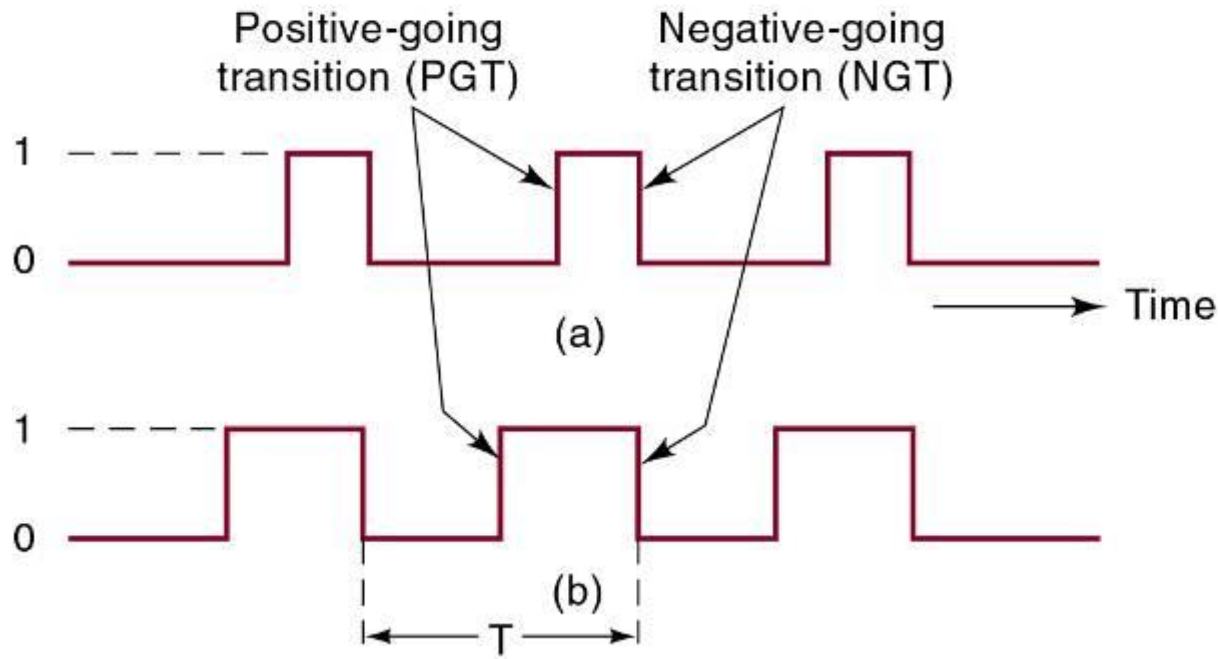
5-5 Clock Signals and Clocked Flip-Flops

- 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*.

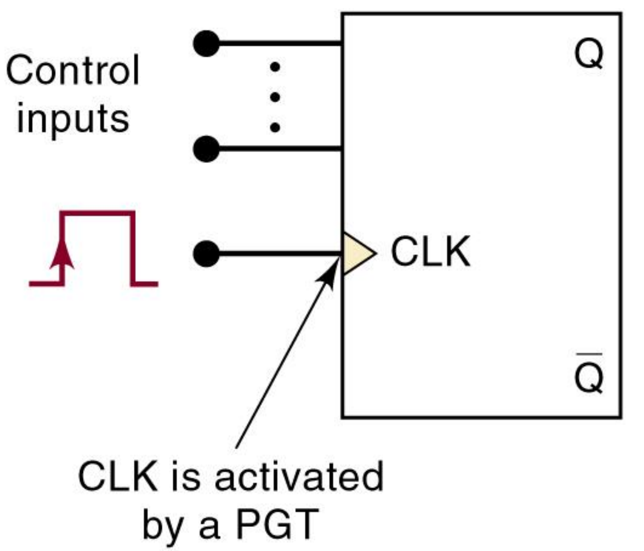


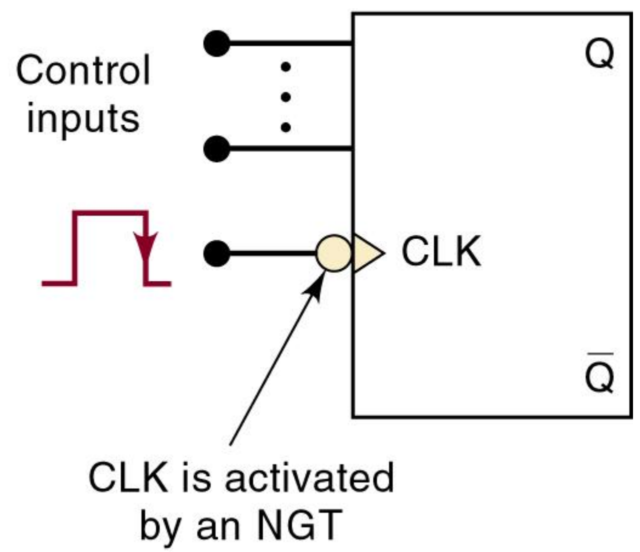
5-5 Clock Signals and Clocked Flip-Flops

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

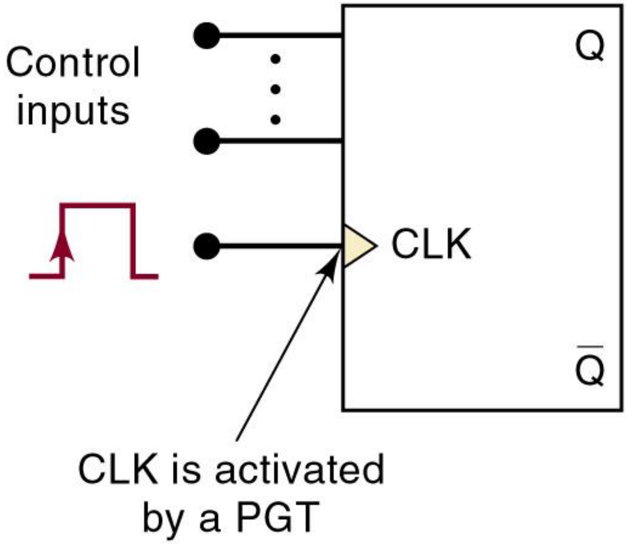
A small triangle at the CLK input indicates that the input is activated with a PGT.

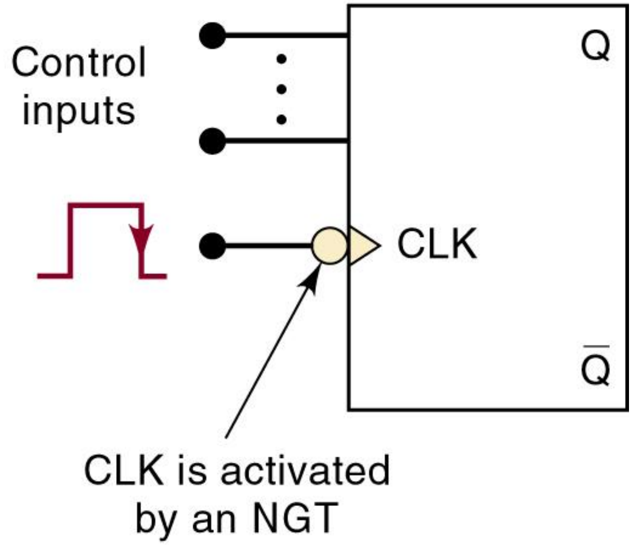
A bubble and a triangle indicates that the CLK input is activated with a NGT.



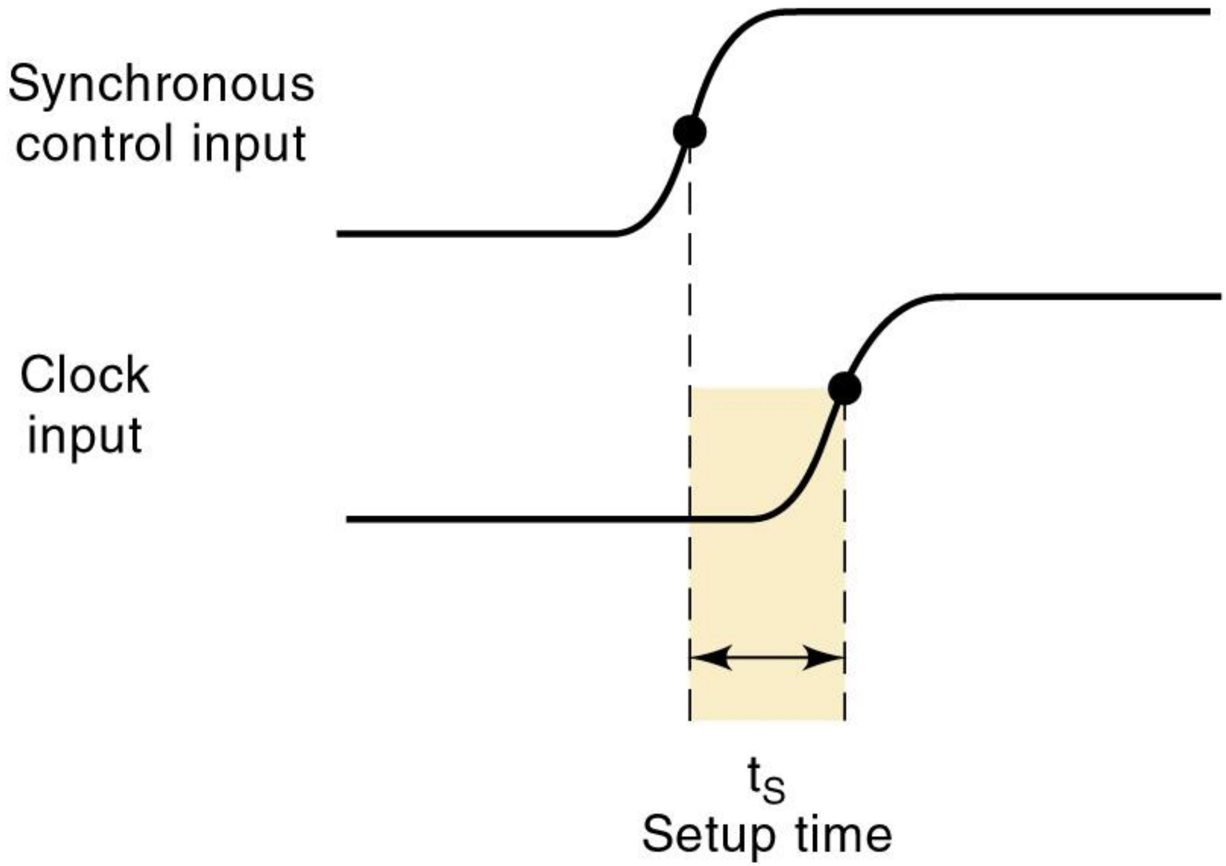


- Control inputs have an effect on the output only at the active clock transition (NGT or PGT)—also called synchronous control inputs.
  - The control inputs get the outputs ready to change, but the change is not triggered until the CLK edge.

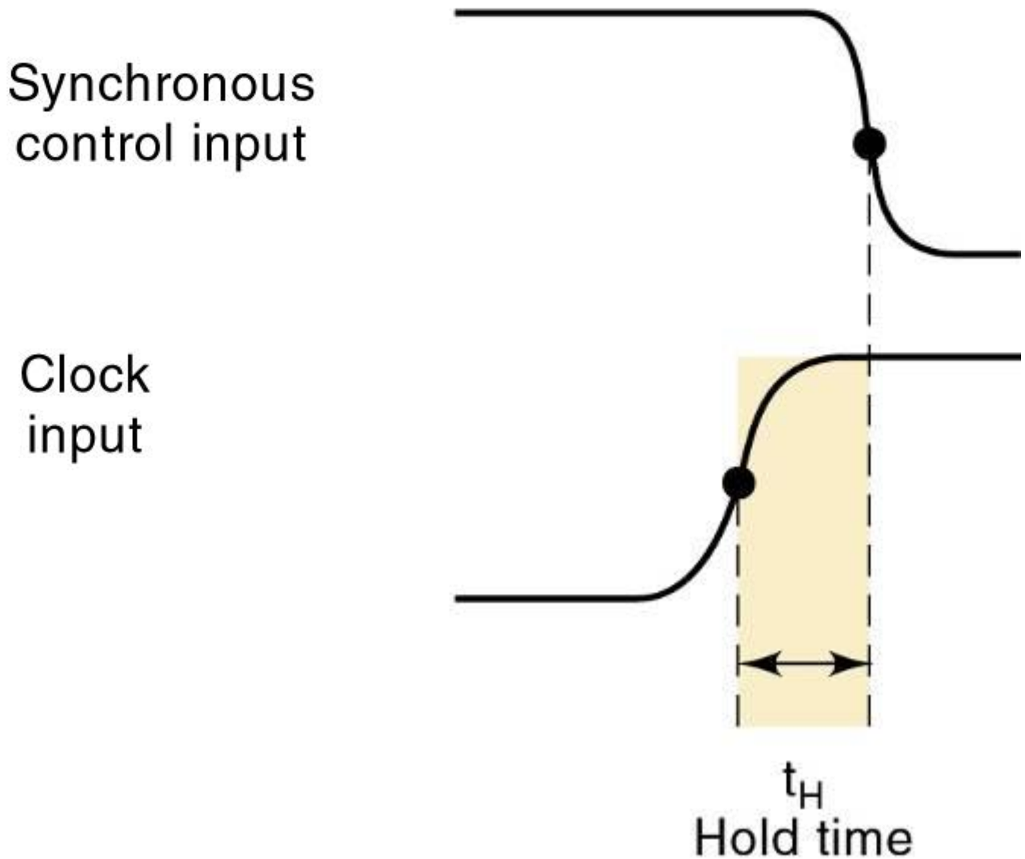




- *Setup time* (t_S) is the minimum time interval before the active CLK transition that the control input must be kept at the proper level.



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

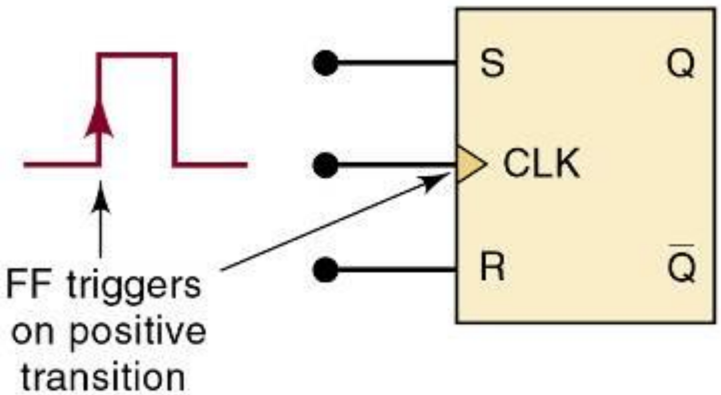


5-6 Clocked S-R Flip-Flop

- 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.



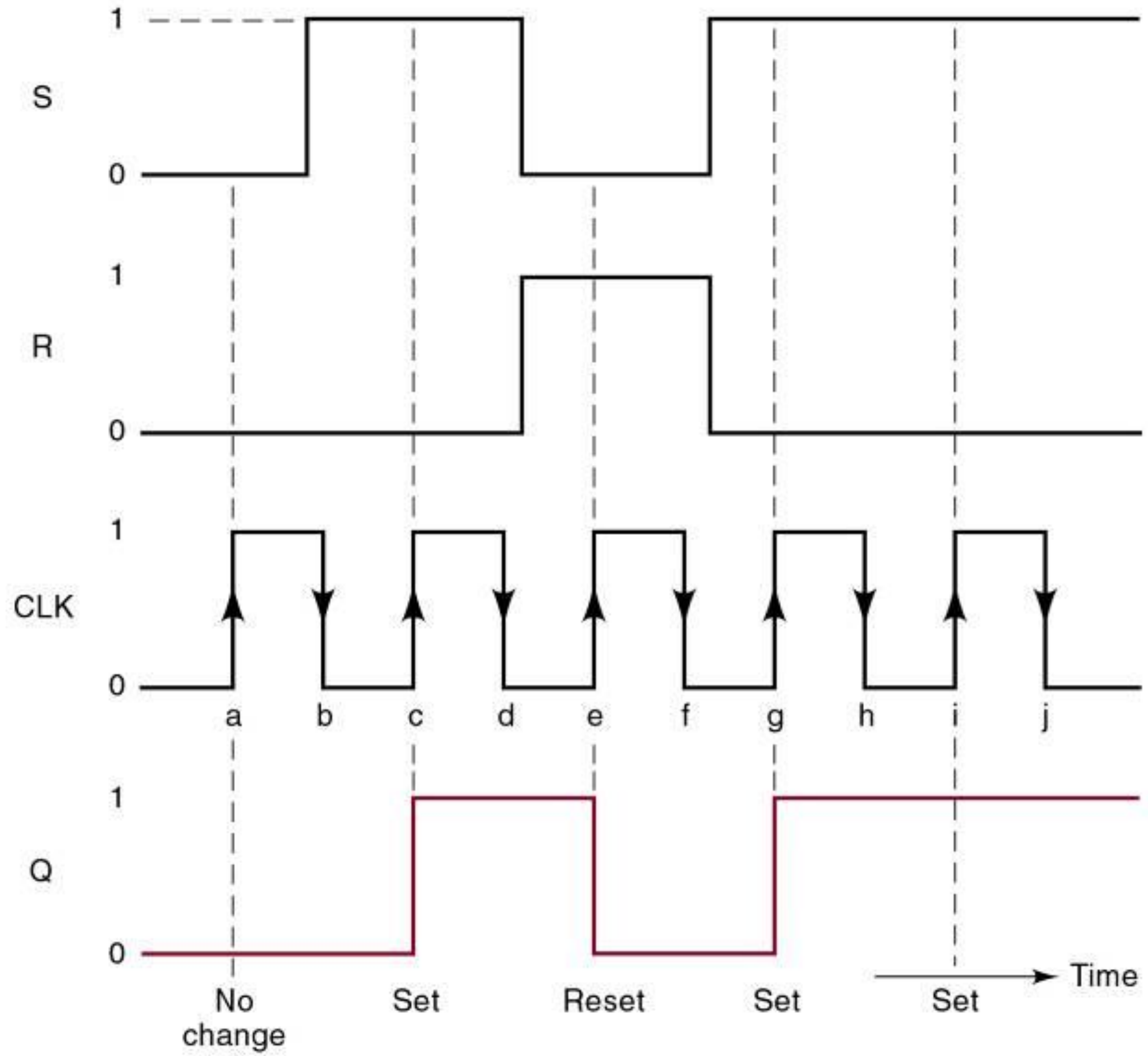
Inputs			Output
S	R	CLK	Q
0	0	↑	Q_0 (no change)
1	0	↑	1
0	1	↑	0
1	1	↑	Ambiguous

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.

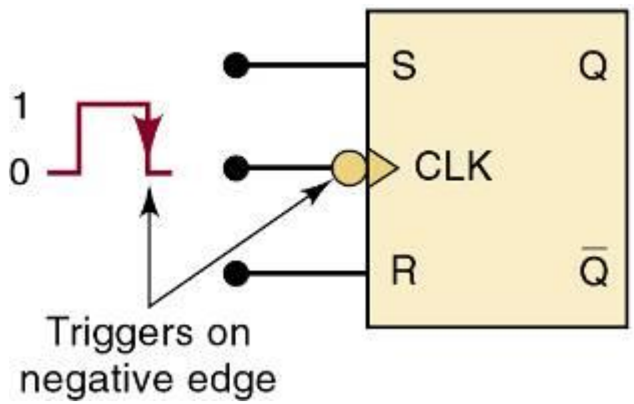
5-6 Clocked S-R Flip-Flop

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

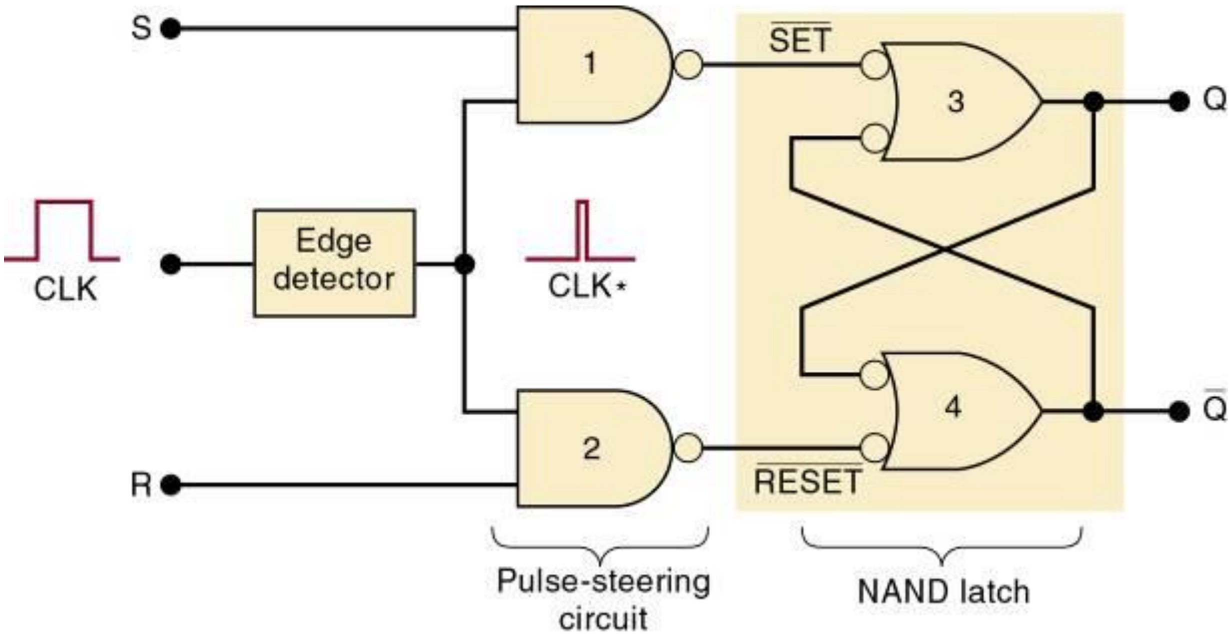
A clocked S-R flip-flop triggered by the negative-going edge of the clock signal.



