



THE OHIO STATE UNIVERSITY

COLLEGE OF ENGINEERING

ECE 3561

Advanced Digital Design

Class 07: Flip-Flops 2 – SR, JK, and T FFs

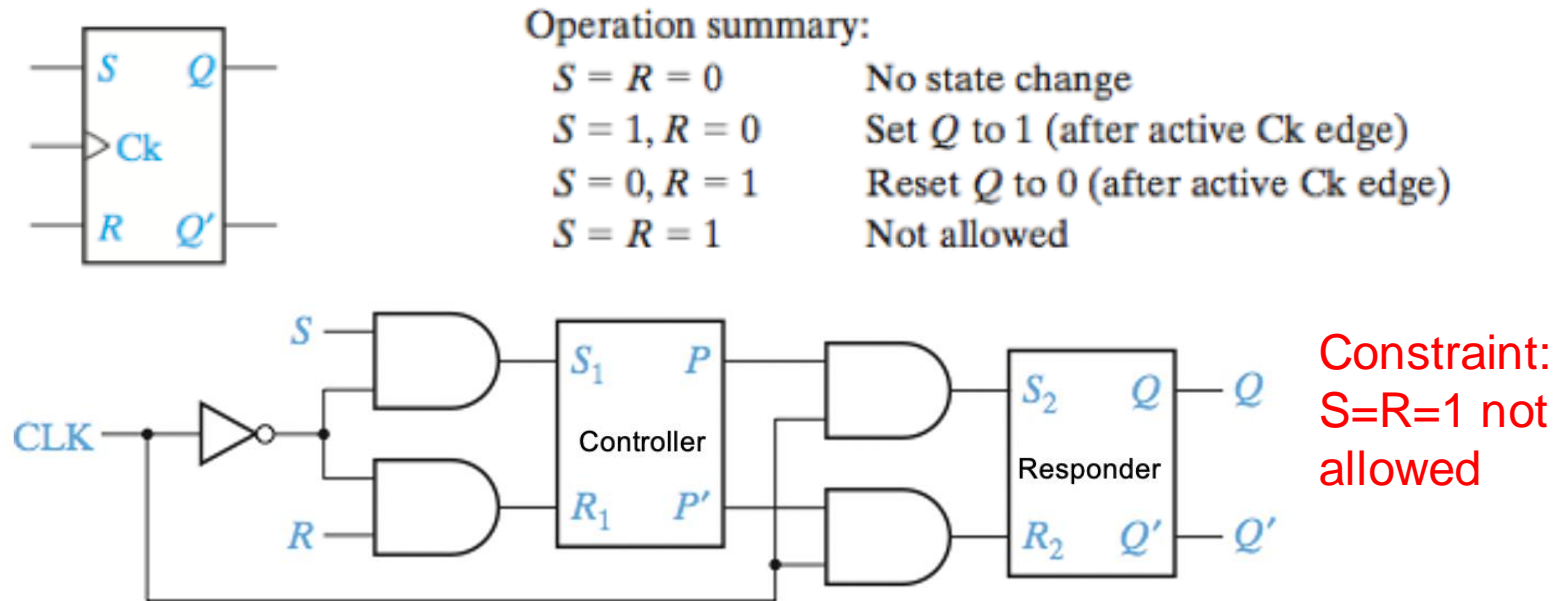
Drew Phillips

Spring 2024



S-R Flip-Flop

- Similar to S-R latch but triggered by edges
- Implementation: controller/responder structure (compare with D-FF)

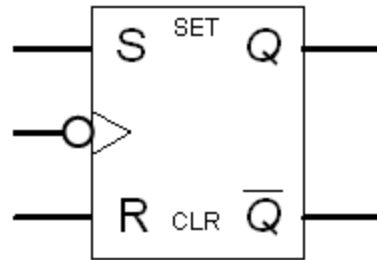


(a) Implementation with two latches



Falling-Edge Triggered S-R FF

- Add a bubble to the CLK



S	R	CLK	Q
0	0		Q
0	1		0
1	0		1
1	1		Not allowed



S-R FF Characteristic Equation

- Use K-map to derive characteristic equation (just like S-R latch):

