



Digital Systems- IT131

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Lecture 10: Sequential Circuits(part3)

Sequential Circuits

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1. Sequential circuits
2. Flip-flops
3. Analysis of clocked sequential circuits
4. Design procedure

Design procedure

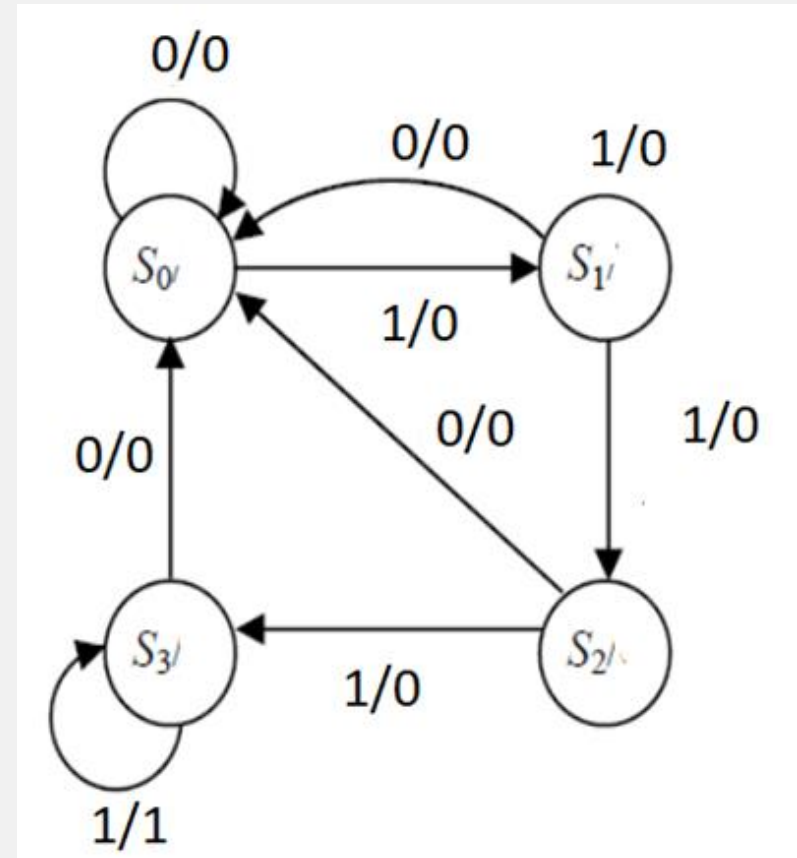
- The procedure for designing synchronous sequential circuit is:
1. Translate the design specifications to the state diagram for the circuit
 2. Assign binary values to the states
 3. Obtain the binary coded state table
 4. Choose the type of flip-flops to be used
 5. Derive the simplified flip-flop input equations and output equations
 6. Draw the logic diagram

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Sequential Circuits

Sequence detector

- **Example:** Design a circuit that detects three or more consecutive 1's in a string of bits coming through an input line
- The state diagram for the circuit is shown:



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Sequence detector (Contd.)

- It is derived by starting with state S_0
- If input is 0, the circuit states in same state
- If the input is 1, it goes to state S_1 to indicate that a 1 was detected
- If the next input is 1, it changes to state S_2 to indicate the arrival of two consecutive 1's

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Sequential Circuits

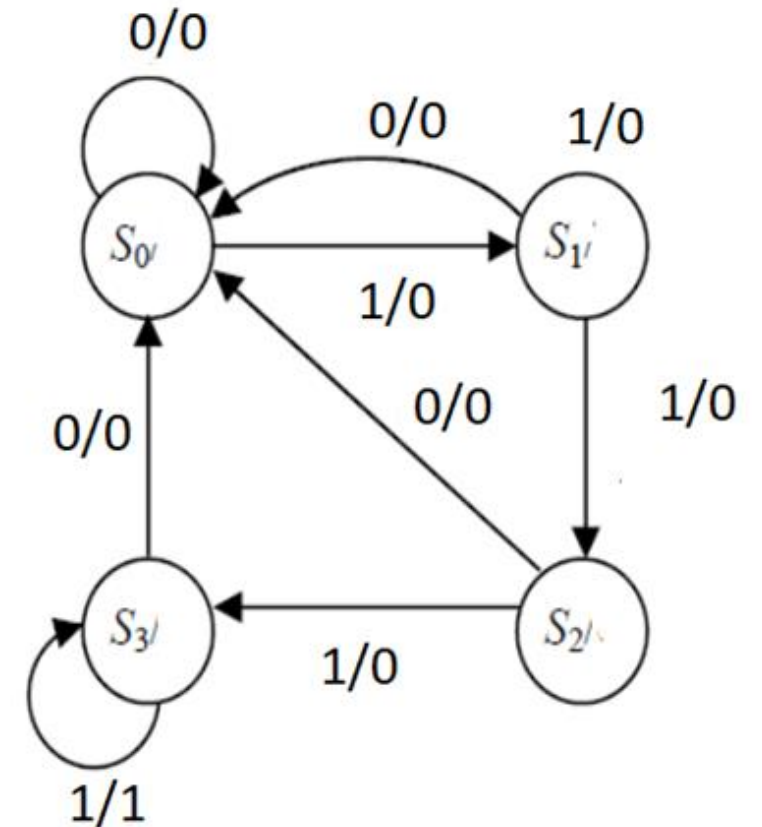
Sequence detector (Contd.)