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.

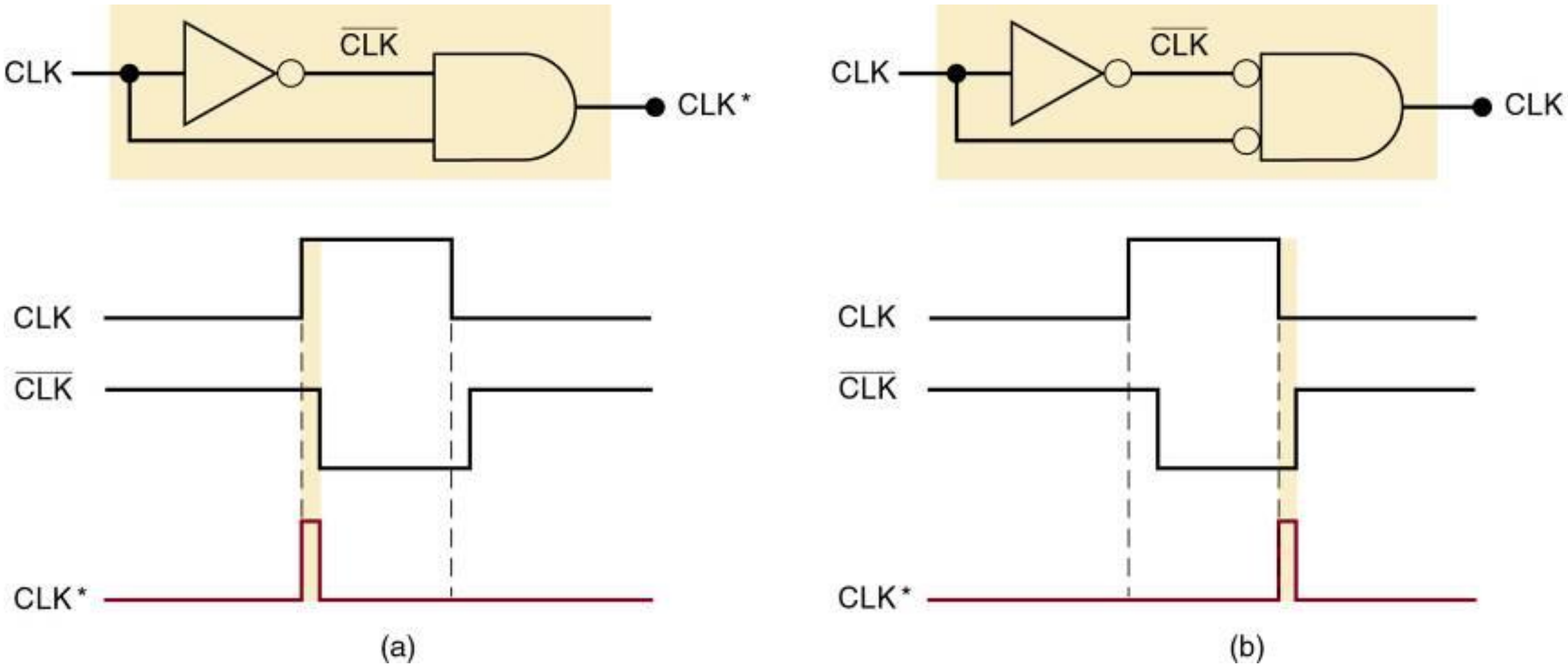
5-6 Clocked S-R Flip-Flop – Internal Circuitry



- 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.

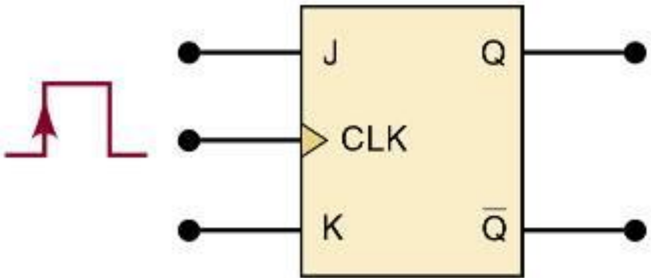


The duration of the *CLK** pulses is typically 2–5 ns.

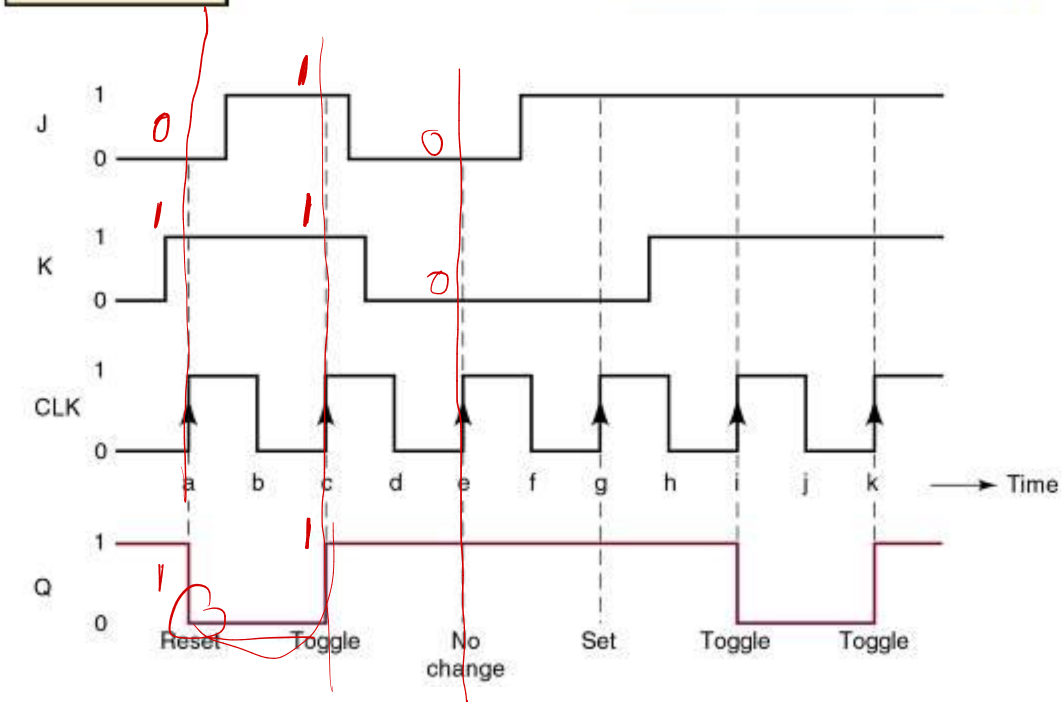
5-7 Clocked J-K Flip-Flop

- 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.

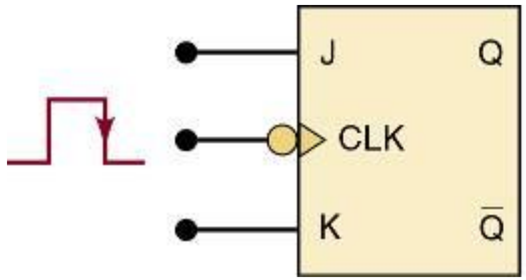
Clocked J-K flip-flop that responds only to the positive edge of the clock.



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



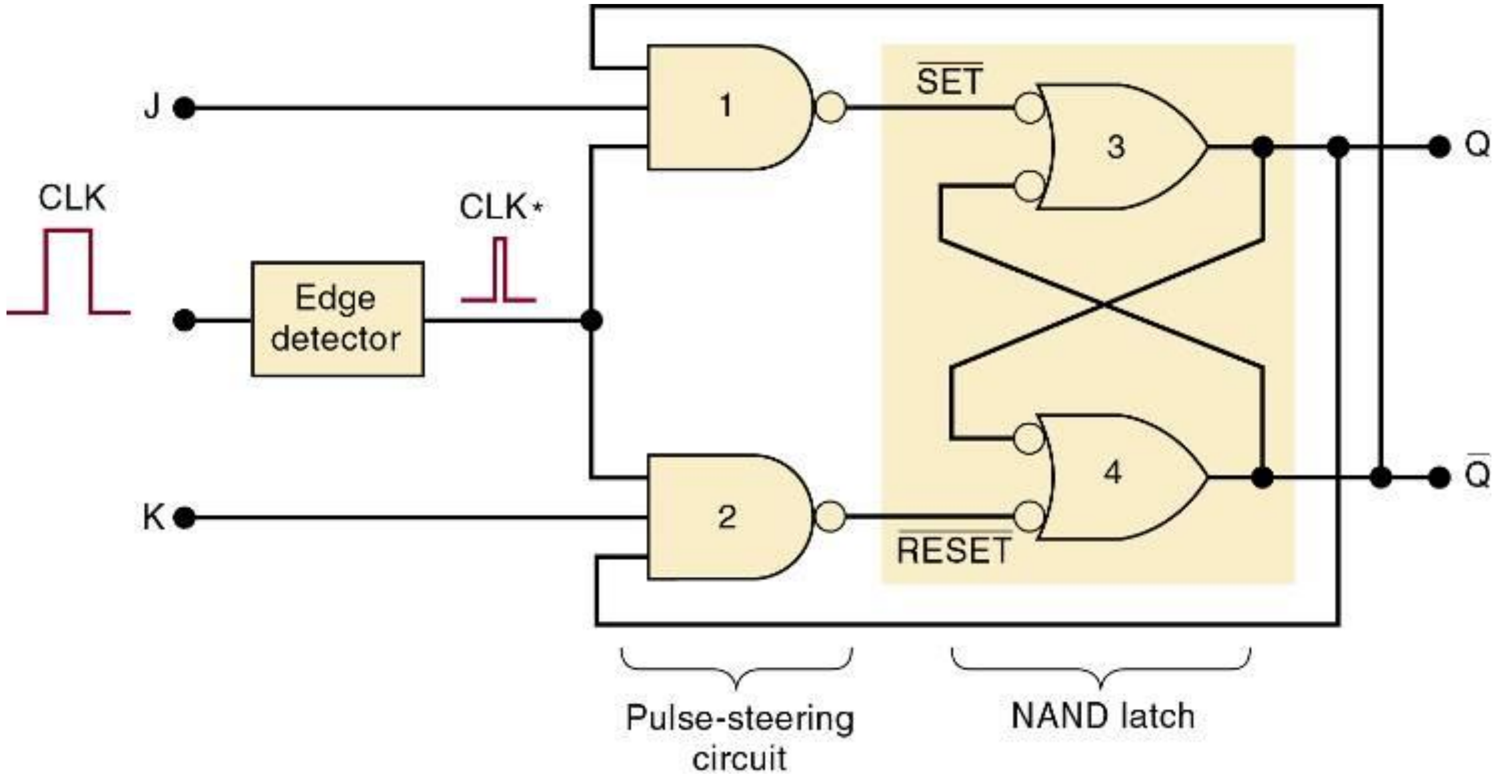
Clocked J-K flip-flop that responds only to the negative edge of the clock.



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.

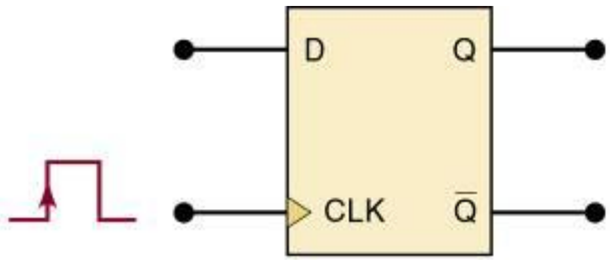


5-8 Clocked D Flip-Flop

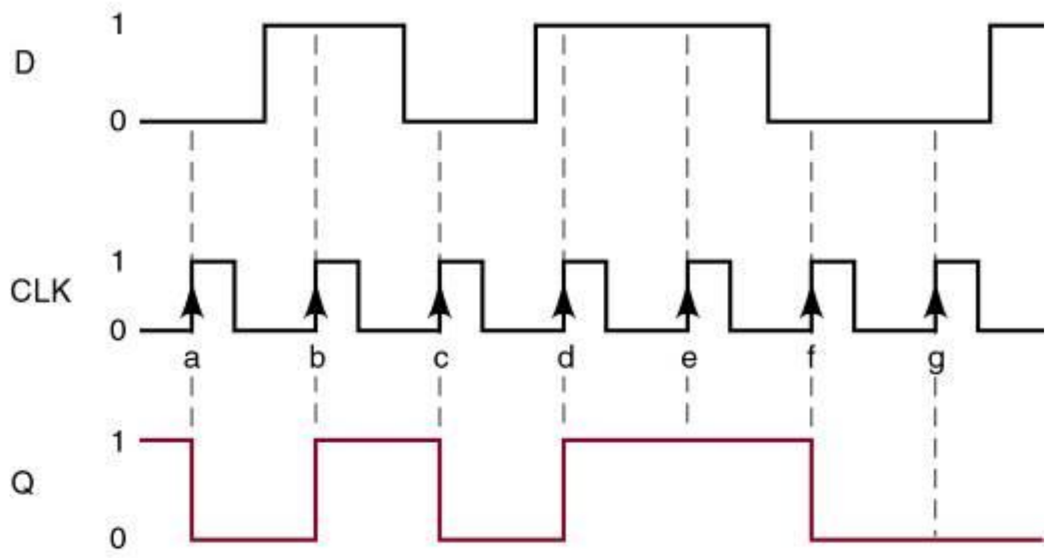
- One data input—output changes to the value of the input at either the positive- or negative-going clock trigger.
- May be implemented with a J-K FF by tying the J input to the K input through an inverter.
- Useful for parallel data transfer.

5-8 Clocked D Flip-Flop

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



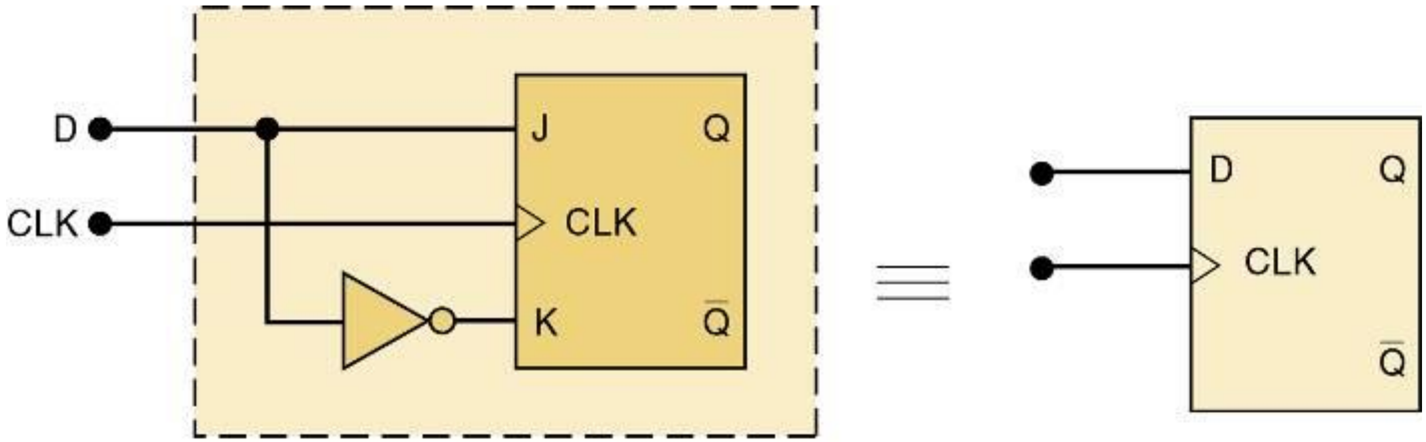
D	CLK	Q
0	↑	0
1	↑	1



5-8 Clocked D Flip-Flop - Implementation

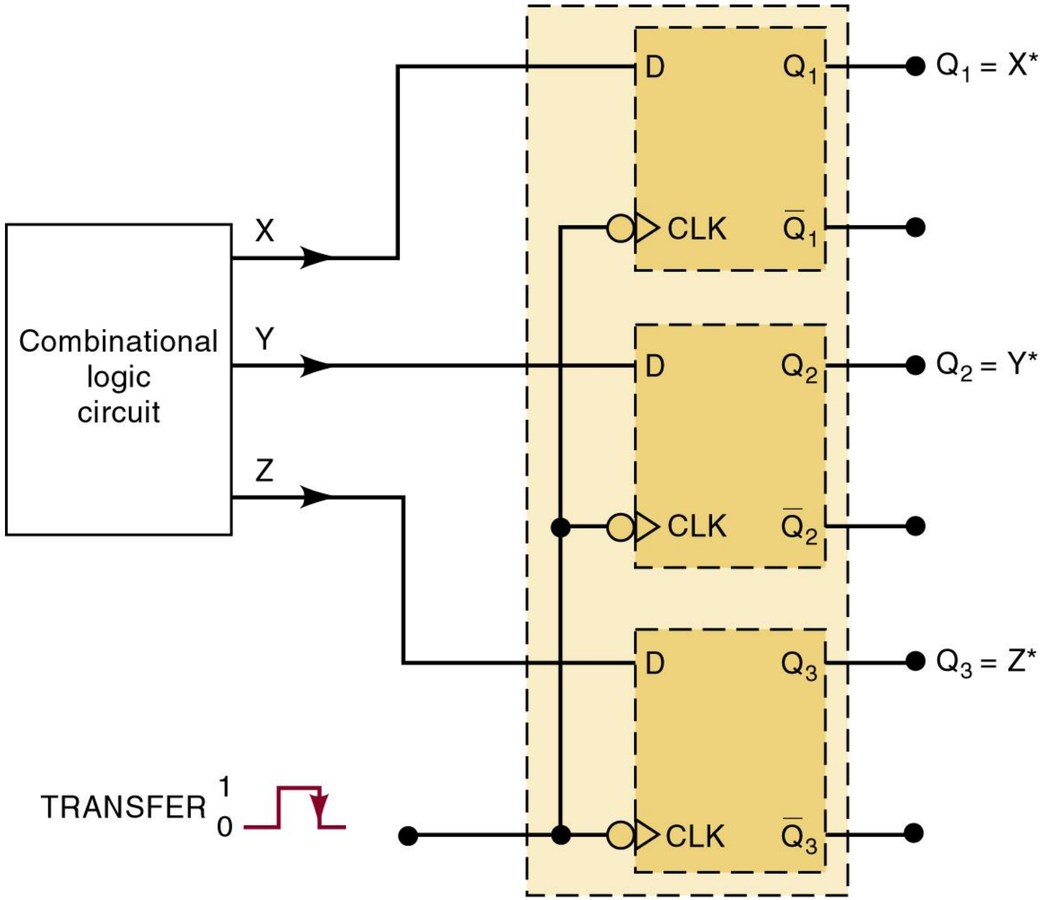
- An edge-triggered D flip-flop is implemented by adding a single INVERTER to the edge-triggered J-K flip-flop.
  - The same can be done to convert a S-R flip-flop to a D flip-flop.

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



Outputs *X, Y, Z* are to be transferred to FFs *Q1*, *Q2*, and *Q3* for storage.