S	R	CLK	Q
0	0	↓	Q
0	1	↓	0
1	0	↓	1
1	1	↓	Not allowed



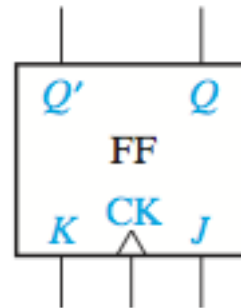
J-K Flip-Flop

- J-K Flip-Flop is an extended S-R Flip-Flop
- Difference: **If $J=K=1$, then $Q^+=Q'$**
 - For S-R FF, $S=R=1$ is not allowed

$$J \leftrightarrow S$$

$$K \leftrightarrow R$$

After eliminating $S=R=1$



(a) J-K flip-flop

J	K	CLK	Q
0	0		Q
0	1		0
1	0		1
1	1		\overline{Q}

$$Q^+ = JQ' + K'Q$$



Variable-Entered K-Map

$Q^+ \backslash JK$					
		00	01	11	10
0	Q	0	0	1	1
1	Q	1	0	0	1

$$Q^+ = J\bar{Q} + \bar{K}Q$$

Variables = Conditional 1's

|||

$J \backslash K$		0	1
0	Q	Q	0
1	\bar{Q}	1	\bar{Q}

\equiv

$J \backslash K$		0	1
0	Q	Q	0
1	\bar{Q}	$Q + \bar{Q}$	\bar{Q}

Q^+

\equiv

$J \backslash K$		0	1
0	Q	Q	0
1	\bar{Q}	Q	0

$Q\bar{K}$

+

$J \backslash K$		0	1
0	Q	0	0
1	\bar{Q}	\bar{Q}	\bar{Q}

$\bar{Q}J$

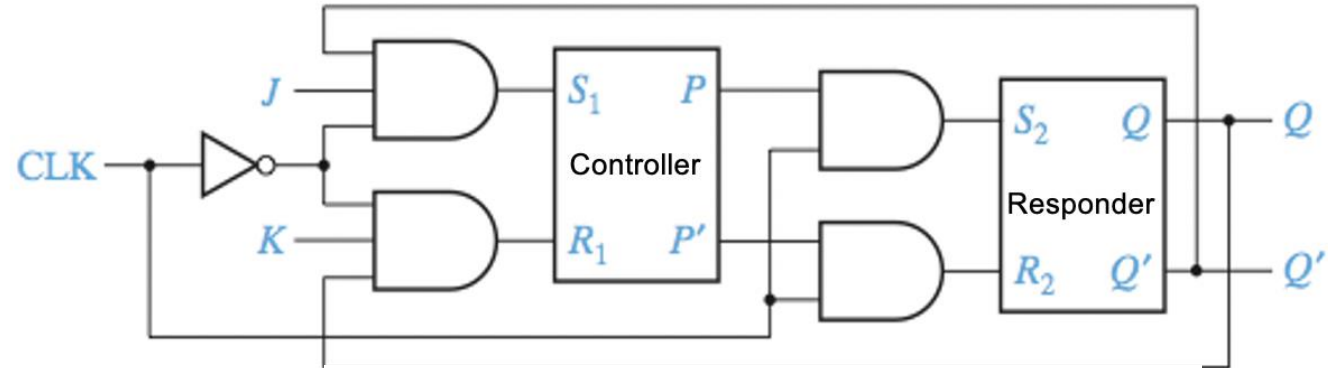


J-K FF Controller-Responder Implementation

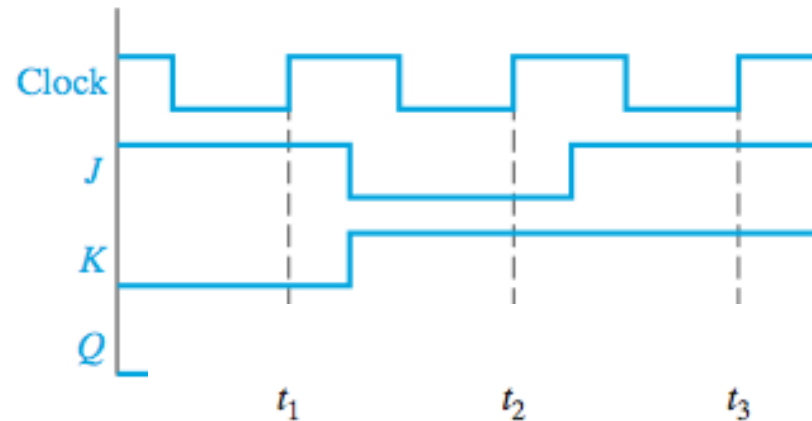
FIGURE 11-25

Controller-Responder
J-K Flip-Flop
(Q Changes on
Rising Edge)