- But, if the input is 0, we go back to state S_0
- Third consecutive 1 sends the circuit to S_3
- If more 1's are detected, circuit stays at S_3
- Any 0 input sends the circuit back to S_0
- Circuit stays at S_3 , for three or more 1's

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Assign binary values to the states

	P.S.	N.S.		Y
		$x = 0$	$x = 1$	
00 →	S_0	S_0	S_1	0
01 →	S_1	S_0	S_2	0
10 →	S_2	S_0	S_3	0
11 →	S_3	S_0	S_3	1



Sequential Circuits

Synthesizing using D flip-flops

- To design the circuit, we need to assign binary codes to the states and list the table
- The state table is derived from the diagram

Present state		Input	Next State		Output
<i>A</i>	<i>B</i>	<i>x</i>	<i>A</i>	<i>B</i>	<i>y</i>
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	0
0	1	1	1	0	0
1	0	0	0	0	0
1	0	1	1	1	0
1	1	0	0	0	1
1	1	1	1	1	1

Sequential Circuits

Using D flip-flops (Contd.)

- We choose two D flip-flops to represent four states and label their outputs A and B
- There is one input x and one output y
- The characteristic equation of D flip-flop is

$$Q(t+1) = D_Q$$

- D flip-flop equations are

$$A(t+1) = D_A(A, B, x) = \sum (3, 5, 7)$$

$$B(t+1) = D_B(A, B, x) = \sum (1, 5, 7)$$

$$y(A, B, x) = \sum (5, 7)$$

Sequential Circuits

Using D flip-flops (Contd.)