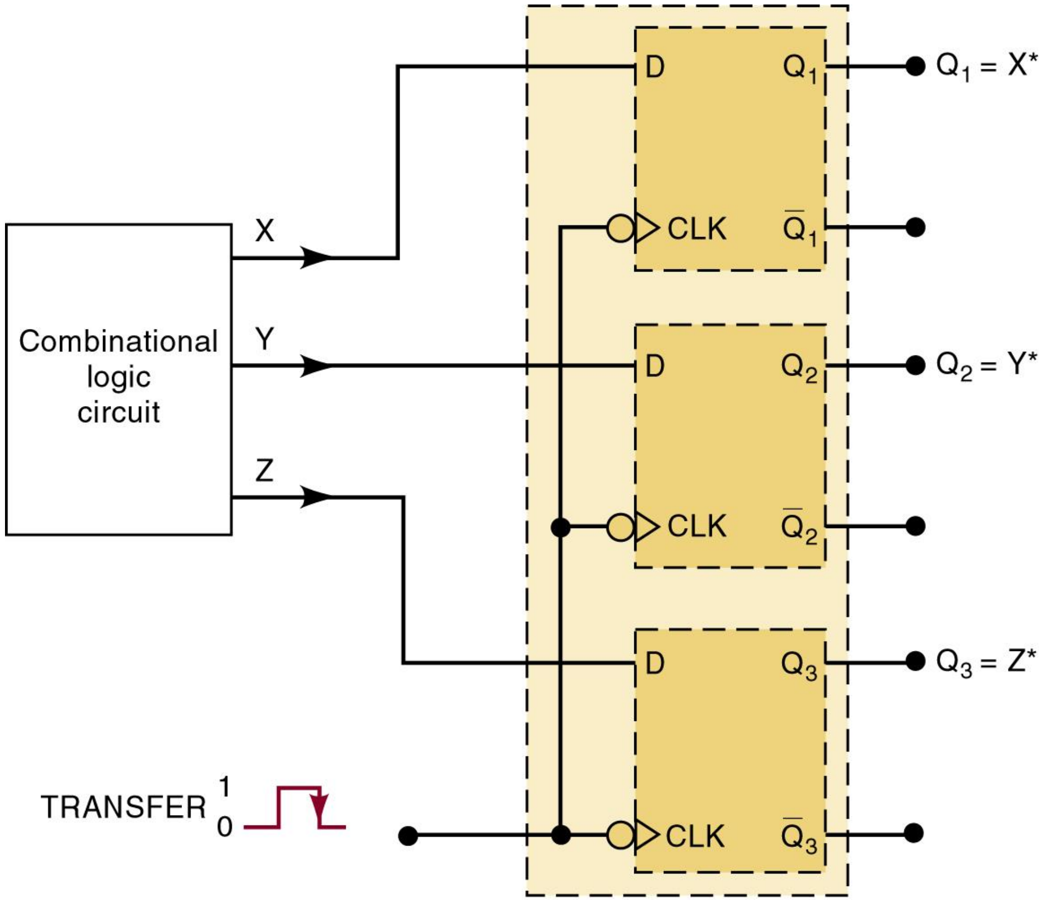
Using D flip-flops, levels present at *X*, *Y* & *Z* will be transferred to *Q*1, *Q*2 & *Q*3, upon application of a TRANSFER pulse to the common *CLK* inputs.



*After occurrence of NGT

Outputs *X, Y, Z* are to be transferred to FFs *Q1*, *Q2*, and *Q3* for storage.

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

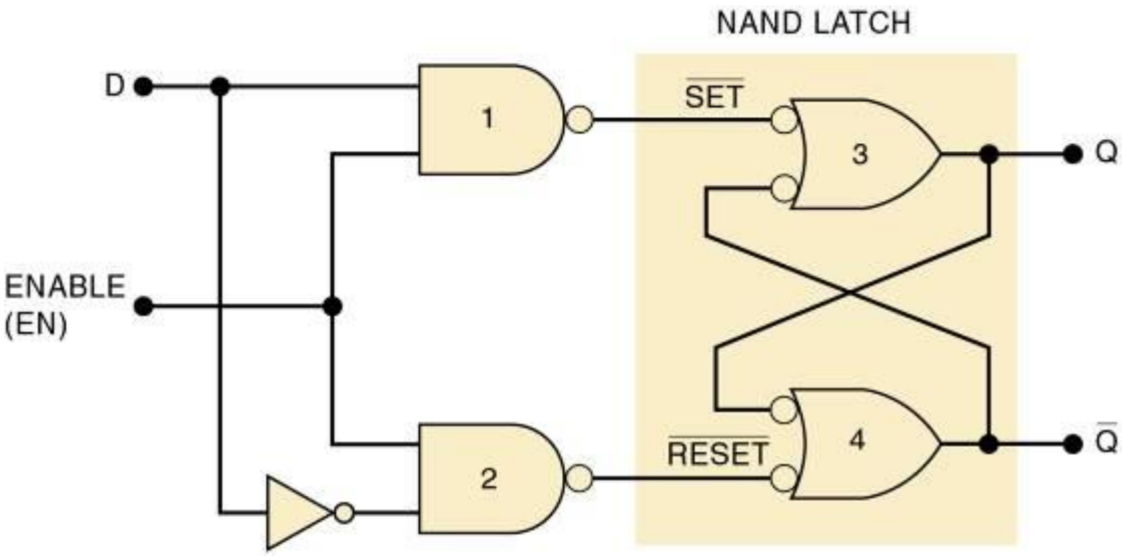


*After occurrence of NGT

5-9 D Latch (Transparent Latch)

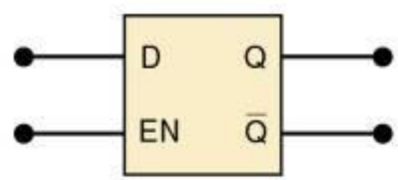
- The edge-triggered D flip-flop uses an edge-detector circuit to ensure the output responds to the *D* input *only* on active transition of the clock.
  - If this edge detector is not used, the resultant circuit operates as a **D latch**.

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."
Q_0 is state Q just prior to EN going LOW.



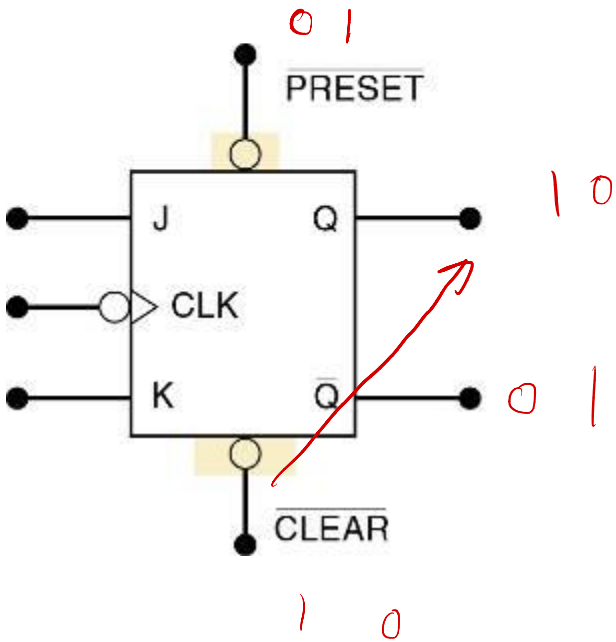
5-9 D Latch (Transparent Latch)

- 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 $\overline{Q}$ 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.

Clocked J-K flip-flop with asynchronous inputs.



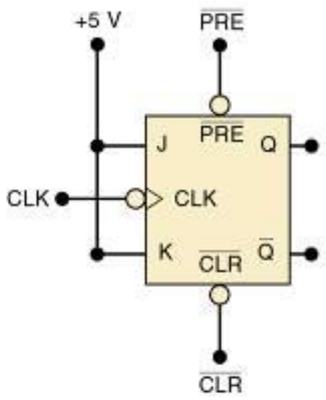
J	K	Clk	$\overline{PRE}$	$\overline{CLR}$	Q
0	0	↓	1	1	Q (no change)
0	1	↓	1	1	0 (Synch reset)
1	0	↓	1	1	1 (Synch set)
1	1	↓	1	1	$\overline{Q}$ (Synch toggle)
x	x	x	1	1	Q (no change)
x	x	x	1	0	0 (asynch clear)
x	x	x	0	1	1 (asynch preset)
x	x	x	0	0	(Invalid)

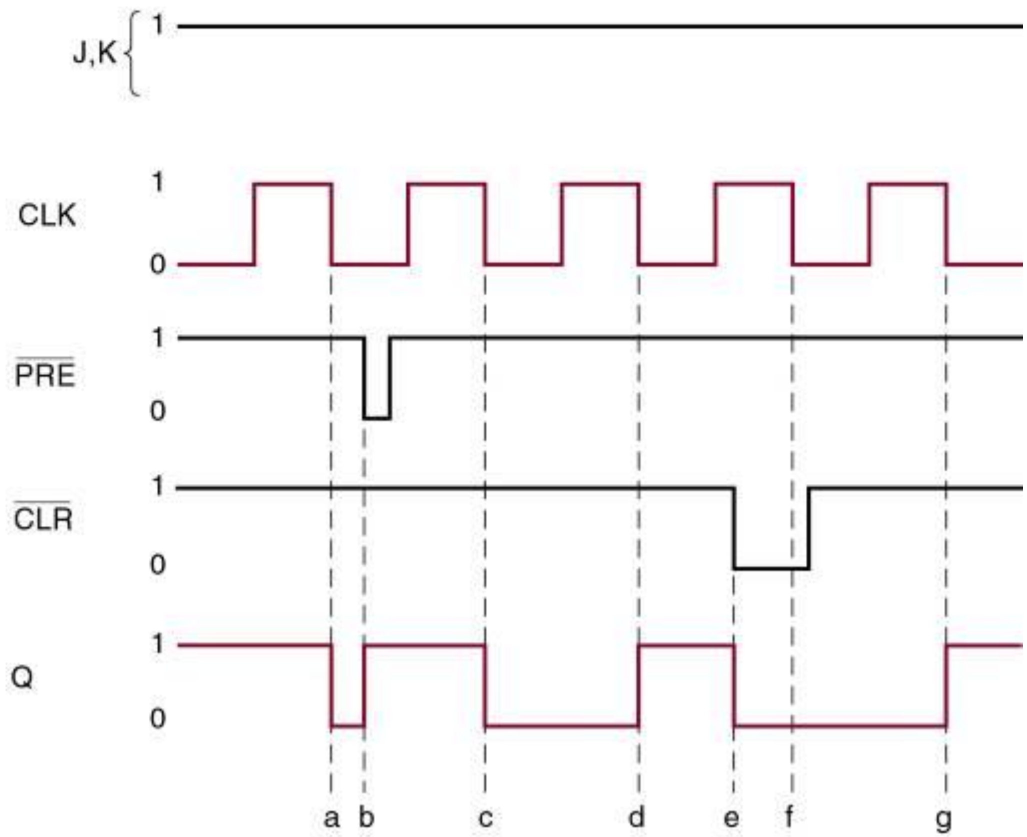
5-10 Asynchronous Inputs - Designations

- 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.



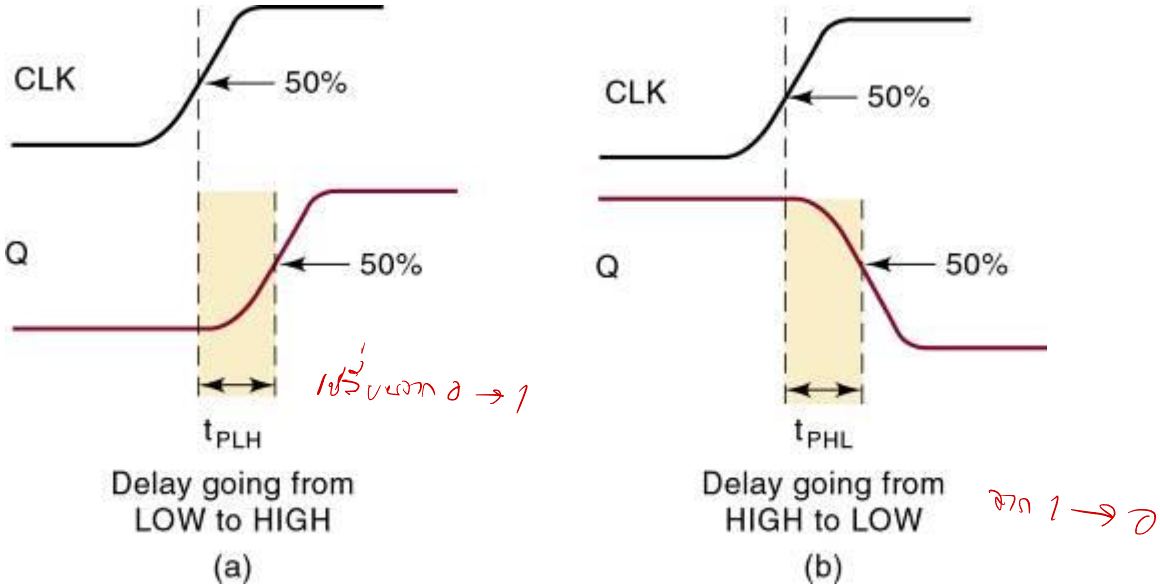


Point	Operation
a	Synchronous toggle on NGT of CLK
b	Asynchronous set on $\overline{PRE}$ = 0
c	Synchronous toggle
d	Synchronous toggle
e	Asynchronous clear on $\overline{CLR}$ = 0
f	$\overline{CLR}$ overrides the NGT of CLK
g	Synchronous toggle

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

FF propagation delays.



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 *CLK* to *Q*	40	24	200	31
t_{PLH}	from *CLK* to *Q*	25	16	200	31
t_{PHL}	from *CLR* to *Q*	40	24	225	41
t_{PLH}	from *PRE* to *Q*	25	16	225	41
$t_W(L)$	*CLK* LOW time	37	15	100	25
$t_W(H)$	*CLK* HIGH time	30	20	100	25
$t_W(L)$	at *PRE* or *CLR*	30	15	60	25
f_{MAX}	in MHz	15	30	5	20

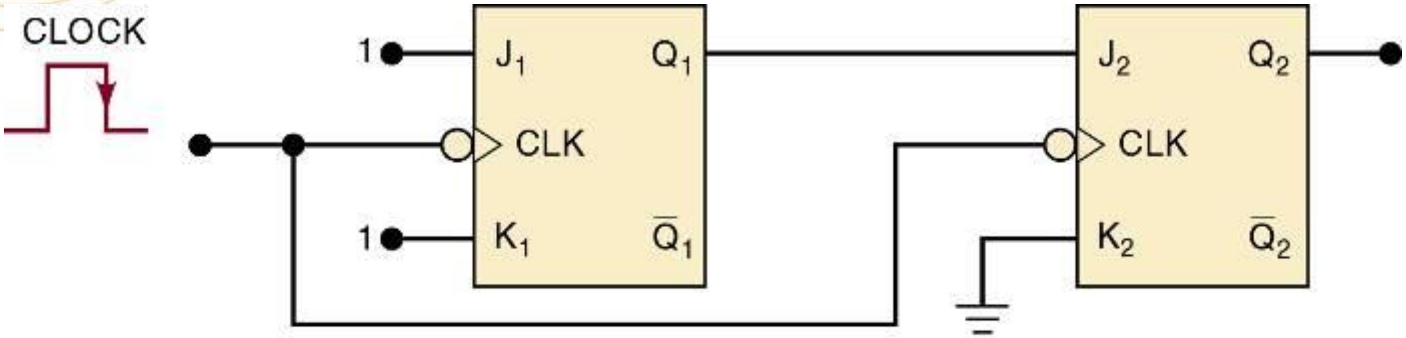
5-12 Potential Timing Problems in FF Circuits

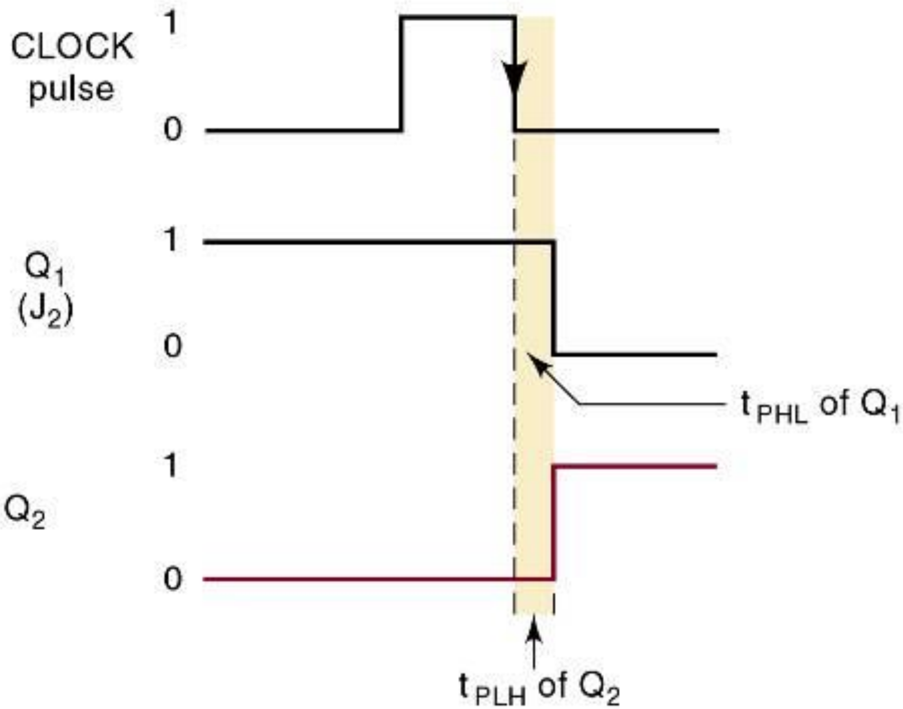
- When the output of one FF is connected to the input of another FF and both are triggered by the same clock, there is a *potential* timing problem.
  - Propagation delay may cause unpredictable outputs.
- Edge-triggered FFs have hold time requirements 5 ns or less—most have $t_H = 0$.
  - They have *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





*Q*2 will respond properly to the level present at *Q*1 prior to NGT of CLK—*provided* *Q*2 's hold time requirement, t_H, is *less* than *Q*1'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.

RS

JK

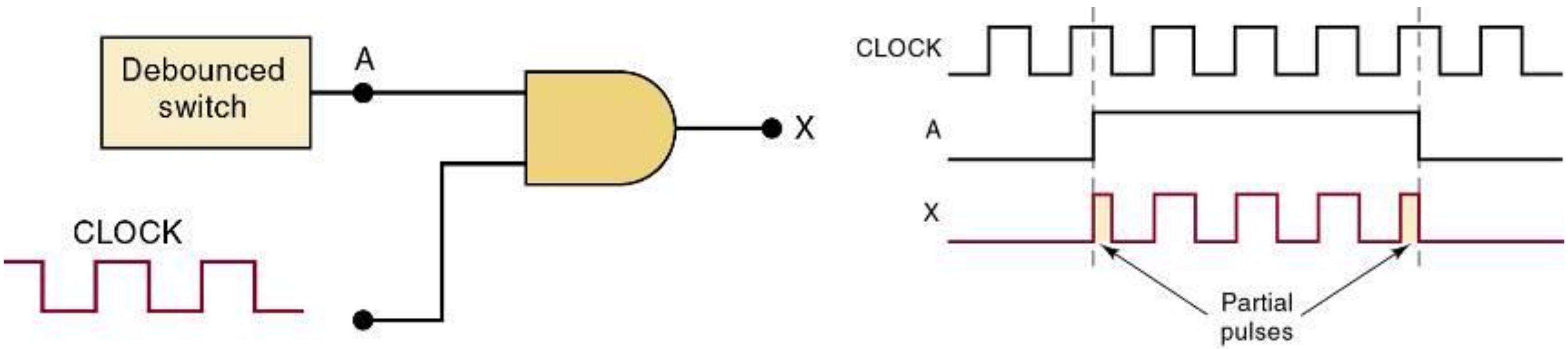
D

T

5-14 Flip-Flop Synchronization

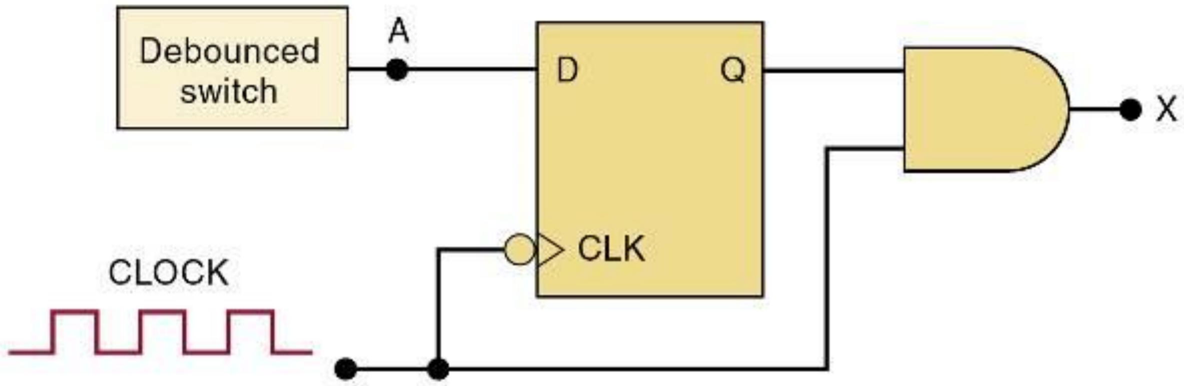
- Most systems are primarily synchronous in operation—in that changes depend on the clock.
- Asynchronous and synchronous operations are often combined—frequently through human input.
  - The random nature of asynchronous inputs *can* result in unpredictable results.