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J	K	CLK	Q
0	0		Q
0	1		0
1	0		1
1	1		\overline{Q}



(c) J-K flip-flop timing

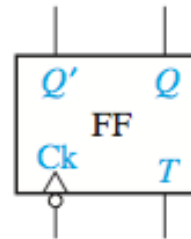


T Flip-Flop

- Toggle (T) Flip-Flop
 - $T=1$: toggle the state
 - $T=0$: keep the state

FIGURE 11-26
T Flip-Flop

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(a)

T	Q	Q^+
0	0	0
0	1	1
1	0	1
1	1	0

(b)



T Flip-Flop Characteristic Equation

If $T=0$: $Q^+=Q$

If $T=1$: $Q^+=Q'$



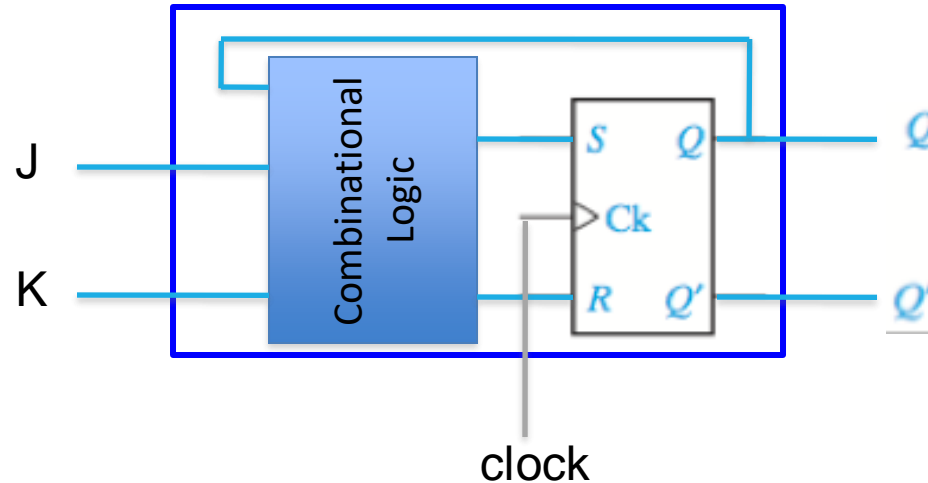
Implementing Flip-Flops

- There are multiple ways to implement flip-flops (or other functions):
 - Controller-responder latch structure (already seen this for D, SR, and JK FFs)
 - Adapter Design Pattern approach
 - Compare characteristic equations



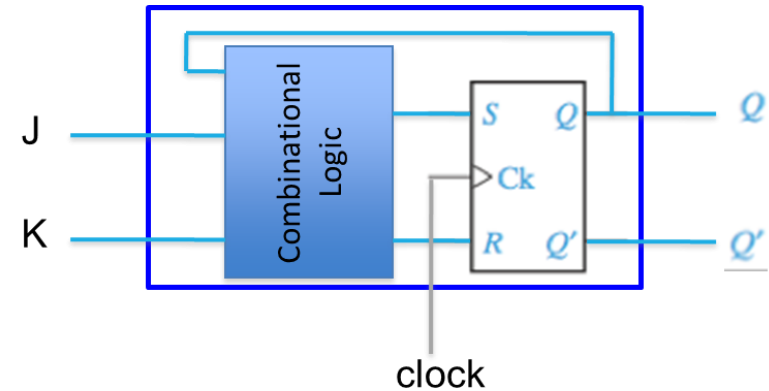
Adapter Design Pattern Approach

- Implement one flip-flop using another flip-flop
- Add combinational logic in front of the inside flip-flop
- Example: Convert S-R FF into a J-K FF