➤ Simplifying the above equations by K-map

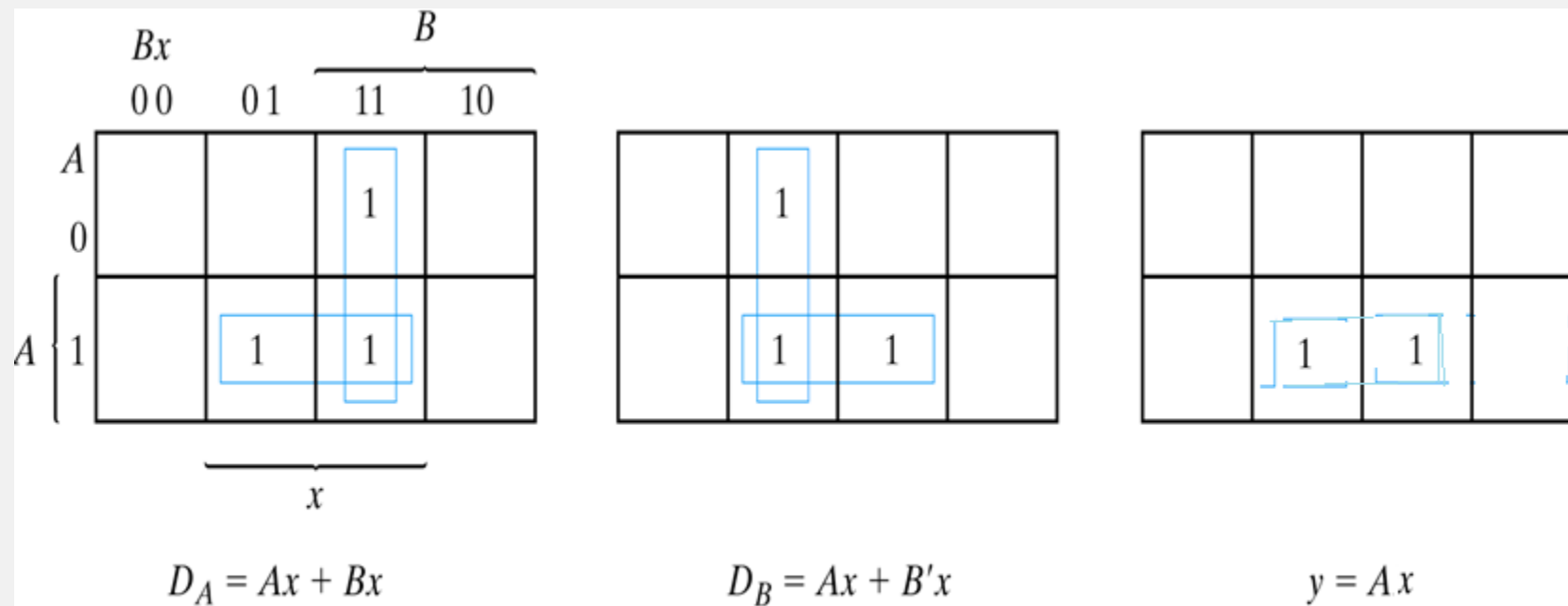


Fig. 5-25 Maps for Sequence Detector

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Sequential Circuits

Using D flip-flops (Contd.)