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

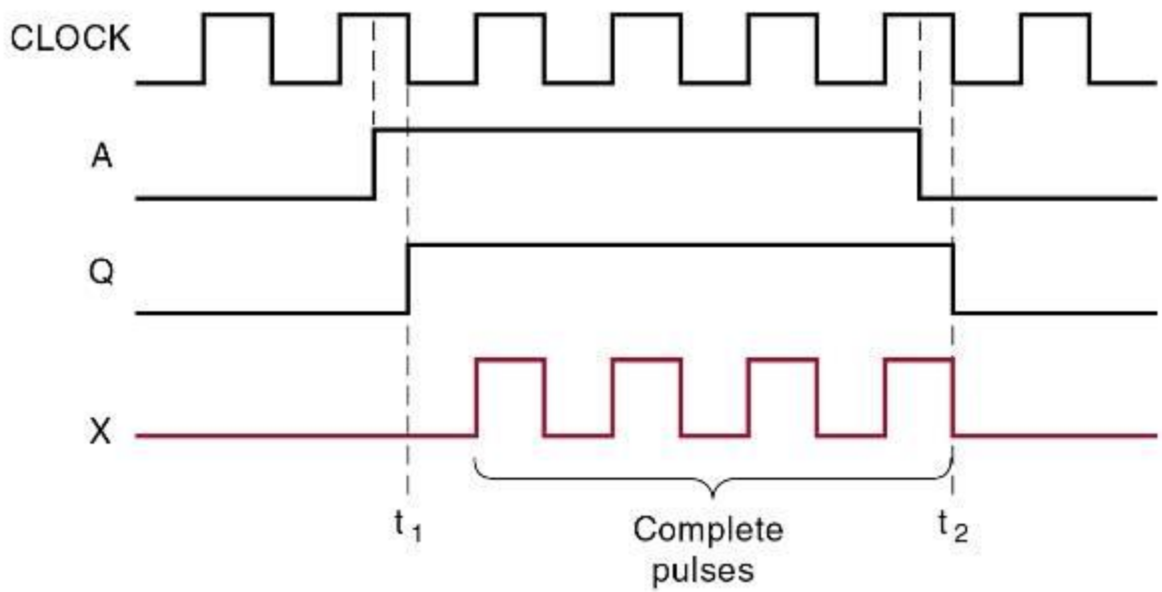


5-14 Flip-Flop Synchronization

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



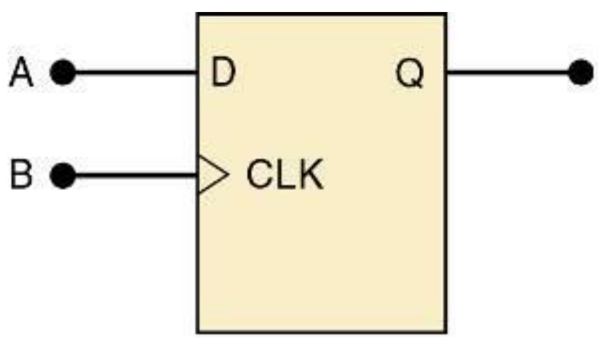
(a)



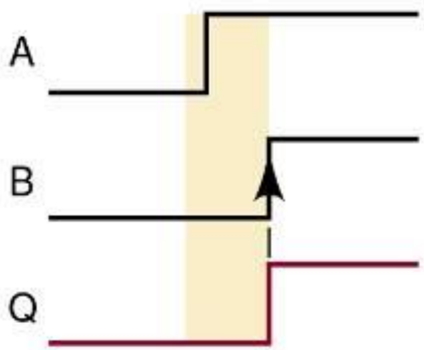
5-15 Detecting an Input Sequence

- 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.

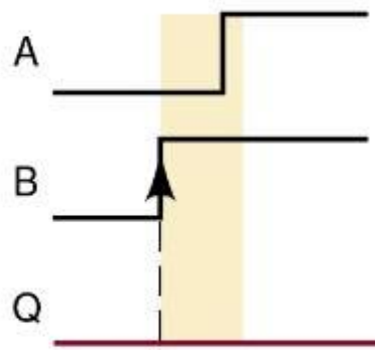
Clocked D flip-flop used to respond to a particular *sequence* of inputs.



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



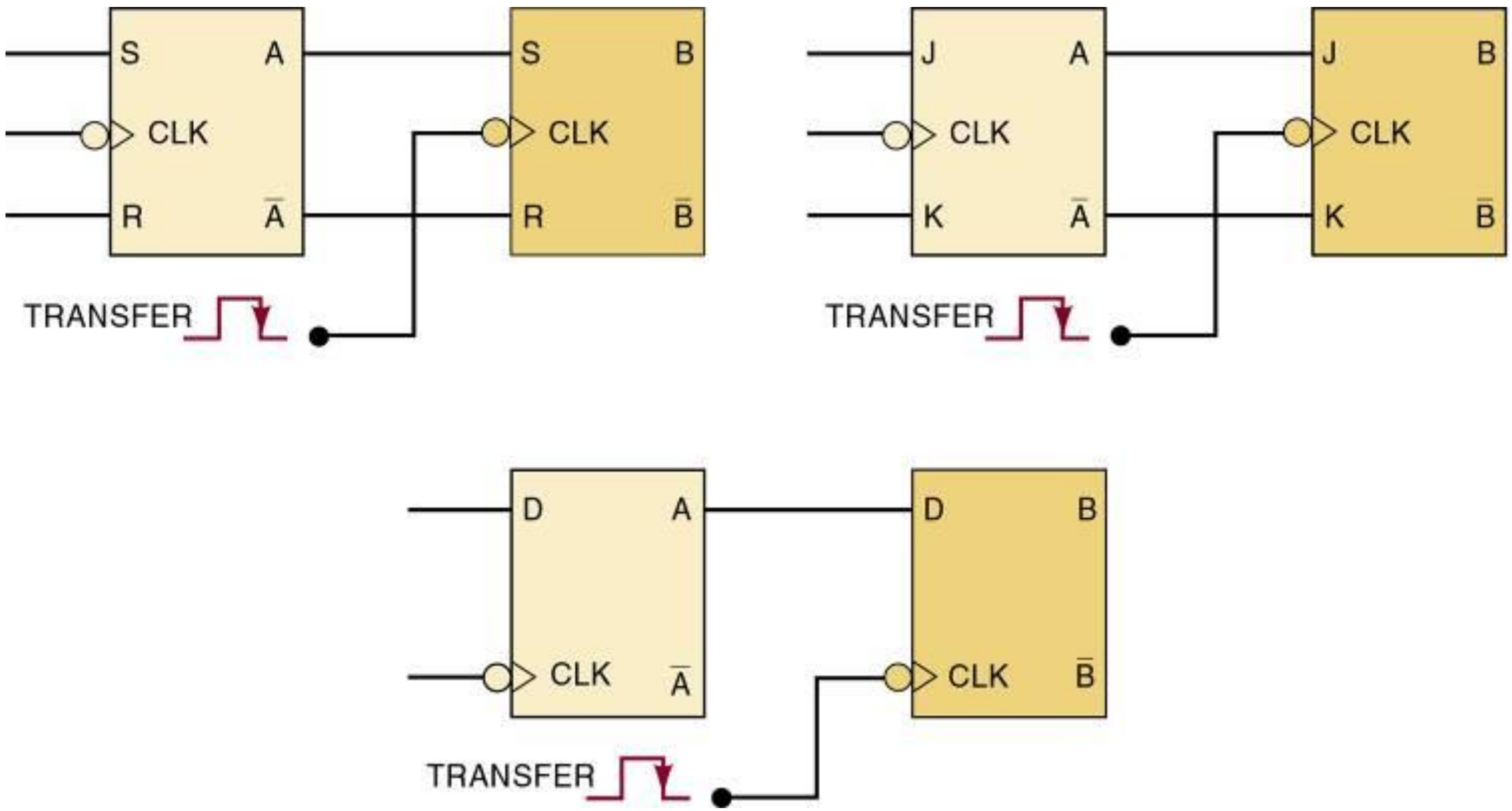
B goes HIGH before A

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

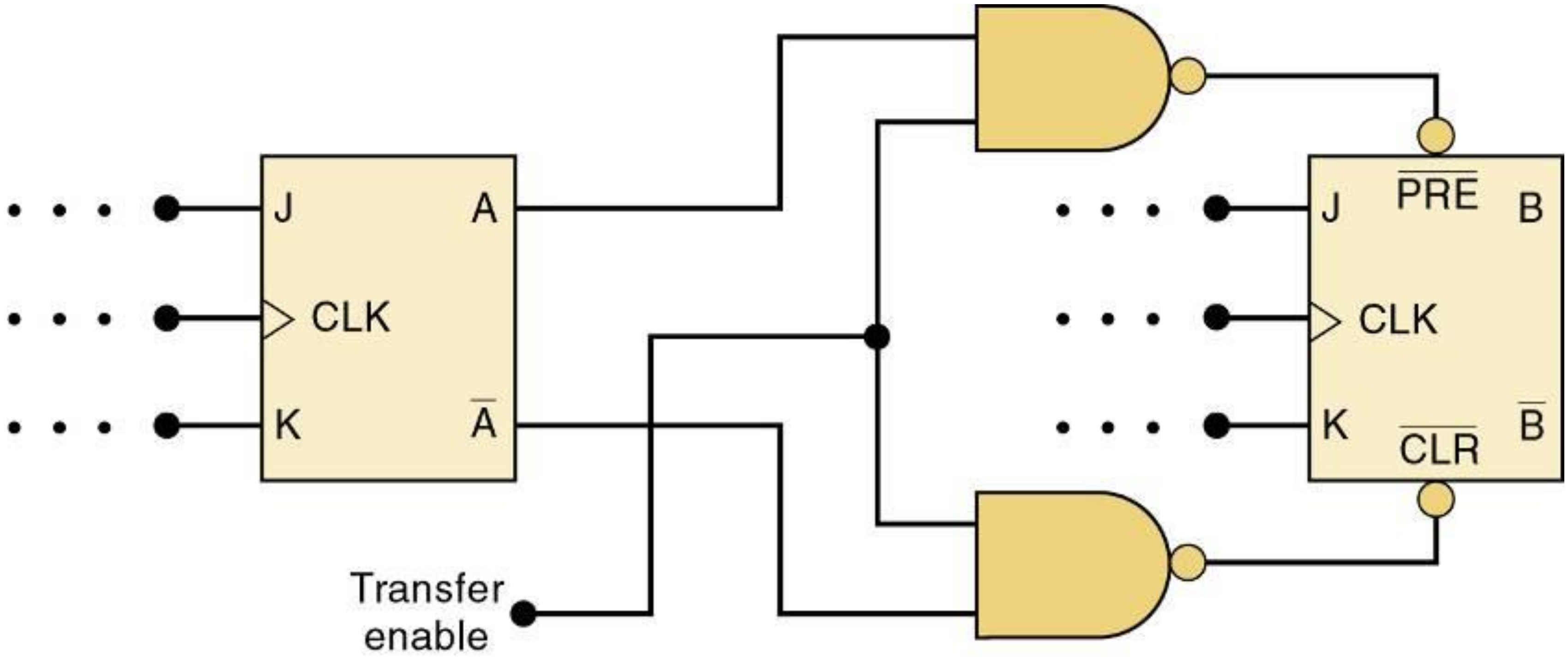
Synchronous data transfer operation by various clocked FFs.



CLK **inputs are used to perform the transfer.**

5-16 Data Storage and Transfer – Asynchronous

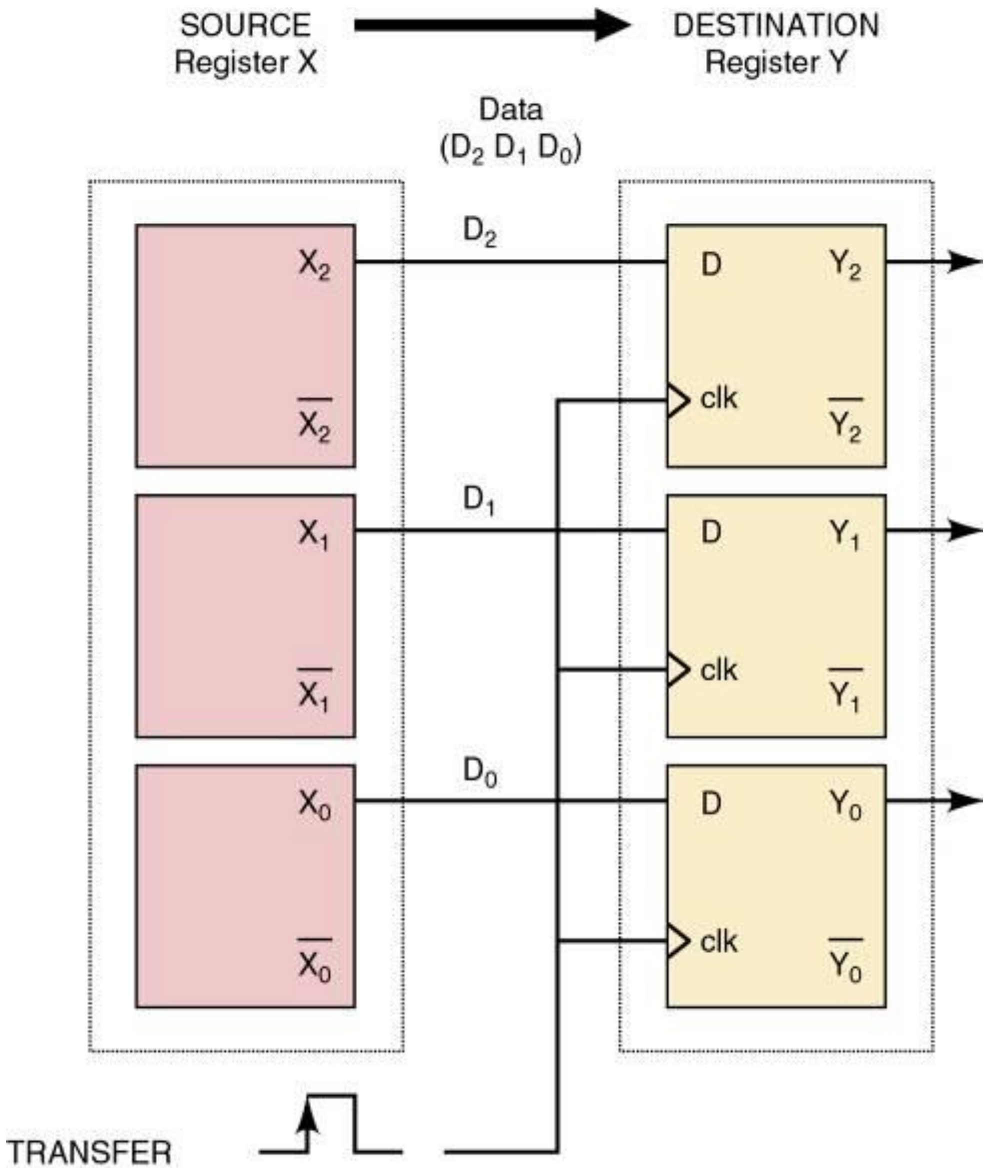
Asynchronous data transfer operation.



PRE and CLR **inputs are used to perform the transfer.**

5-16 Data Storage and Transfer – Parallel

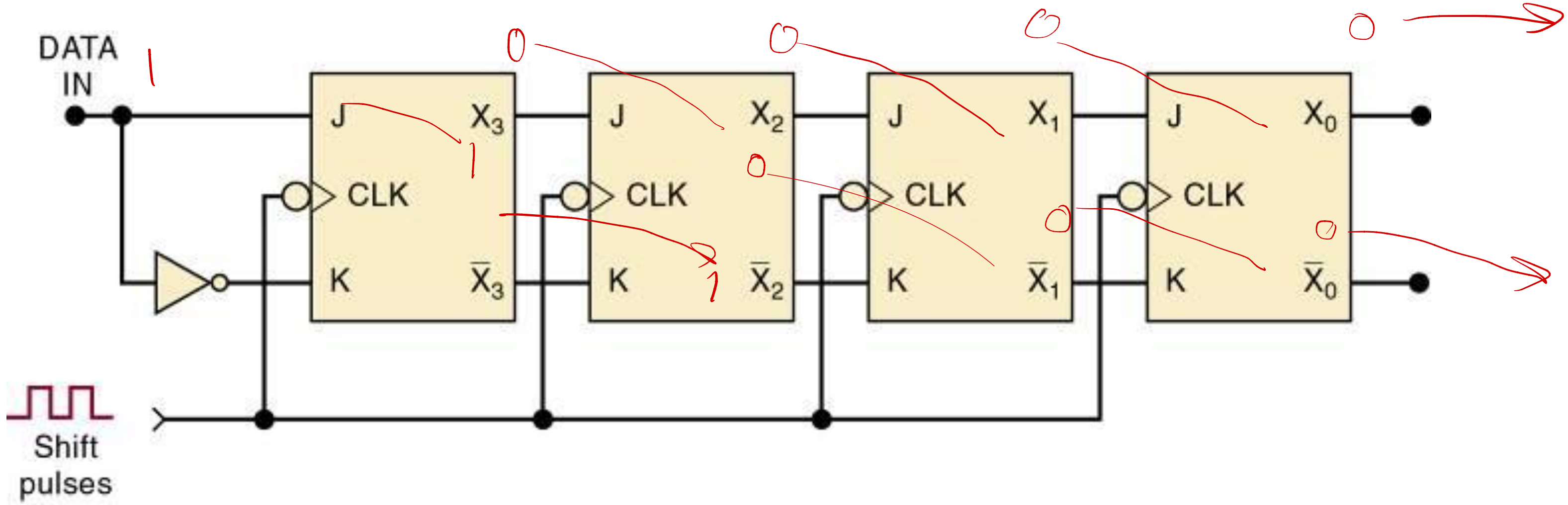
Transferring the bits of a register *simultaneously* is a *parallel* transfer.



5-17 Serial Data Transfer

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

- 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.



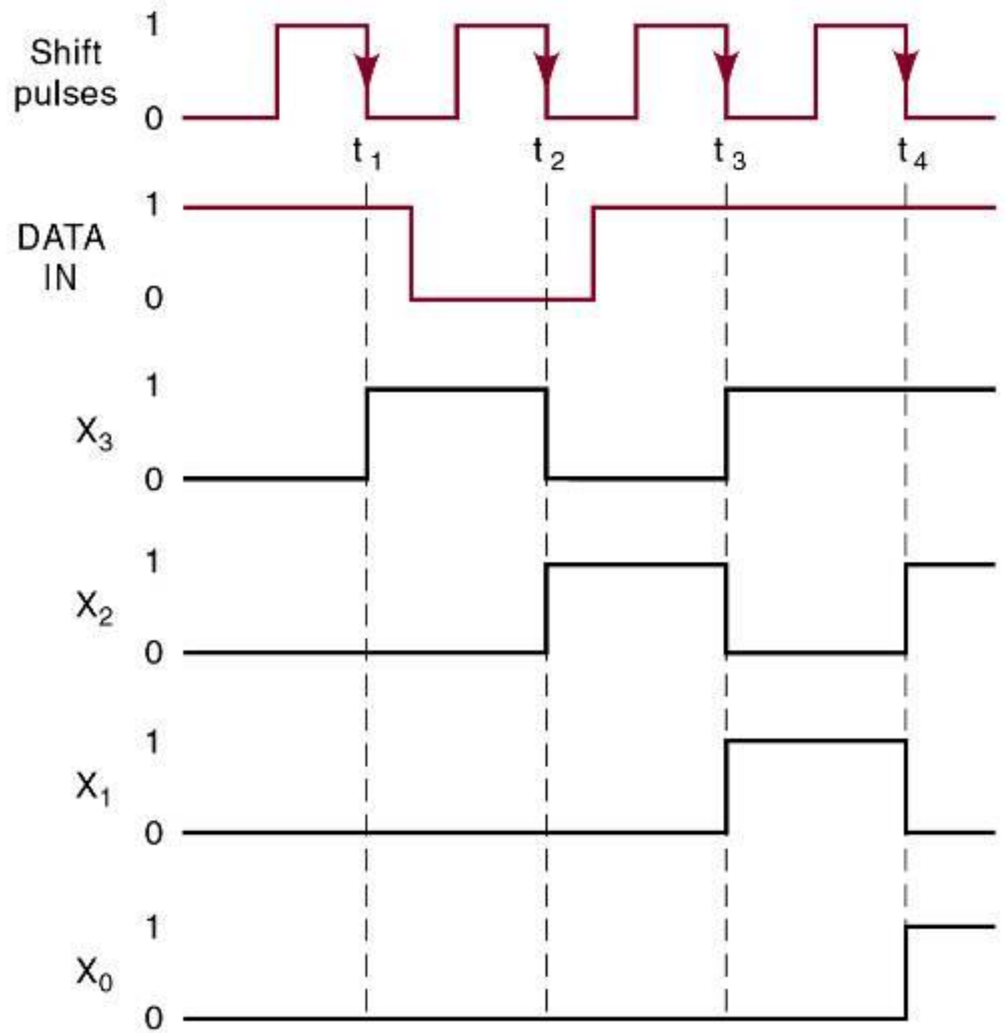
J-K flip-flops operated as a four-bit shift register.

