

3.4 Latches and flip-flops

Name: _____ Class: _____ Date: _____

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KEY WORDS latch • flip-flop • clock edge • toggle
• excitation table

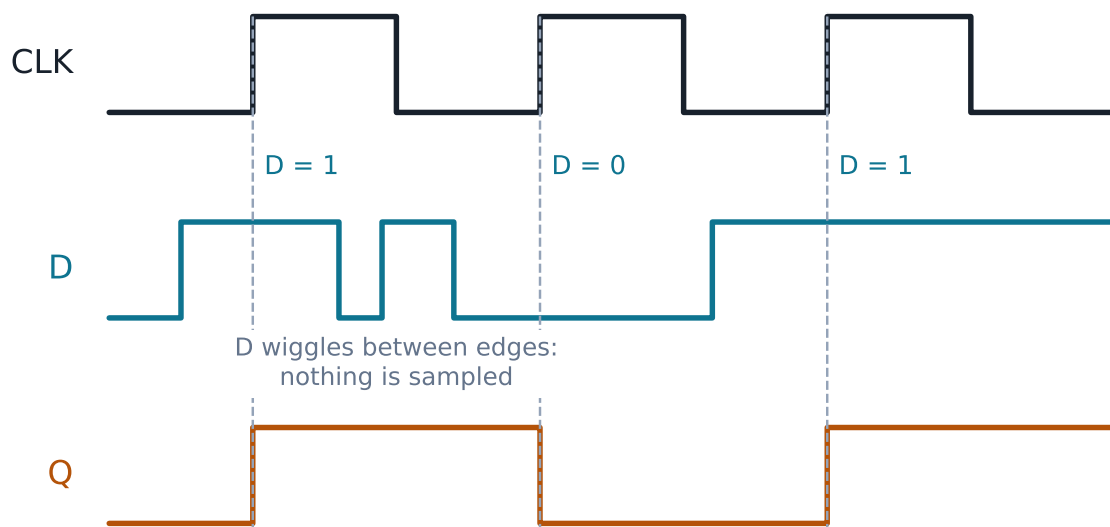
Objective

Trace latches and flip-flops on timing diagrams, use excitation tables to plan transitions, and distinguish level-sensitive from edge-triggered behaviour – every trace checked against the component's defining rule.

1 Key knowledge and worked examples

■ Latch: level-sensitive

A **latch** follows its input while enabled. The D latch with $EN = 1$ copies D to Q continuously ("transparent"); with $EN = 0$ it freezes Q. The SR latch (two cross-coupled NORs) sets on S, resets on R, holds on 00 – and $S = R = 1$ is the forbidden combination.



■ Flip-flop: edge-triggered

A **flip-flop** samples only at the **clock edge**. The D flip-flop's one rule: $Q(\text{next edge}) = D(\text{before that edge})$. Between edges, D may change freely – nothing happens. The J-K extends SR with $J = K = 1$ meaning **toggle**.

Worked example. D flip-flop, D sequence 1, 0, 1 at three rising edges: Q reads 1, 0, 1 after each edge. If D wiggles $1 \rightarrow 0 \rightarrow 1$ between edges 1 and 2, Q still holds its last sampled value – the timing diagram shows Q changing **ONLY** at edge instants. That is the entire difference from the latch.

■ Excitation tables: design in reverse

Given a desired $Q \rightarrow Q^+$ transition, the **excitation table** lists the inputs required:

$Q \rightarrow Q^+$	D	J K	T
$0 \rightarrow 0$	0	$0 \times$	0
$0 \rightarrow 1$	1	$1 \times$	1
$1 \rightarrow 0$	0	$\times 1$	1
$1 \rightarrow 1$	1	$\times 0$	0

(the $\times$ entries are free choices – J-K design exploits them to minimise logic). $D = Q^+$ always; $T = 1$ exactly when the state changes.

2 Practice

2.1 A D latch ($EN = 1$) sees D change $0 \rightarrow 1 \rightarrow 0$ over 60 ns. What does Q do, and when? [2]

2.2 A D flip-flop clocks on rising edges at $t = 10, 20, 30$ ns; D is 0 at 10, 1 at 20, 1 at 30. Give Q after each edge. [3]

2.3 From the excitation table: for $1 \rightarrow 0$ give the D input, the J-K inputs (one valid pair), and T. [3]

3 Exam-style questions

3.1 A J-K flip-flop starts at $Q = 0$ and receives $(J, K) = (1, 0), (1, 1), (0, 1), (1, 1)$ at four successive falling edges.

Give Q after each edge with one line of reasoning each. Then state what makes $(1, 1)$ different here from the SR latch's forbidden state. [6]

3.2 A D flip-flop's clock rises at 0, 10, 20, 30, 40 ns. $D(t)$ is 1 for $0 \leq t < 15$, then 0 for $15 \leq t < 25$, then 1 for $t \geq 25$.

Draw (describe) $Q(t)$ piecewise, giving its value after each edge. State the value sampled at $t = 20$ and why the D-change at $t = 25$ does not appear until $t = 30$. Explain why the same D stream into a D latch with EN high from $t = 20$ would differ at once. [7]

Solutions

2.1

- Q follows D immediately (transparent): Q goes $0 \rightarrow 1 \rightarrow 0$ as D does, with only propagation delay.

2.2

- After 10 ns: $Q = 0$.
- After 20 ns: $Q = 1$.
- After 30 ns: $Q = 1$ (D still 1).

2.3

- $D = 0$.
- J-K: $J = 0$, $K = 1$ (from the table's $\times 1$ row; $J = \times$, $K = 1$ required – J's value free, give 0).
- $T = 1$ (a change).

3.1

- Edge 1 (1, 0): set $\rightarrow Q = 1$.
- Edge 2 (1, 1): toggle $\rightarrow Q = 0$.
- Edge 3 (0, 1): reset $\rightarrow Q = 0$.
- Edge 4 (1, 1): toggle $\rightarrow Q = 1$.
- (1, 1) toggles instead of conflicting because the J-K's feedback ensures each output drives the OTHER gate's input – the “forbidden” pair becomes the useful toggle action.
- Contrast: SR with $S = R = 1$ drives both outputs to the same value at once and holds an invalid state; J-K never does.

3.2

- Edge at 0: $D = 1 \rightarrow Q = 1$ (from $t = 0$).
- Edge at 10: $D = 1 \rightarrow Q = 1$.
- Edge at 20: $D = 0 \rightarrow Q = 0$.
- Edge at 30: $D = 1$ (since 25) $\rightarrow Q = 1$.
- Edge at 40: $D = 1 \rightarrow Q = 1$. Summary: $Q = 1, 1, 0, 1, 1$ after the five edges.
- Sampled at 20 ns: 0 (D changed to 0 at 15, before the edge).
- The D change at 25 waits for the next edge (30) because the flip-flop samples only at edges; a latch with $EN = 1$ from $t = 20$ would copy the $t = 25$ change through immediately (transparent).