- The logic diagram for the circuit

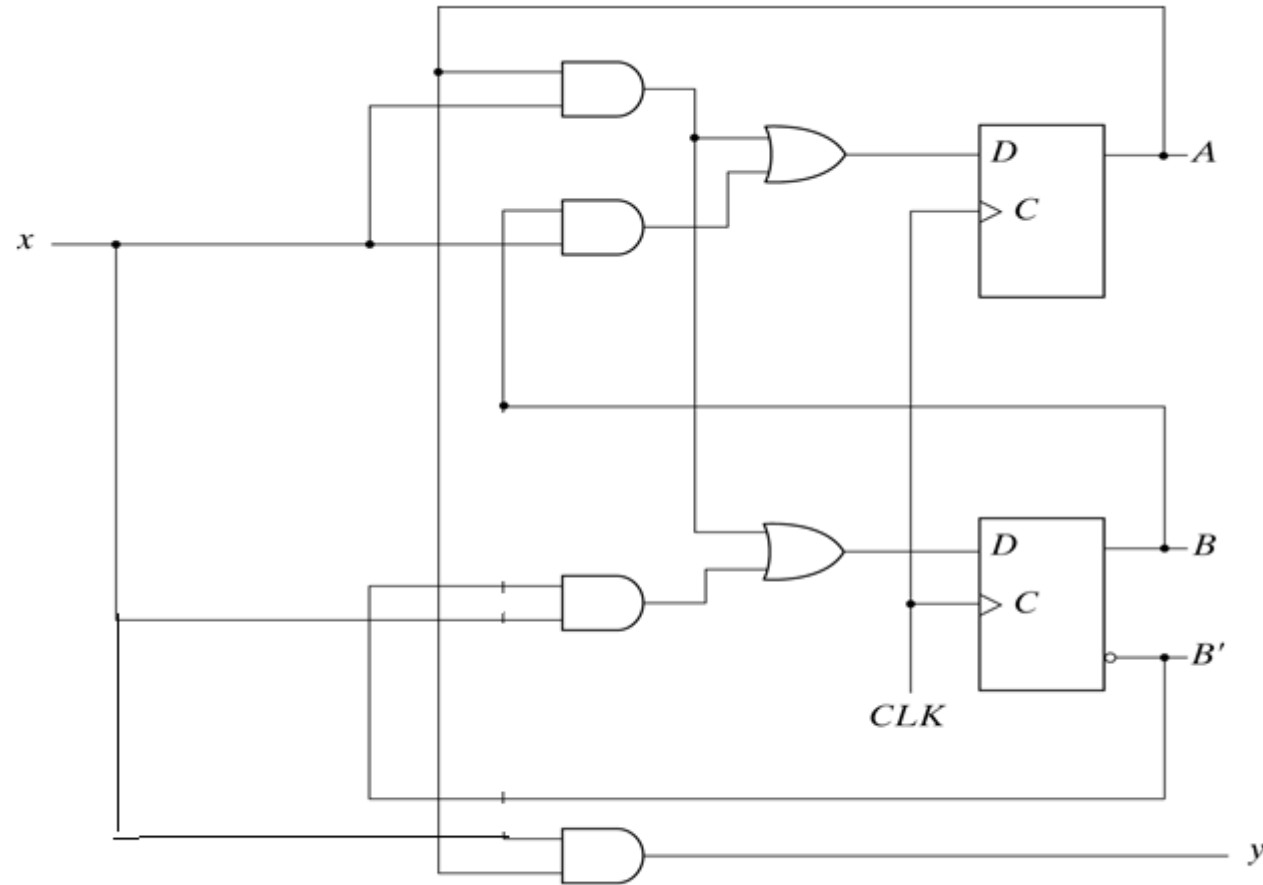


Fig. 5-26 Logic Diagram of Sequence Detector

Sequential Circuits

Excitation table

- Design with other types of flip-flops is not straightforward as the next state cannot directly be related to the input equations
- In such cases we should use excitation tables, which list the required input for a given change of state
- Next slide shows excitation tables for JK & T Flip-Flops
- The symbol X represents a don't care condition

Sequential Circuits

Excitation table (Contd.)

$Q(t)$	$Q(t+1)$	J	K
0	0	0	x
0	1	1	x
1	0	x	1
1	1	x	0

Excitation table of a
 JK flip-flop

$Q(t)$	$Q(t+1)$	T
0	0	0
0	1	1
1	0	1
1	1	0

Excitation table of a
 T flip-flop

Sequential Circuits

Synthesizing using JK flip-flops

- **Example:** Consider the sequential circuit given by the following table:

Present state		Input	Next State	
<i>A</i>	<i>B</i>	<i>x</i>	<i>A</i>	<i>B</i>
0	0	0	0	0
0	0	1	0	1
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	1	1
1	1	0	1	1
1	1	1	0	0

Sequential Circuits

Using JK flip-flops (Contd.)

- Assume that it is desired to design this sequential circuit using JK flip-flops
- Using excitation table of JK FF, we have:

Present state		Input	Next State		Flip-Flop Inputs			
A	B		A	B	J_A	K_A	J_B	K_B
0	0	0	0	0	0	x	0	x
0	0	1	0	1	0	x	1	x
0	1	0	1	0	1	x	x	1
0	1	1	0	1	0	x	x	0
1	0	0	1	0	x	0	0	x
1	0	1	1	1	x	0	1	x
1	1	0	1	1	x	0	x	0
1	1	1	0	0	x	1	x	1

Sequential Circuits

Using JK flip-flops (Contd.)

		Bx			
		00	01	11	10
A	0				1
	1	X	X	X	X

x

$$J_A = Bx'$$

		Bx			
		00	01	11	10
A	0	X	X	X	X
	1			1	

x

$$K_A = Bx$$

		Bx			
		00	01	11	10
A	0		1	X	X
	1		1	X	X

x

$$J_B = x$$

		Bx			
		00	01	11	10
A	0	X	X		1
	1	X	X	1	

x

$$K_B = (A \oplus x)'$$

Fig. 5-27 Maps for J and K Input Equations

Sequential Circuits

Using JK flip-flops (Contd.)