5-17 Serial Data Transfer – Shift Register

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

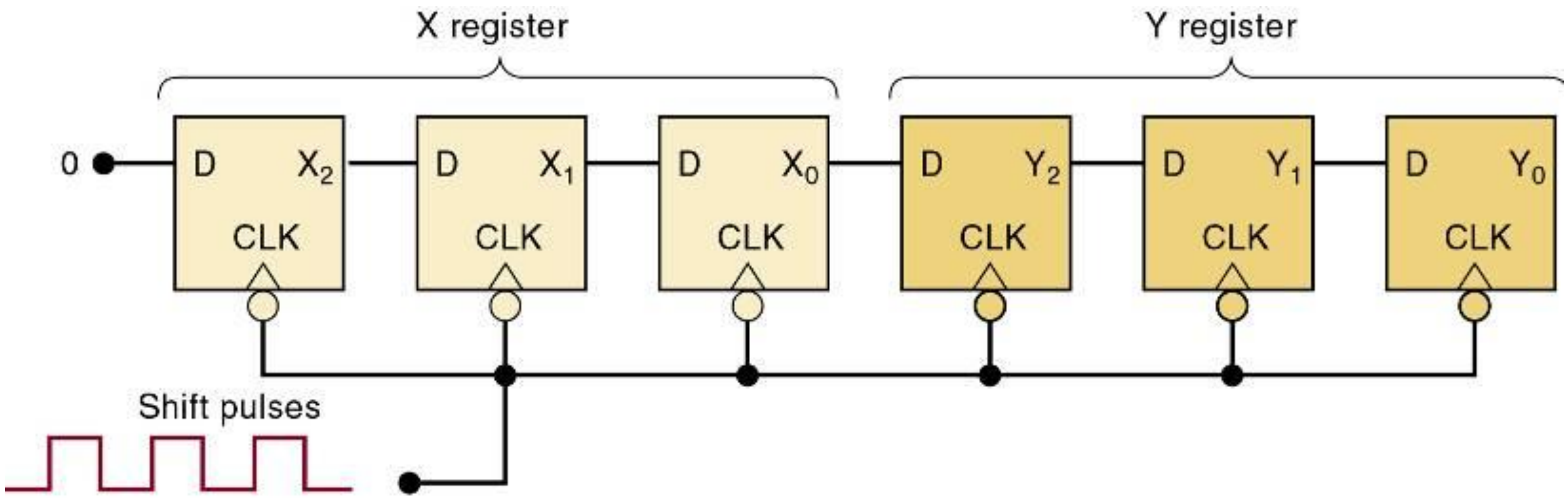
In this shift-register arrangement, it is necessary to have FFs with very small hold time requirements.

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.

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	← After second pulse
0	0	0	1	0	1	

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	← After second pulse
0	0	0	1	0	1	← After third 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.

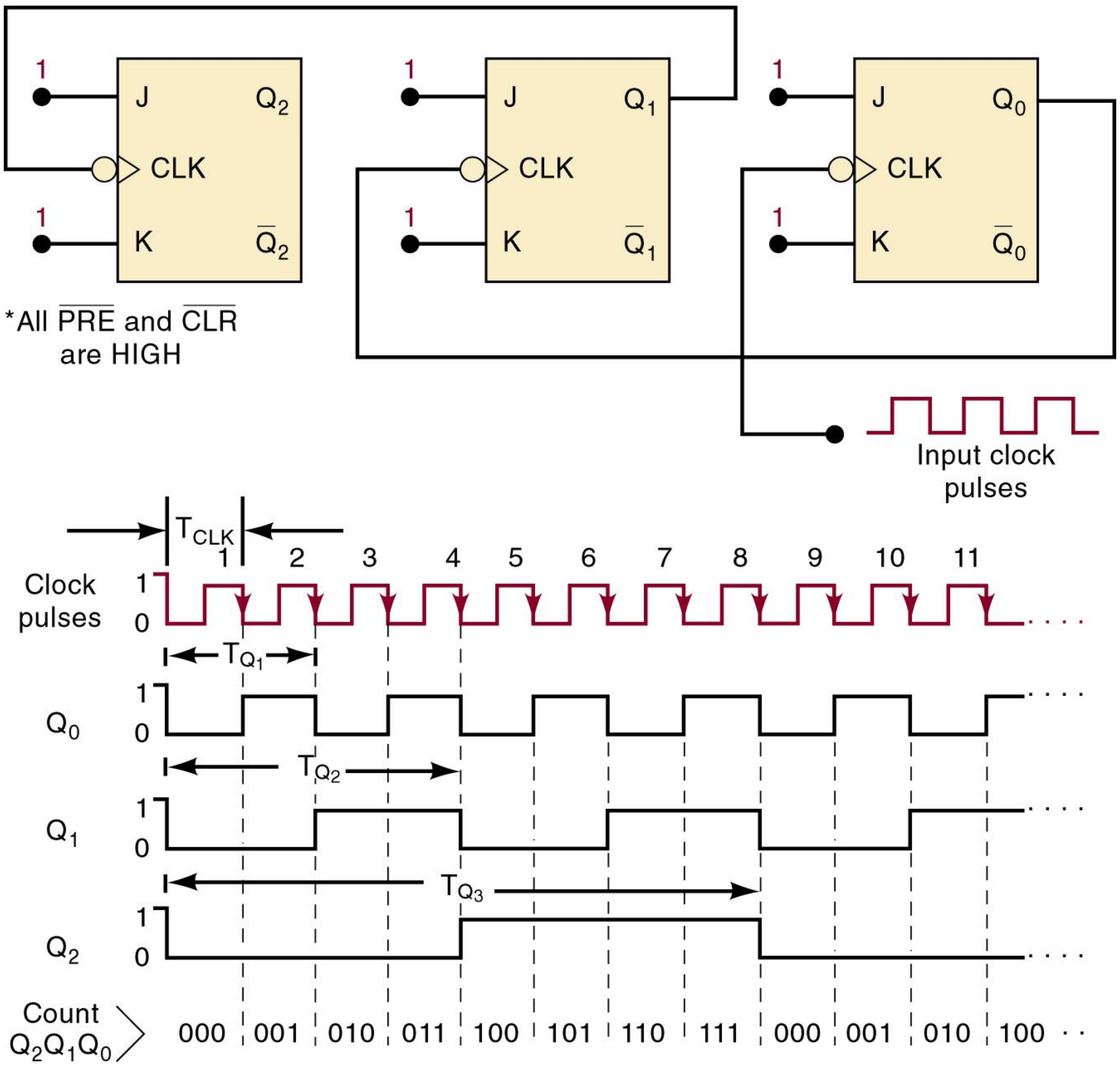
5-18 Frequency Division and Counting

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.



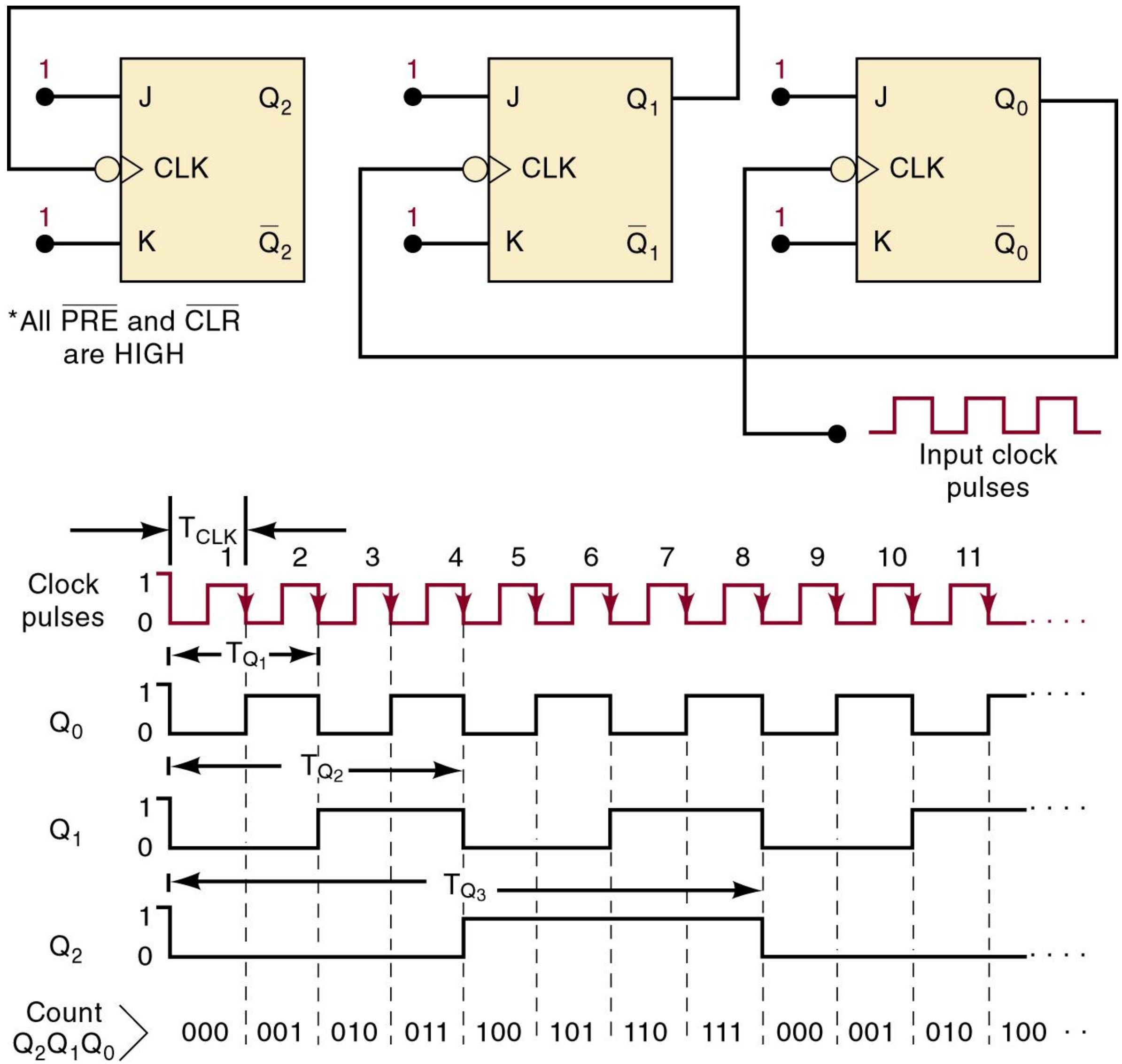
5-18 Frequency Division and Counting

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 000_2 to 111_2 or 0_{10} to 7_{10}.

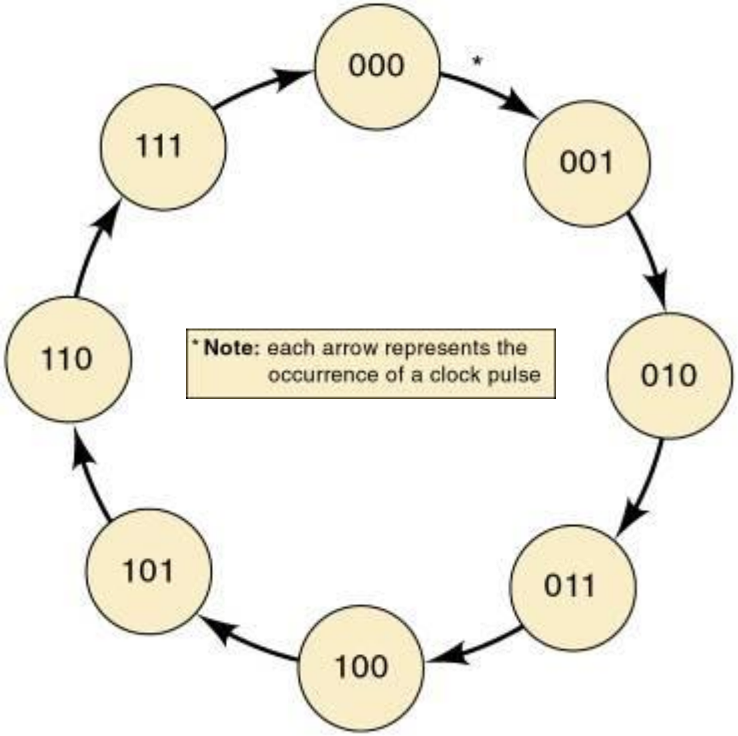
The number of states possible in a counter is the modulus or MOD number.



A MOD-8 (2^3) counter.

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

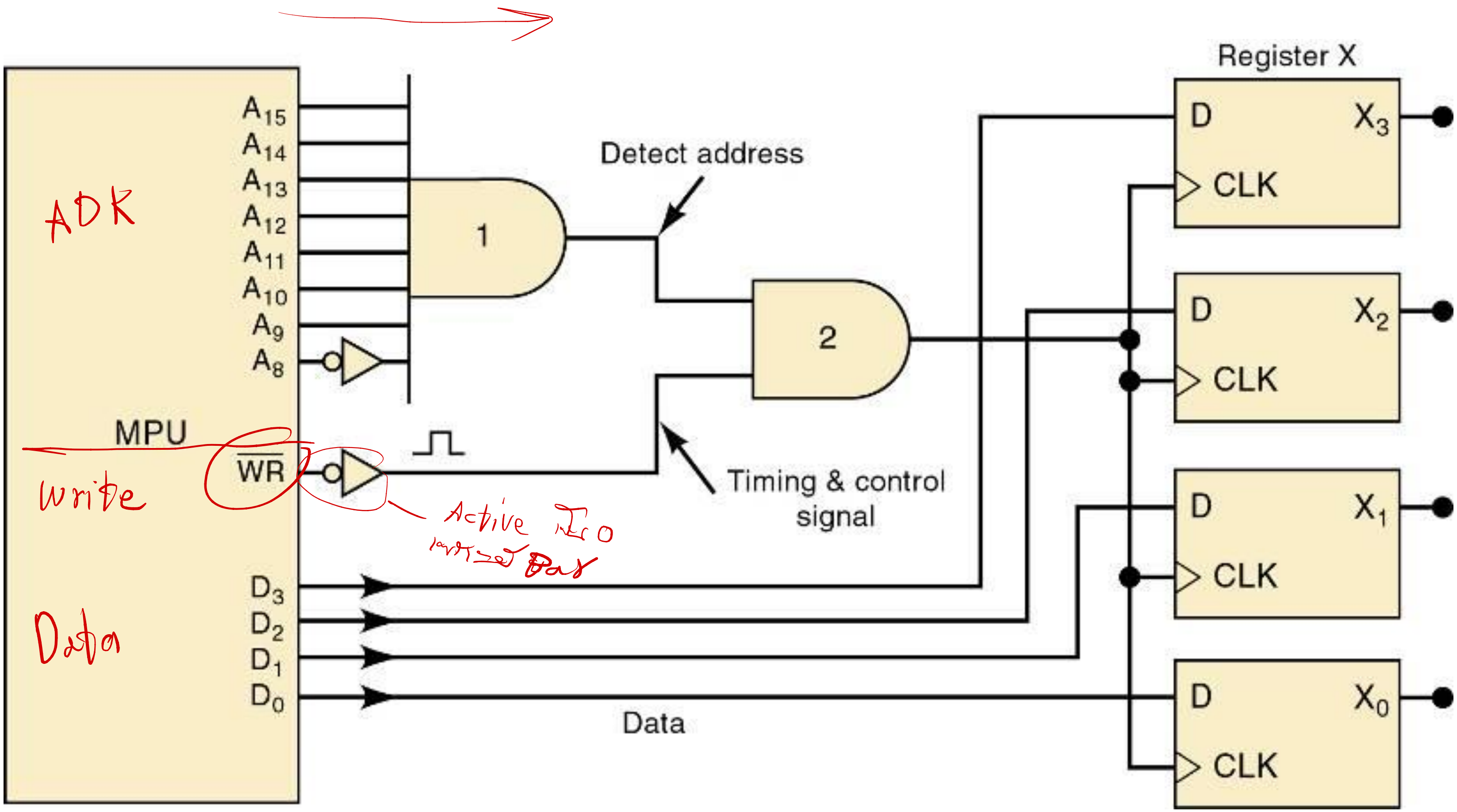
2^2 Q_2	2^1 Q_1	2^0 Q_0	
0	0	0	Before applying clock pulses
0	0	1	After pulse #1
0	1	0	After pulse #2
0	1	1	After pulse #3
1	0	0	After pulse #4
1	0	1	After pulse #5
1	1	0	After pulse #6
1	1	1	After pulse #7
0	0	0	After pulse #8 recycles to 000
0	0	1	After pulse #9
0	1	0	After pulse #10
0	1	1	After pulse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

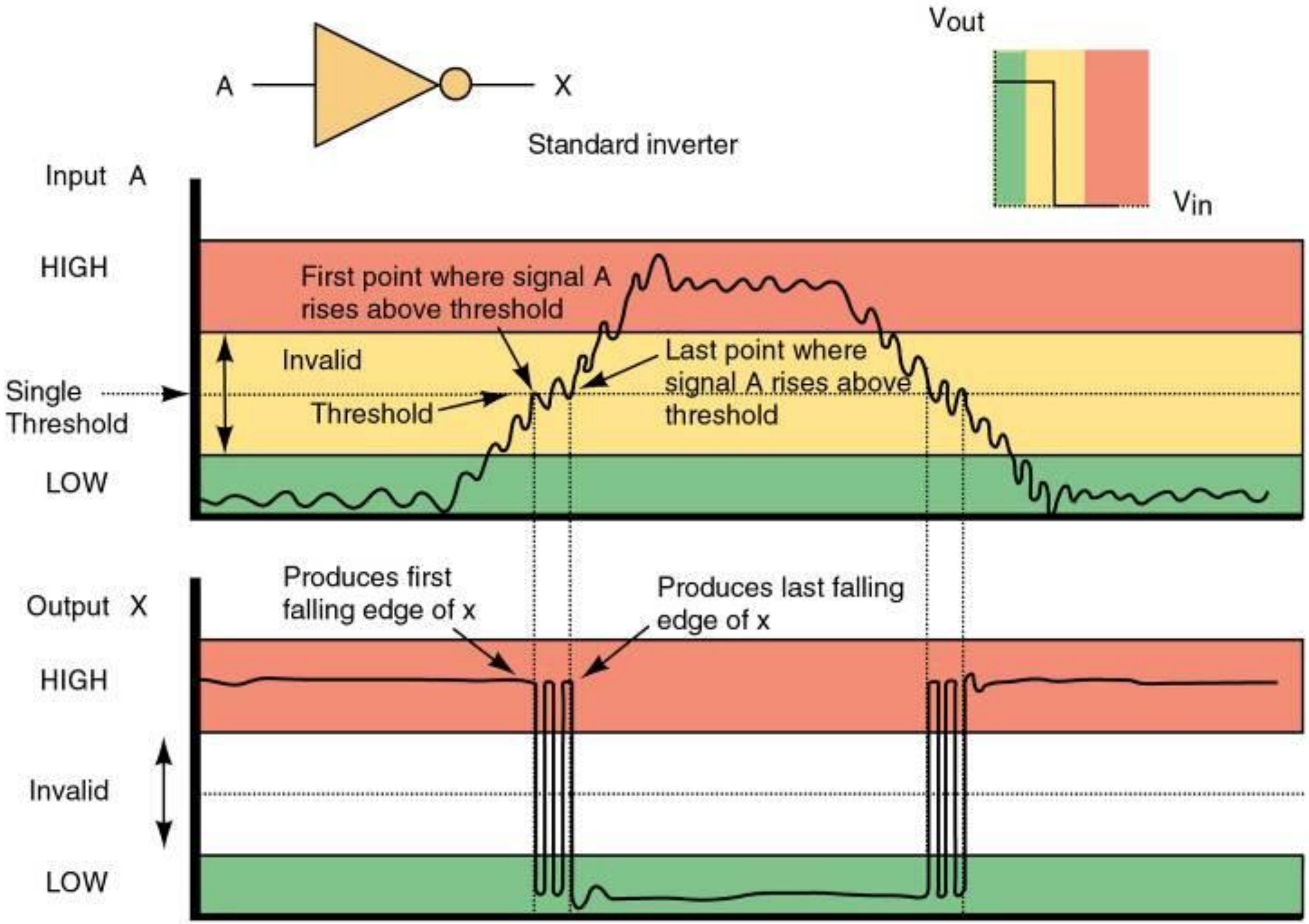
Microprocessor transferring binary data to an external register.