Adapter Design Pattern Approach

- Identify the input and output of the combinational circuit, which transforms a set of input signals to another set of targeted input signals
 - $(J, K, Q) \rightarrow (S, R)$
- Find the truth table
 - Inputs: (J, K, Q)
 - Outputs: (S, R)
- To construct the truth table, use the already known truth table of S-R FF and the expected truth table of J-K FF under your design
 - Both should generate the same $Q \rightarrow Q^+$
 - These two truth tables give a relationship between (J, K, Q) and (S, R)





Adapter Design Pattern Example

J-K Inputs		Outputs		S-R Inputs	
J	K	Q	Q ⁺	S	R
0	0	0	0		
0	0	1	1		
0	1	0	0		
0	1	1	1		
1	0	0	0		
1	0	1	1		
1	1	0	0		
1	1	1	1		



Adapter Design Pattern Example

Draw the circuit.



Compare Characteristic Equations

- Compare next state equations of T and J-K FFs:

$$Q^+ = T \oplus Q = T'Q + TQ'$$

$$Q^+ = K'Q + JQ'$$

- Compare next state equations of T and D FFs:

$$Q^+ = T \oplus Q = T'Q + TQ'$$

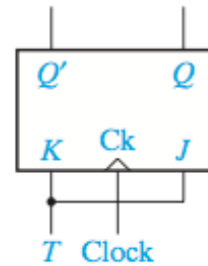
$$Q^+ = D$$



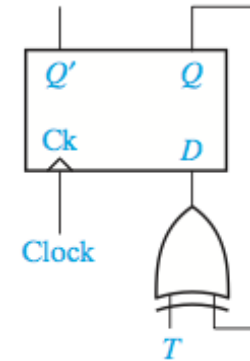
T Flip-Flop Implementation

FIGURE 11-28
Implementation
of T Flip-Flops

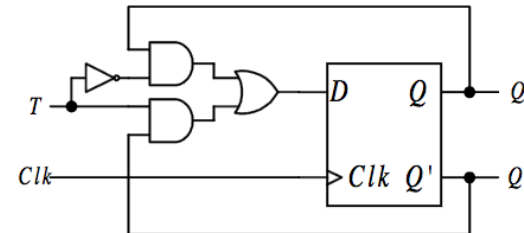
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(a) Conversion of J-K to T



(b) Conversion of D to T





Practice Problem: Convert D FF to J-K FF

- Use either:
 - Adapter design pattern approach
 - Compare characteristic equations
- Draw the circuit

D	Q	Q^+
0	0	0
0	1	0
1	0	1
1	1	1

$$Q^+ = D$$



J	K	CLK	Q
0	0		Q
0	1		0
1	0		1
1	1		\overline{Q}

$$Q^+ = JQ' + K'Q$$

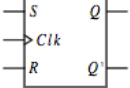

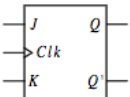

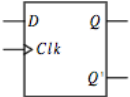

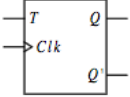



Convert D FF to J-K FF





Summary of Flip-Flops

Name / Symbol	Characteristic (Truth) Table	State Diagram / Characteristic Equations	Excitation Table																																																								
SR 	<table><tr><th><i>S</i></th><th><i>R</i></th><th><i>Q</i></th><th><i>Q_{next}</i></th></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>0</td><td>1</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td><td>×</td></tr><tr><td>1</td><td>1</td><td>1</td><td>×</td></tr></table>	<i>S</i>	<i>R</i>	<i>Q</i>	<i>Q_{next}</i>	0	0	0	0	0	0	1	1	0	1	0	0	0	1	1	0	1	0	0	1	1	0	1	1	1	1	0	×	1	1	1	×	<p>SR=00 or 01</p>  <p>SR=01</p> <p>$Q_{next} = S + R'Q$ $SR = 0$</p>	<table><tr><th><i>Q</i></th><th><i>Q_{next}</i></th><th><i>S</i></th><th><i>R</i></th></tr><tr><td>0</td><td>0</td><td>0</td><td>×</td></tr><tr><td>0</td><td>1</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>×</td><td>0</td></tr></table>	<i>Q</i>	<i>Q_{next}</i>	<i>S</i>	<i>R</i>	0	0	0	×	0	1	1	0	1	0	0	1	1	1	×	0
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