- The logic diagram can be obtained from the input equations given above

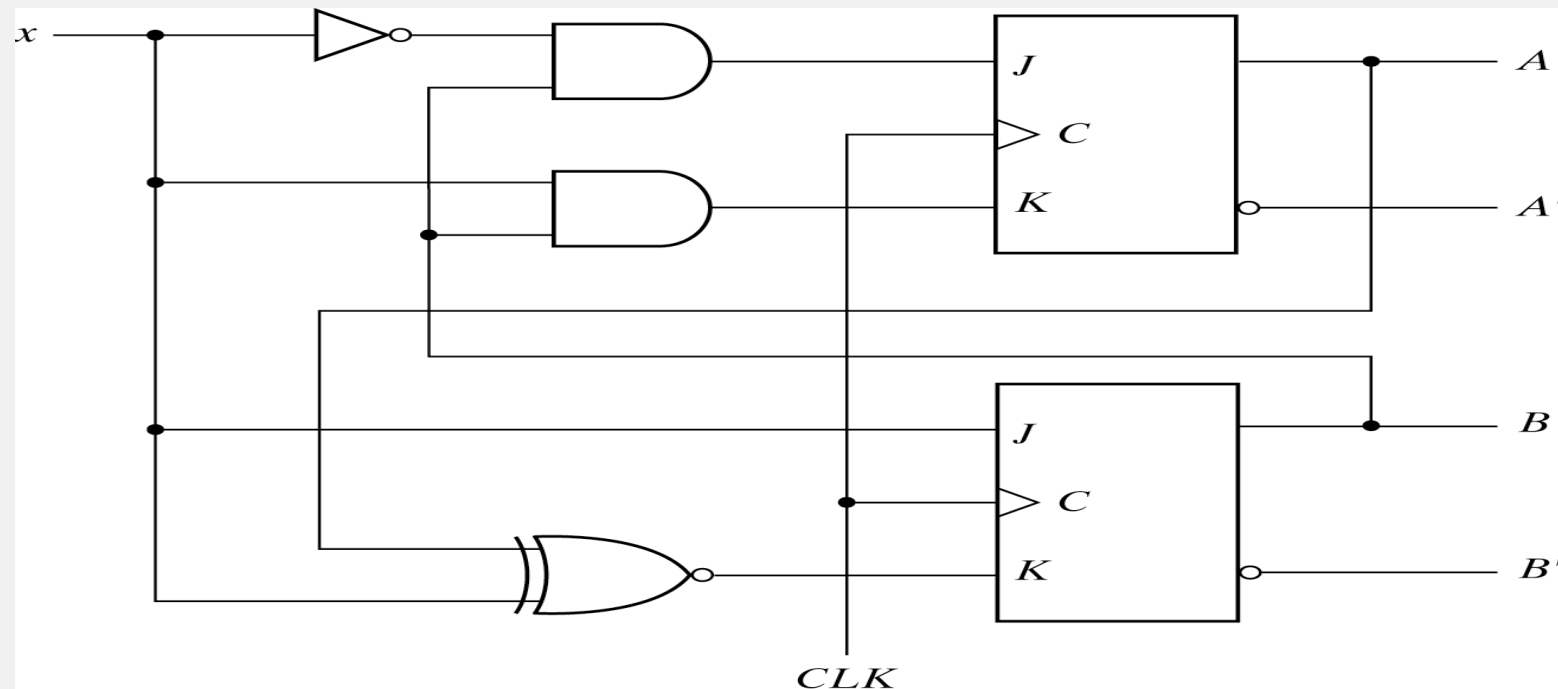
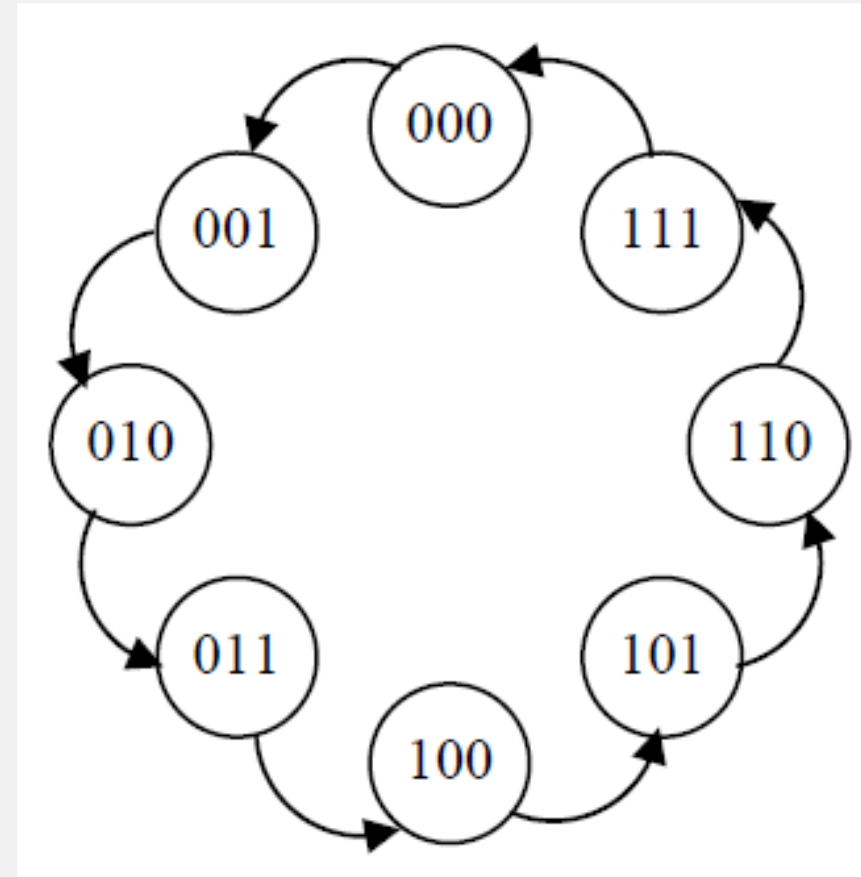


Fig. 5-28 Logic Diagram for Sequential Circuit with JK Flip-Flops

Sequential Circuits

Synthesizing using T flip-flops

- **Example:** Consider a 3-bit binary counter shown in the diagram:
- In fact the only input to the circuit is the clock and the output is the present state of the flip-flops.