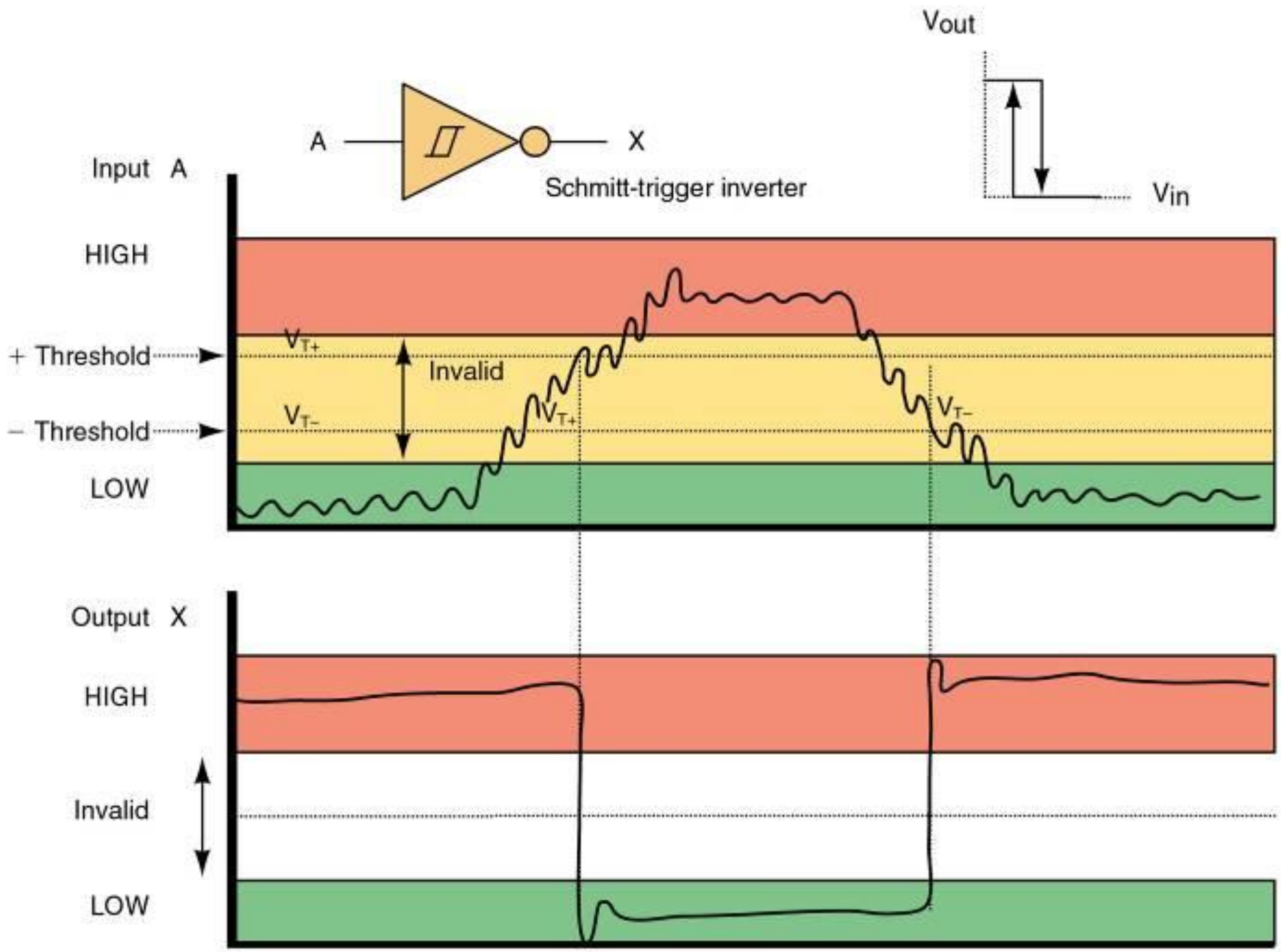
5-20 Schmitt-Trigger Devices

- 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.

Standard inverter response to slow noisy input.



Schmitt-trigger response to slow noisy input.



5-21 One-shot (Monostable Multivibrator)

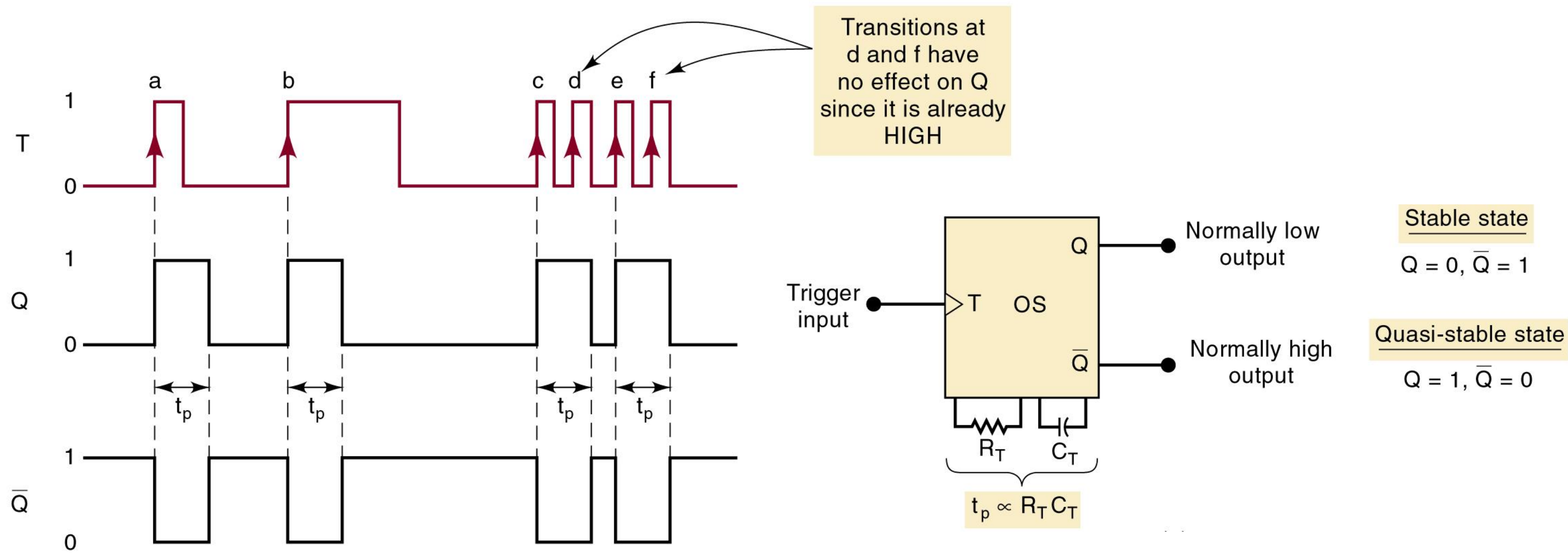
- Like the FF, the OS has two outputs, Q and $\overline{Q}$.
  - The inverse of each other.
- One shots are called monostable multivibrators because they have only one stable state.
  - Prone to triggering by noise.
- Changes from stable to quasi-stable state for a fixed time-period (t_p).
  - Usually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

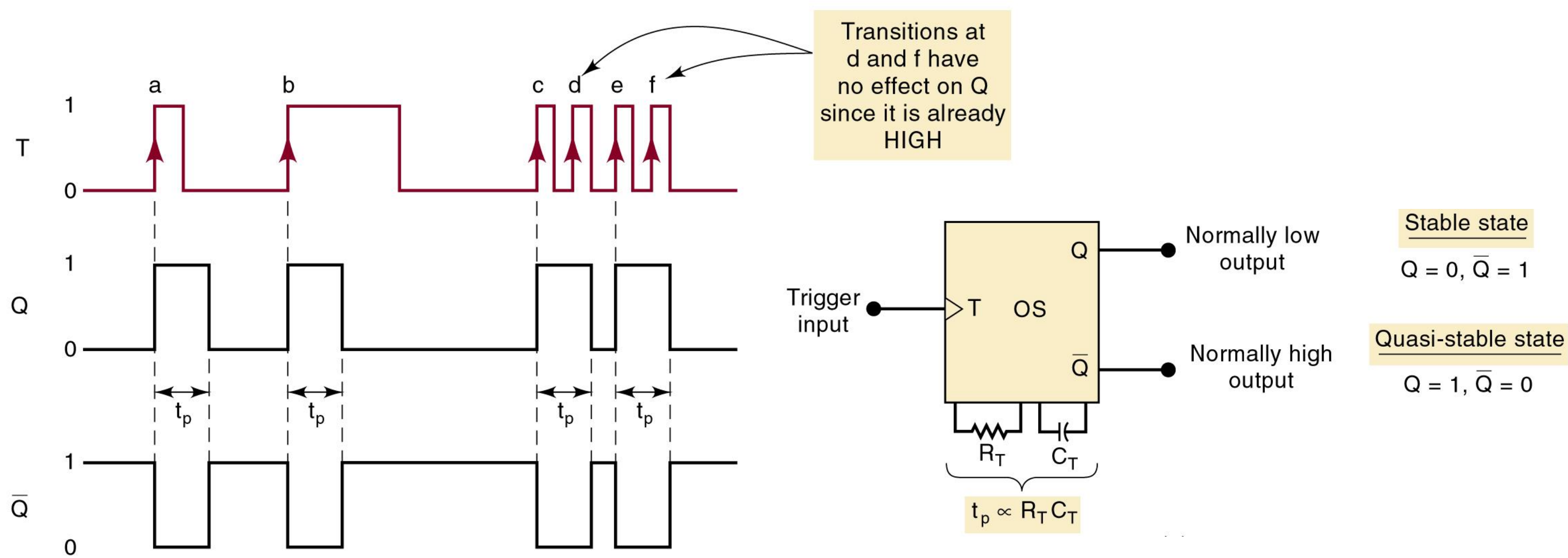


PGTs at points *a, b, c,* and *e* will trigger the OS to its quasi-stable state for a time t_p.

After which it automatically returns to the stable state.

5-21 One-shot (Monostable Multivibrator)

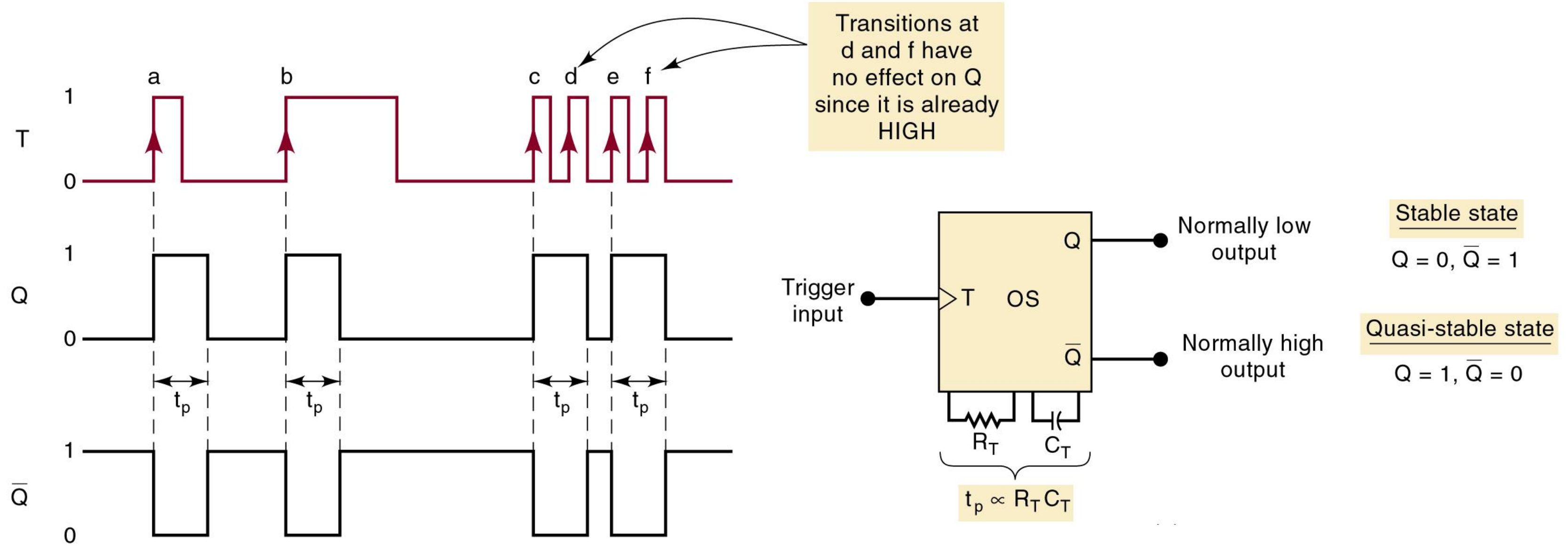
OS symbol and typical waveforms for nonretriggerable operation.



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.

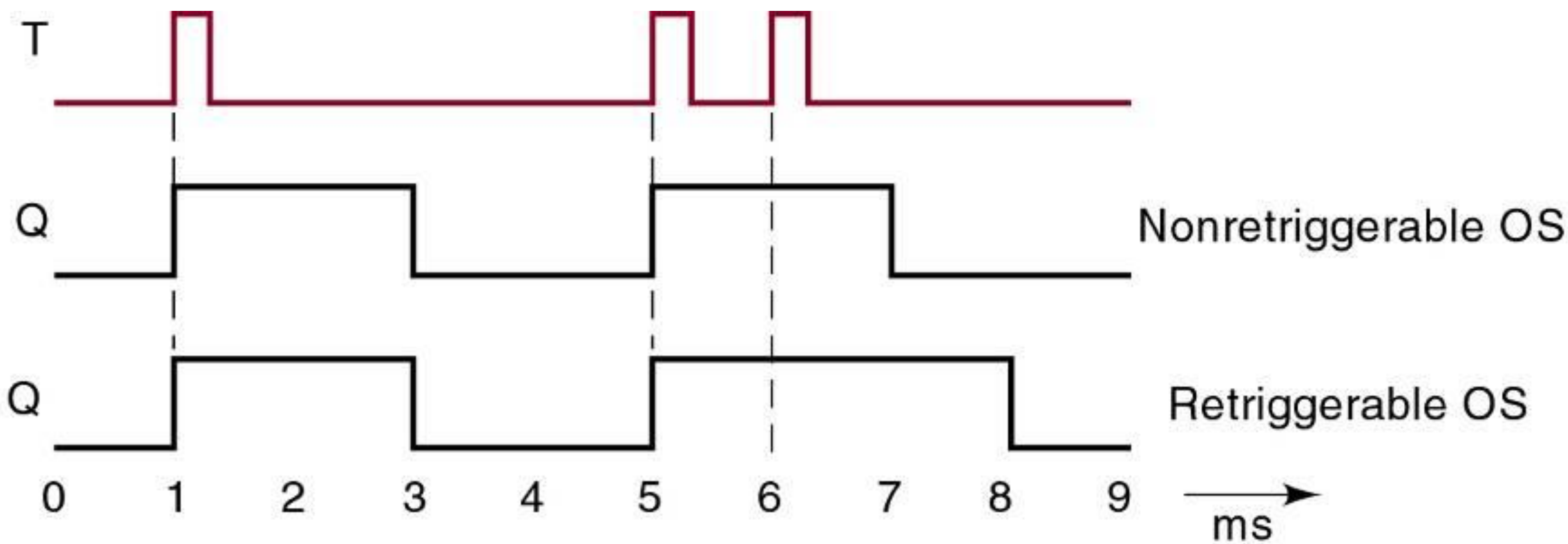
OS symbol and typical waveforms for nonretriggerable operation.



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

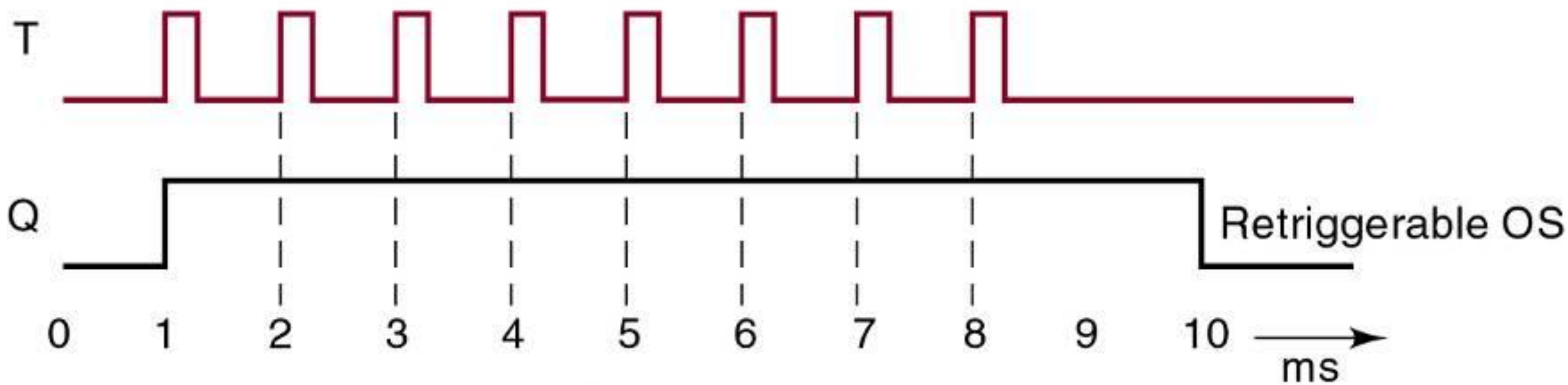
Time t_p depends only on R_T, C_T & internal OS circuitry.

Comparison of nonretriggerable and retriggerable OS responses for t_p = 2ms.



5-21 One-shot (Monostable Multivibrator)

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

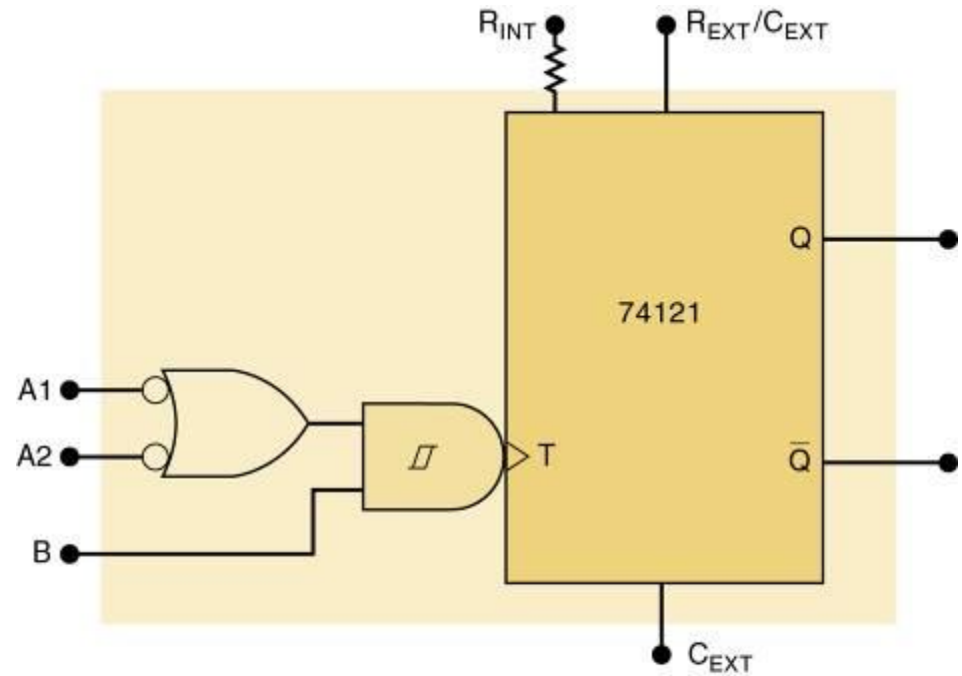


74121 nonretriggerable one-shot IC.