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Sequential Circuits

Using T flip-flops (Contd.)

➤ The state table for this example is as follows:

Present State			Next State			From Excitation table Flip-Flop Inputs		
A_2	A_1	A_0	A_2	A_1	A_0	T_{A_2}	T_{A_1}	T_{A_0}
0	0	0	0	0	1	0	0	1
0	0	1	0	1	0	0	1	1
0	1	0	0	1	1	0	0	1
0	1	1	1	0	0	1	1	1
1	0	0	1	0	1	0	0	1
1	0	1	1	1	0	0	1	1
1	1	0	1	1	1	0	0	1
1	1	1	0	0	0	1	1	1

Sequential Circuits

Using T flip-flops (Contd.)

- The most efficient way to construct a binary counter is by using T flip-flops, because of their complement property.

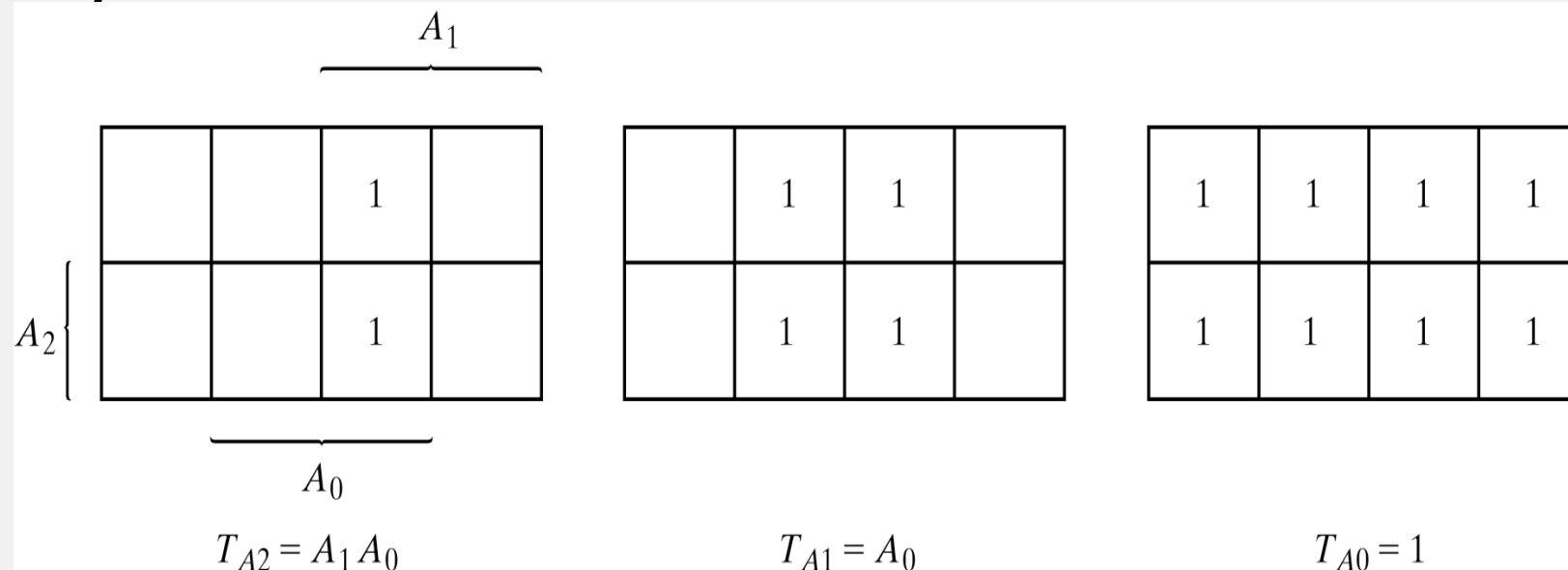


Fig. 5-30 Maps for 3-Bit Binary Counter

Using T flip-flops (Contd.)

➤ Logic diagram of the counter:

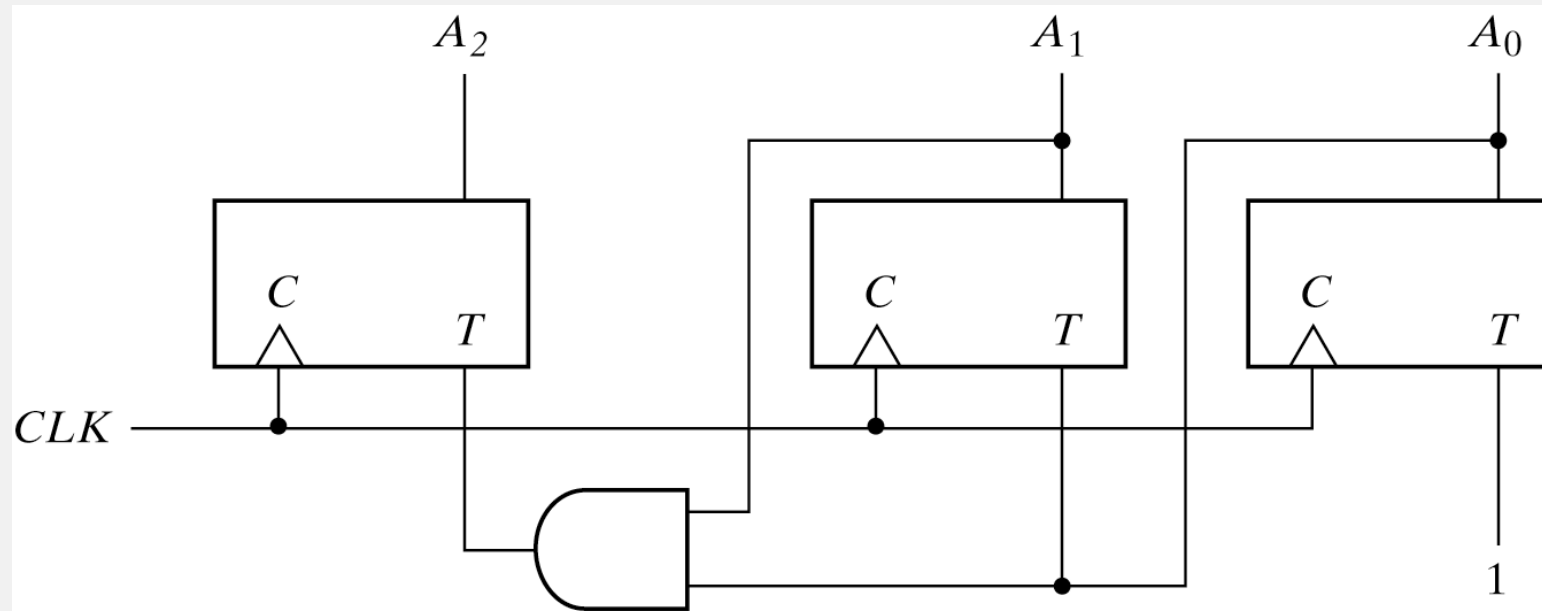


Fig. 5-31 Logic Diagram of 3-Bit Binary Counter

Sequential Circuits

Registers

- A register is a memory device that can be used to store more than one bit of information.
- A register is a circuit capable of storing data. In general, an n -bit register consists of n FFs, together with some other logic that allows simple processing of the stored data.
- A register is a generalization of a flip-flop. Where a flip-flop stores one bit, a register stores several bits

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Registers

- The main operations on a register are the same as for any storage devices, namely:
 - Load or Store: Put new data into the register
 - Read: Retrieve the data stored in the register (usually without changing the stored data).

Sequential Circuits

Registers

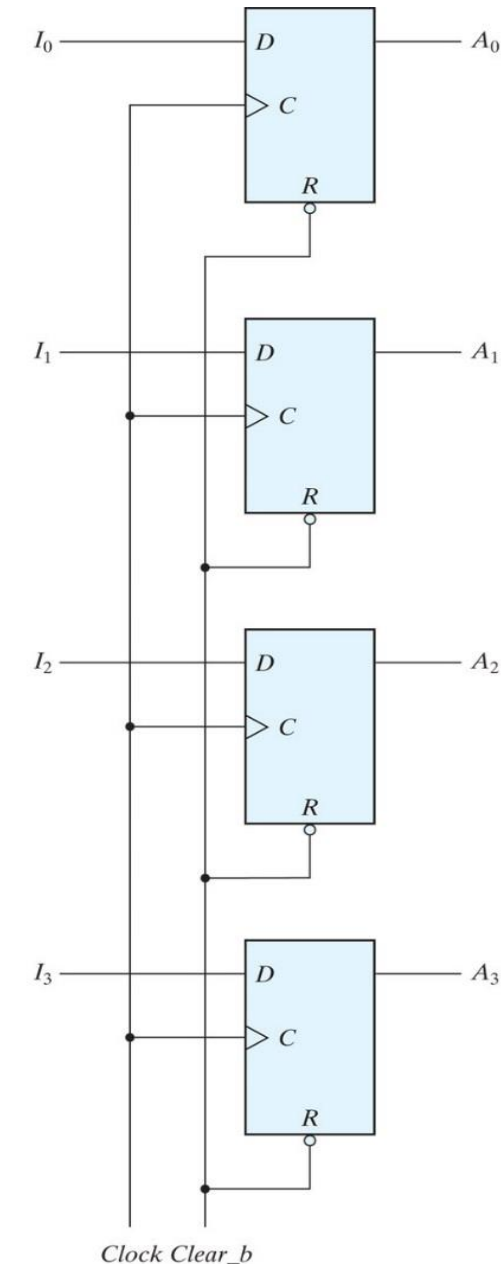
➤ Types of transfer(load):