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.

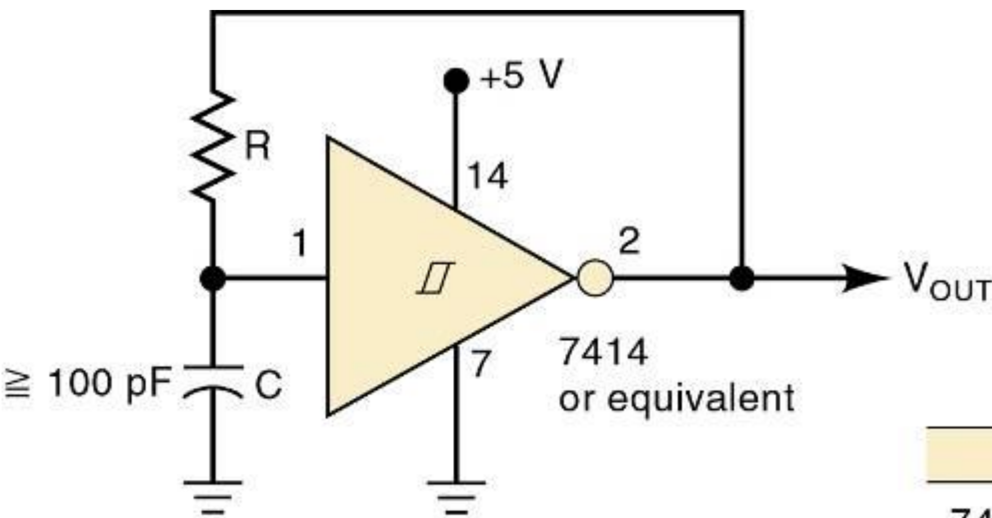


5-22 Clock Generator Circuits

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

Schmitt-trigger oscillator using a 7414 INVERTER.

A 7413 Schmitt-trigger NAND may also be used.



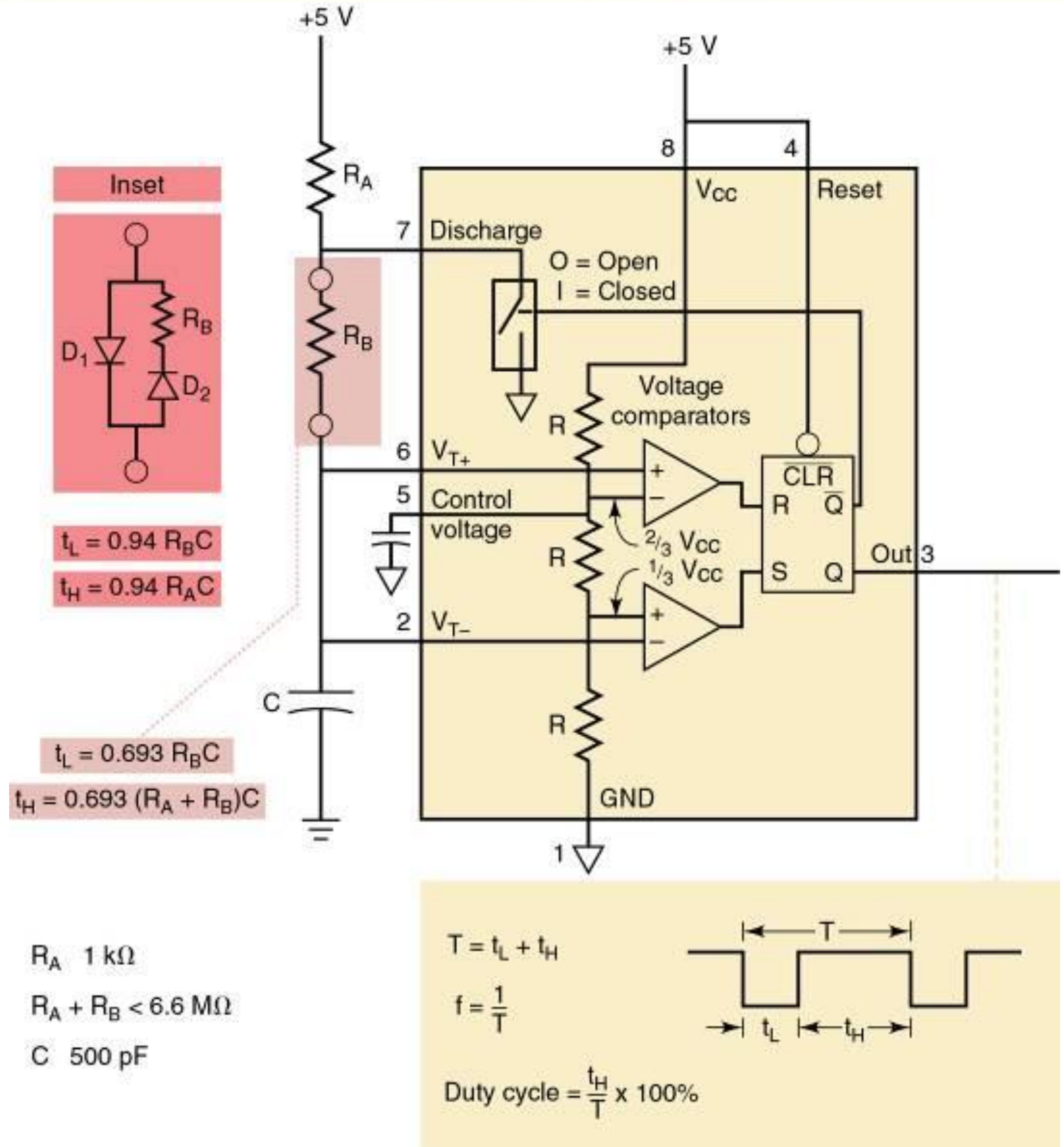
IC	Frequency	
7414	≈ 0.8/RC	(R ≦ 500 Ω)
74LS14	≈ 0.8/RC	(R ≦ 2 kΩ)
74HC14	≈ 1.2/RC	(R ≦ 10 MΩ)

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.



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

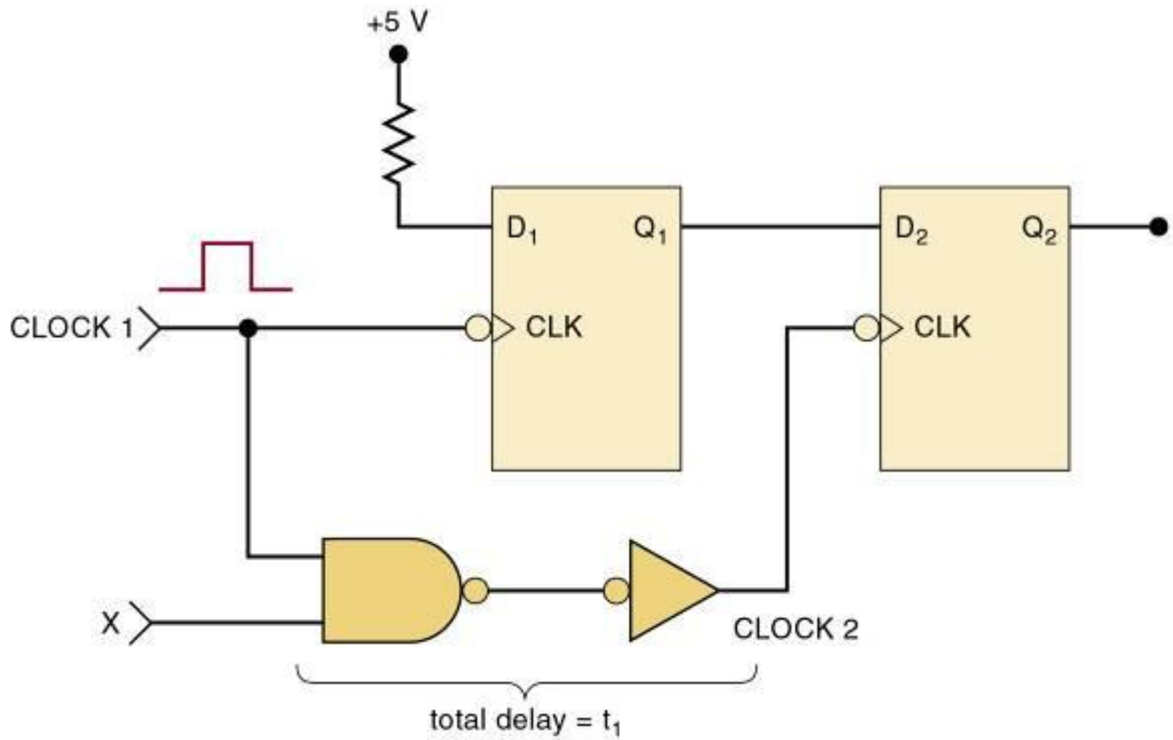
- FFs are subject to the same faults that occur in combinational logic circuits.
  - Timing problems create some faults and symptoms that are not seen in combinational logic circuits.
- Unconnected or floating inputs are particularly susceptible spurious voltage fluctuations—*noise.*
- Given sufficient 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

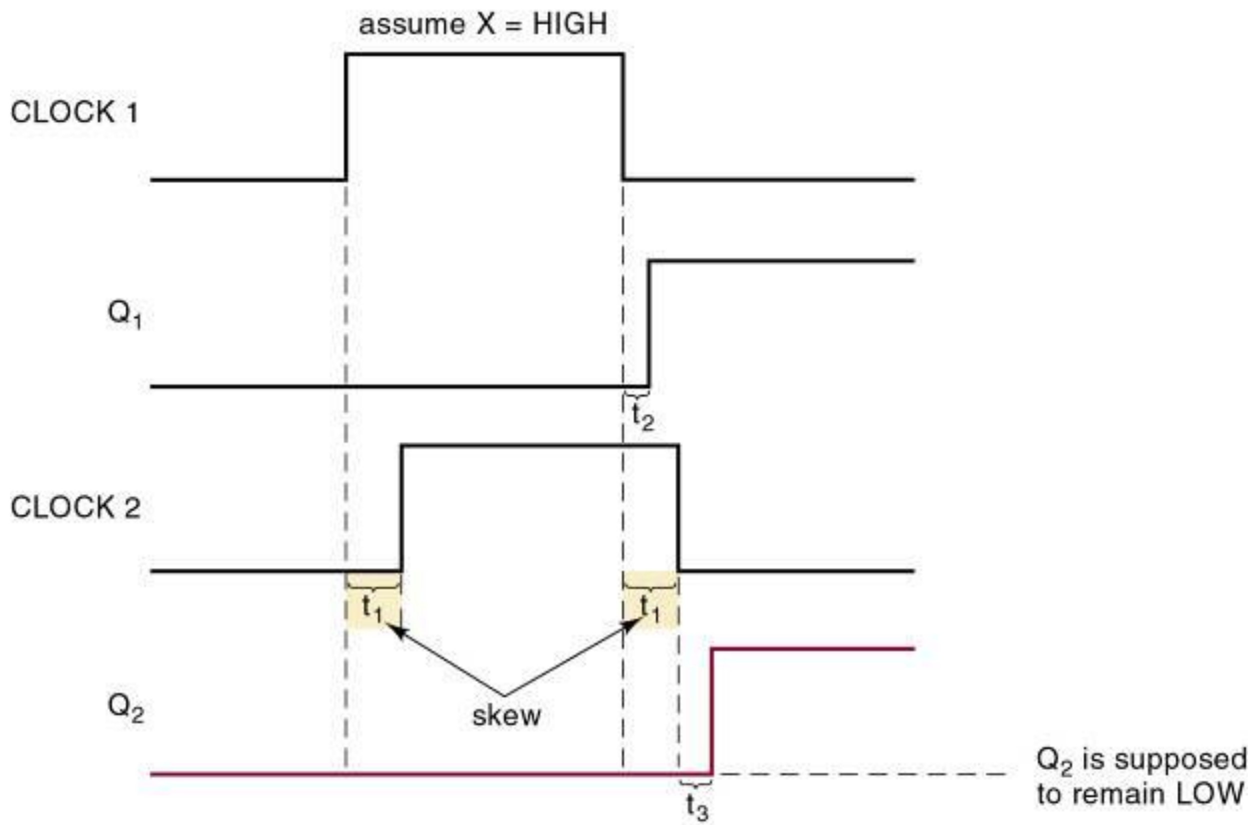
- Clock skew occurs when CLK signals arrive at different FFs at different times.
  - The fault may be seen only intermittently, or may disappear during testing.

5-23 Troubleshooting Flip-Flop Circuits

Extra gating circuits can cause clock skew.



Extra gating circuits can cause clock skew.



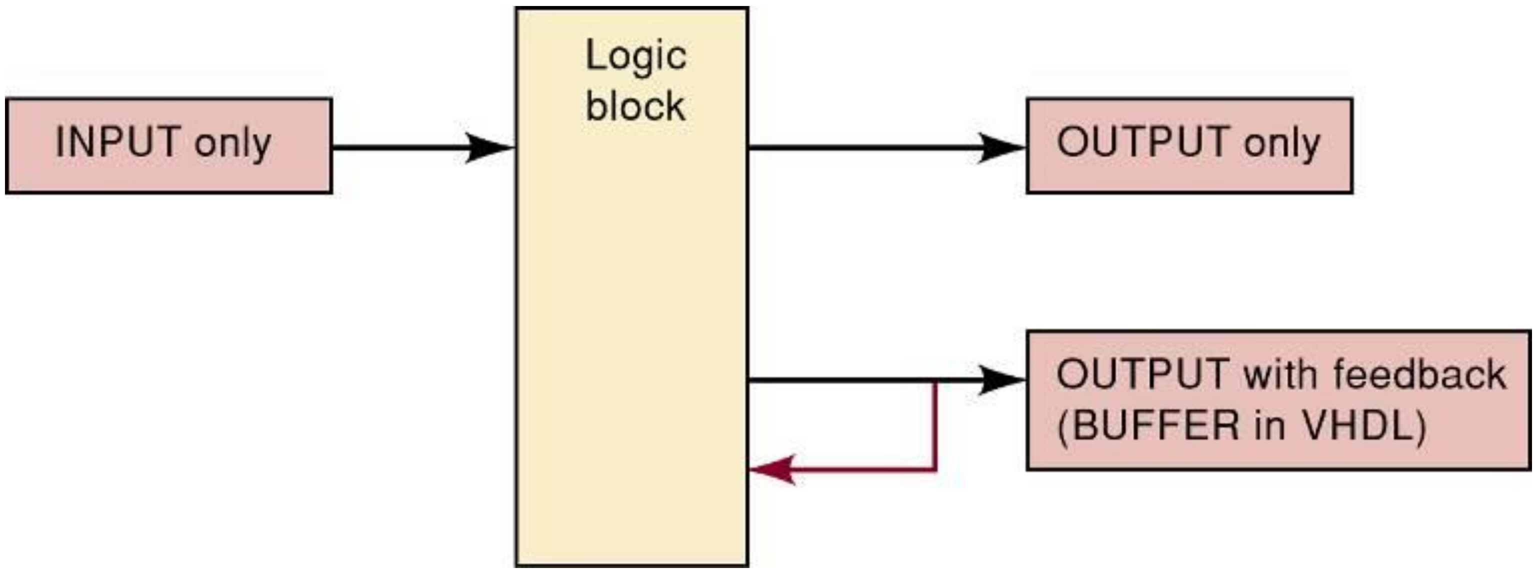
t_1 = skew = combined delay of NAND gate and INVERTER
$t_2 = t_{PLH}$ of Q_1
$t_3 = t_{PLH}$ of Q_2

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.

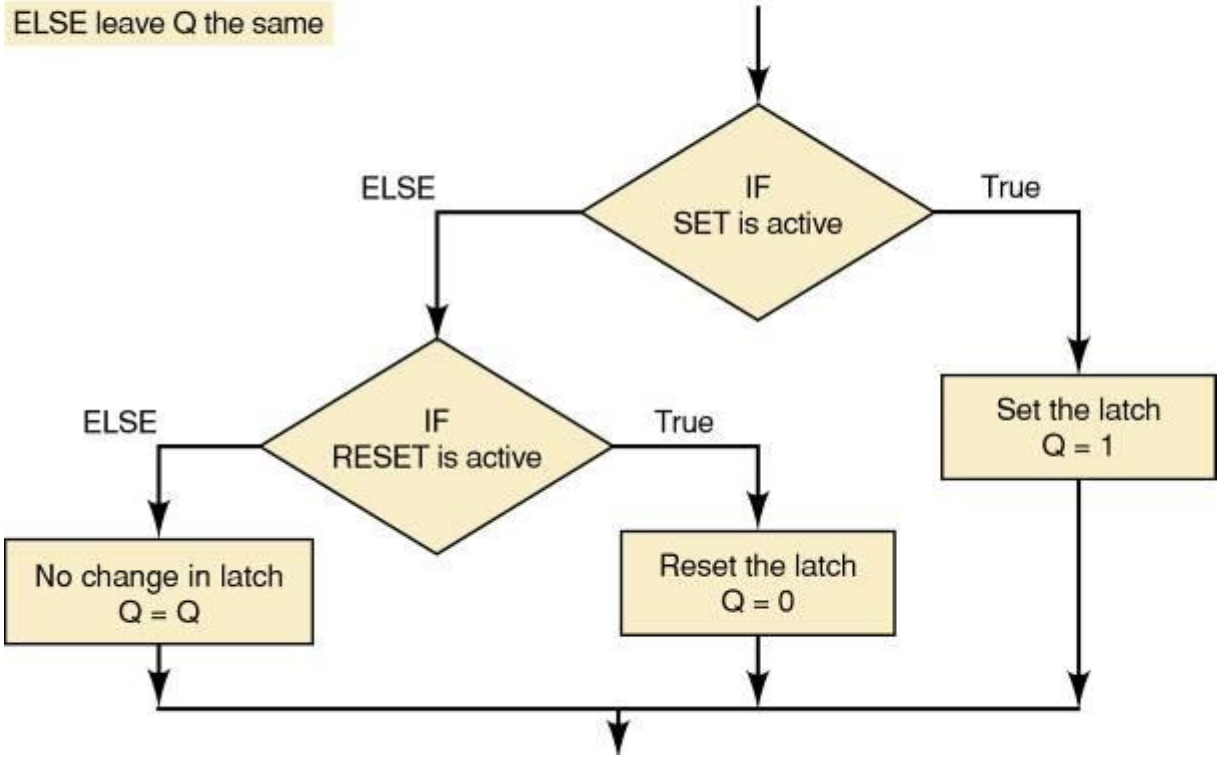


The logic of a behavioral description of an S-R latch.

IF (SET is active) THEN Make Q HIGH

ELSE IF (RESET is active) THEN Make Q LOW

ELSE leave Q the same



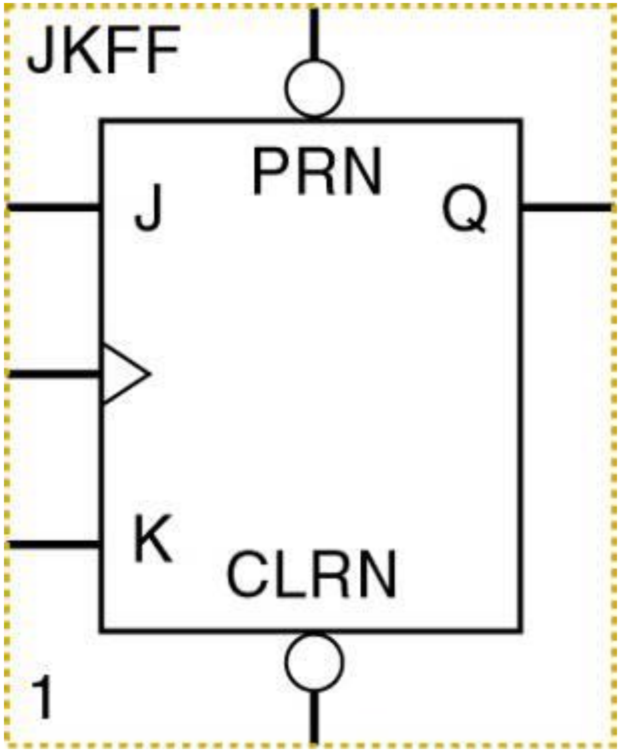
5-25 Sequential Circuits Using HDL

- 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

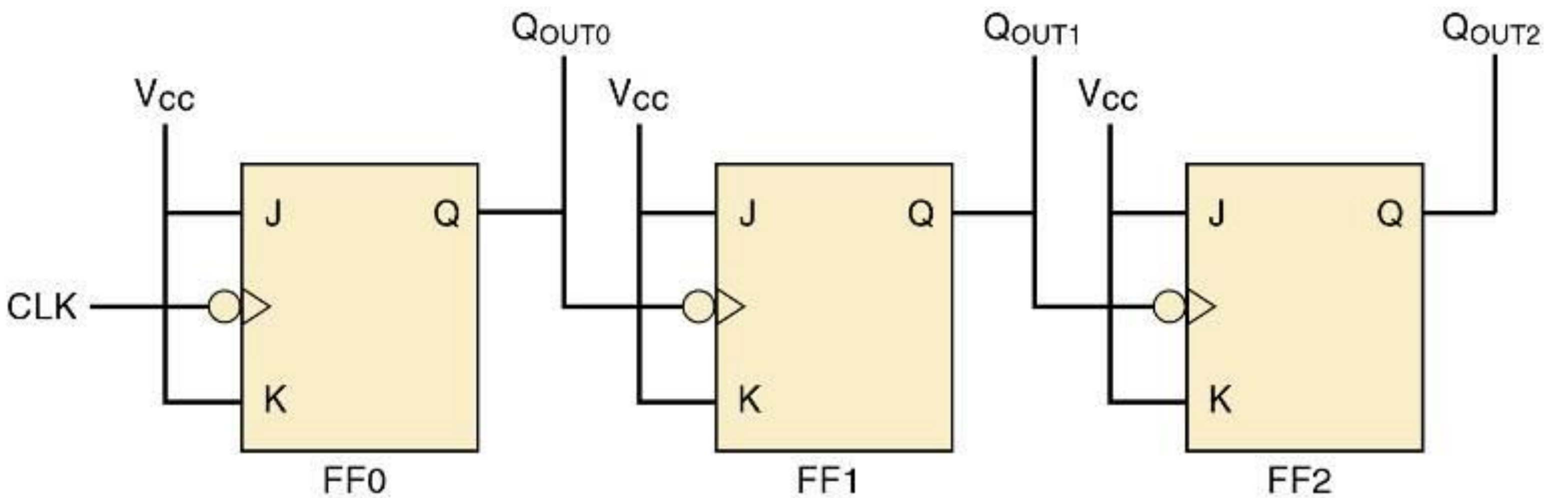
- Edge-triggered device output respond to the inputs when the clock input sees an “edge.”
  – An edge is a transition from HIGH to LOW, or vice versa—and is often referred to as an **event**.

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.

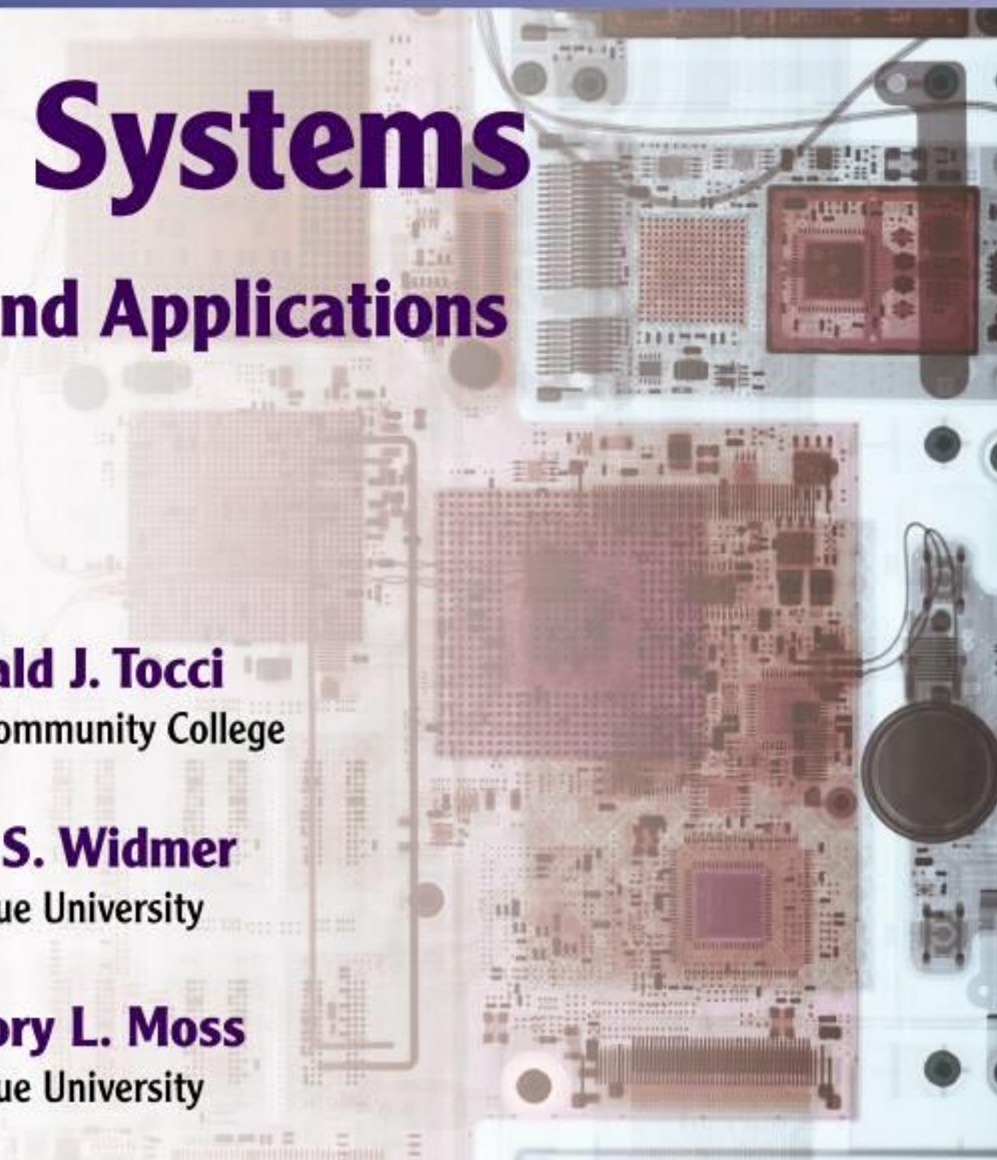


These logic symbols are negative edge-triggered.

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

END

ELEVENTH EDITION



Digital Systems

Principles and Applications

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PEARSON

หา แปลง ฐาน 2 → 10

ดึงลงตัวแรก ×2

loop บวก ×2

1 0 1 0 1 0 0 0 1

1

×2

=

2 + 2 = 4

×2

4 + 1 = 5

5 ×2

10

118

336

337

42 ×8

336

339

$2^0 = 1$	$2^{10} = 1024 = 1k$		1 = k
$2^1 = 2$	$2^{11} = 2048 = 2k$		2 = m
$2^2 = 4$	$2^{12} = 4096 = 4k$		3 = G
$2^3 = 8$	$2^{13} = 8192 = 8k$		4 = T
$2^4 = 16$	$2^{14} = 16k$		5 = P
$2^5 = 32$	$2^{15} = 32k$		
$2^6 = 64$	$2^{16} = 64k$		
$2^7 = 128$	$2^{17} = 128k$		
$2^8 = 256$	$2^{18} = 256k$		
$2^9 = 512$	$2^{19} = 512k$		

$A \quad \bar{A} \quad 0 \quad 1$

กฎ 11 ข้อ

$A \cdot 0 = 0$ | $A + 0 = A$

$A \cdot 1 = A$ | $A + 1 = 1$

$A \cdot A = A$ | $A + A = A$

$A \cdot \bar{A} = 0$ | $A + \bar{A} = 1$

$A + \cancel{\bar{A}}B$ | $A(B + C) = AB + AC$

$\bar{A} + \cancel{A}B$

$\bar{\bar{A}} = A$

D' Morgan

$\overline{AB} = \bar{A} + \bar{B}$

$\overline{A + B} = \bar{A} \cdot \bar{B}$

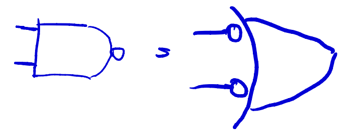
ตัด บาร์ครึ่ง เป็น or → and

and → or

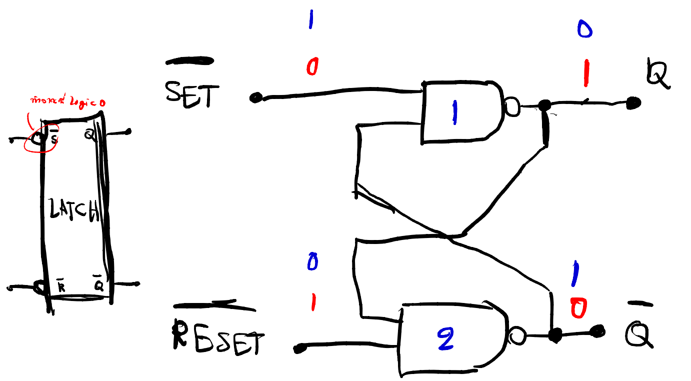
Flip-flops เรียกว่า latch ได้, bistable multivibrator

Q เป็น 1 เรียกว่า SET state

Q เป็น 0 เรียกว่า RESET state, CLEAR

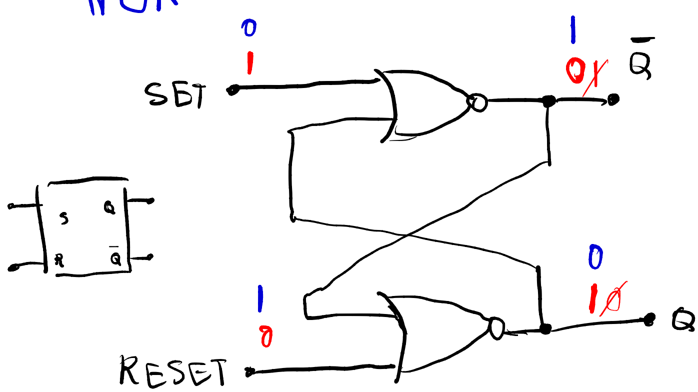


NAND



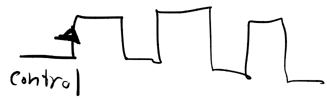
ค่า	$\overline{SET}$	$\overline{RESET}$	Q | $\bar{Q}$
	1	1	ได้ค่าเดิม
	0	1	Q = 1
	1	0	Q = 0
	0	0	Q=1, $\bar{Q}$=1 ไม่ใช้งาน

NOR



SET	RESET	Q | $\bar{Q}$
0	0	ได้ค่าเดิม
1	0	Q = 1
0	1	Q = 0
1	1	Q = 0, $\bar{Q}$=0 ไม่ใช้

Synchronous sys output จะเปลี่ยน ตามช่วงเวลาที่กำหนด



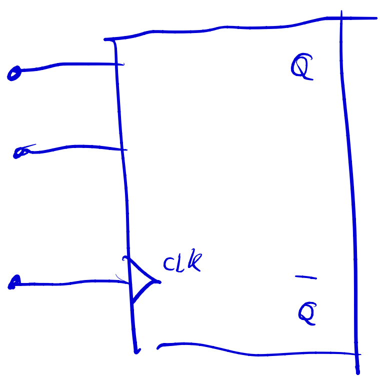
Asynchronous sys output จะเปลี่ยนได้ตลอด ไม่รอ clk

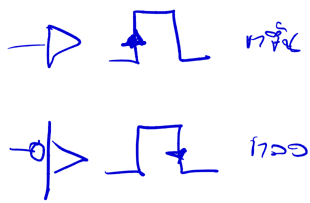
เรียก control → clock

Flip-Flops ต้องมี clk

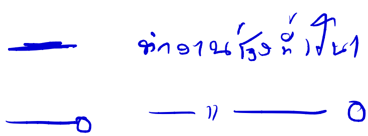
ถ้าไม่มี clk เรียก LATCH

Clk สัญญาณ ซ้ำๆ ที่เปลี่ยนจาก 0 1 แบบเหลี่ยม





edge triggering

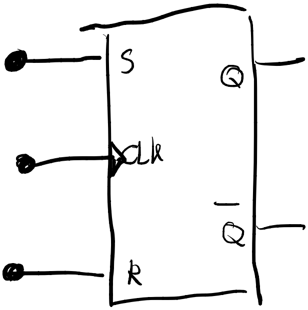


Level triggering

S – R ff

R – S ff

Reset set



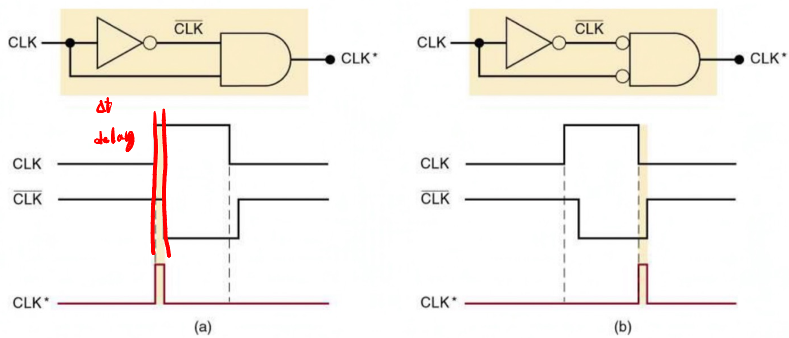
S	R	CLK	Q
0	0		Q_0 ไม่เปลี่ยน
1	0	↑	1
0	1		0
1	1		Ambiguous

Q_0 เดิม output CLK ที่ ↑

↓ CLK no change ที่ Q

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

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



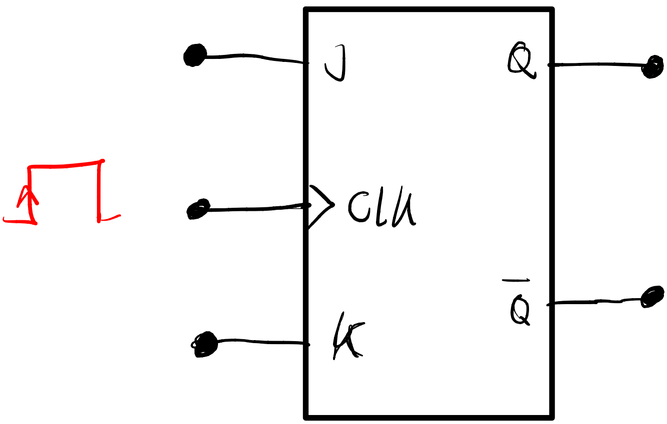
The duration of the *CLK** pulses is typically 2–5 ns.

JK ff

J → SET

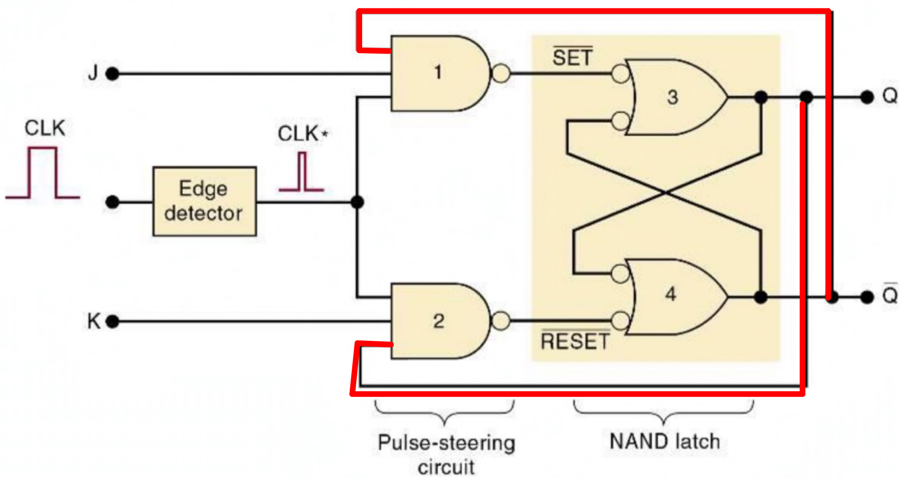
K → CLEAR

Toggle 1 → 0
  0 → 1



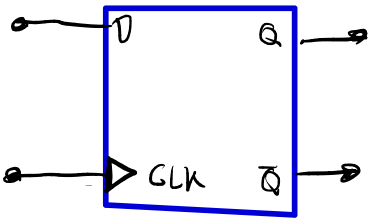
J	K	Clk	Q
0	0		Q_0 (ไม่เปลี่ยน)
1	0	↑	1
0	1		0
1	1	↓	$\bar{Q}_0$ (Toggle)

R-S ff + 2 เส้น

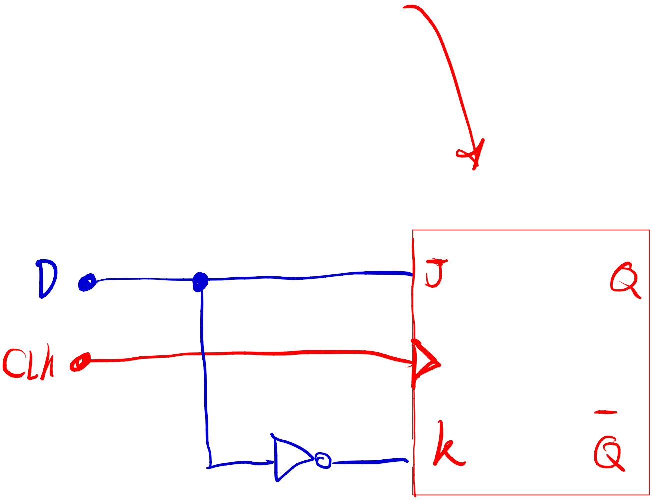


J
K
CLK
CLK*
Edge detector
1
2
3
4
SET
RESET
Q
Q̄
Pulse-steering circuit
NAND latch

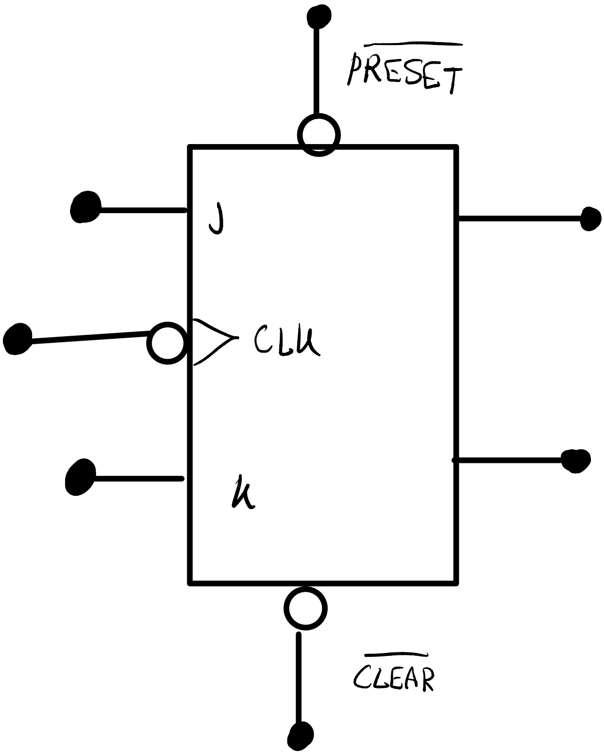
D ff



D	CLK	Q
0	↑	0
1		1

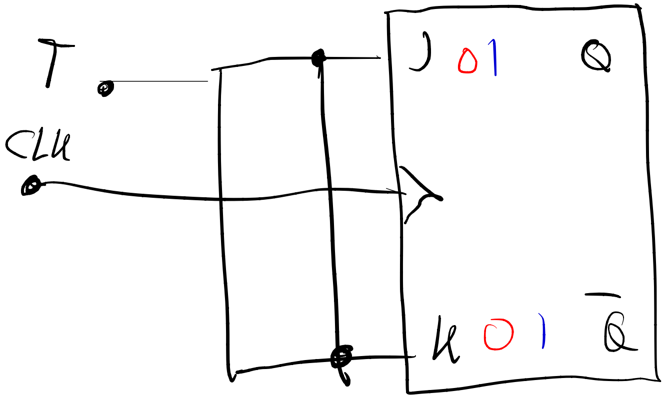


Clocked J-K ff asynchronous input



J	K	Clk	$\overline{PRE}$	$\overline{CLR}$	Q
0	0	$\downarrow$	1	1	Q (no change)
0	1	$\downarrow$	1	1	0 (Synch reset)
1	0	$\downarrow$	1	1	1 (Synch set)
1	1	$\downarrow$	1	1	$\overline{Q}$ (Synch toggle)
X	X	X	1	1	Q (no ch)
X	X	X	1	0	0 (asynch clear)
X	X	X	0	1	1 (asynch preset)
X	X	X	0	0	(Invalid)

T ff



Toggle ff

1 → Invert

↑ ขอบclock

0 → ค่าเดิม

↑ ขอบclock