- **Parallel transfer** : When all bits of the register are loaded in the same time.
- **Serial transfer**: information is transferred one bit at a time.

Sequential Circuits

Registers

- Figure shows one of the simplest register
 - The clock input triggers FFs on positive edge.
 - Four inputs are transferred into registers.
 - The four outputs are to obtain the stored information.
 - Clear_b is direct input to reset FFs.



Shift Registers

- It is a register that can shift information in each cell to its neighboring cell.
- It has chain of FF in cascade
 - The output of one FF is connected to the input of the next FF.
- Can be unidirectional(one direction) or bidirectional.

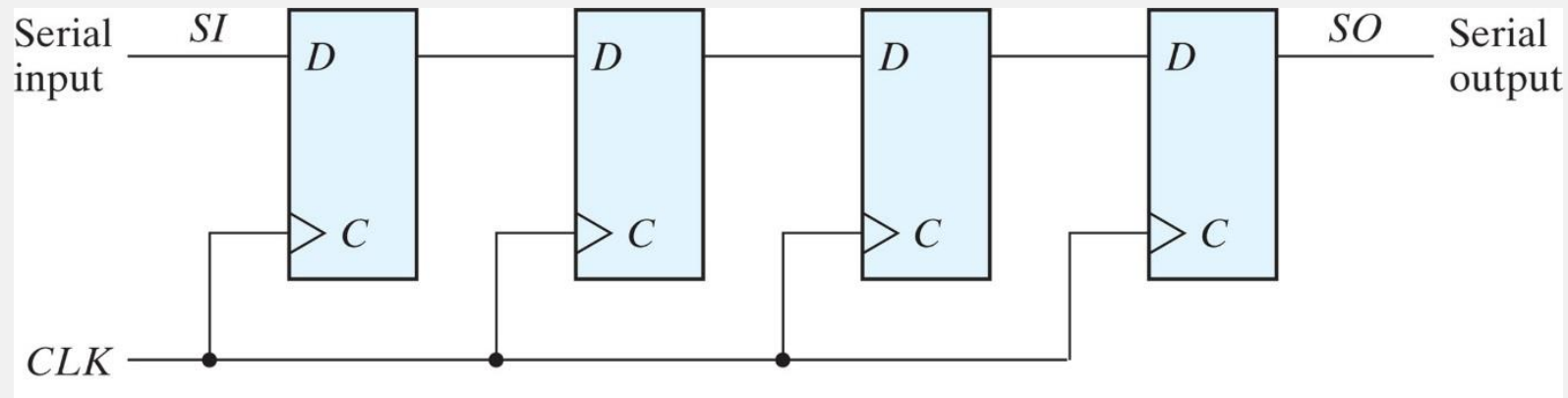
Shift Registers

- This shift register is unidirectional (left-to-right). Each clock pulse shifts the contents of the register one bit position to the right. The configuration does not support a left shift
- Serial input: determines what will go into the leftmost FF.
- Serial output is taken from the output of the rightmost flip-flop

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Shift Registers



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Counters

- It is a sequential circuit capable of incrementing and/or decrementing its contents
 - $Q \leftarrow Q \text{ plus } n$
 - $Q \leftarrow Q \text{ minus } n$
- The definition of "plus" and "minus" depends on the way the register contents encode the integers
- Binary Counters: Encode the integers with the binary number code
- It is a register that goes through a predetermined sequence of binary states.

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Counters

➤ Counters categories:

➤ Ripple (Asynchronous) counters

➤ A FF output transition is a source for triggering other FFs.

➤ Synchronous counters:

➤ All FFs receives a common clock.

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Sequential Circuits

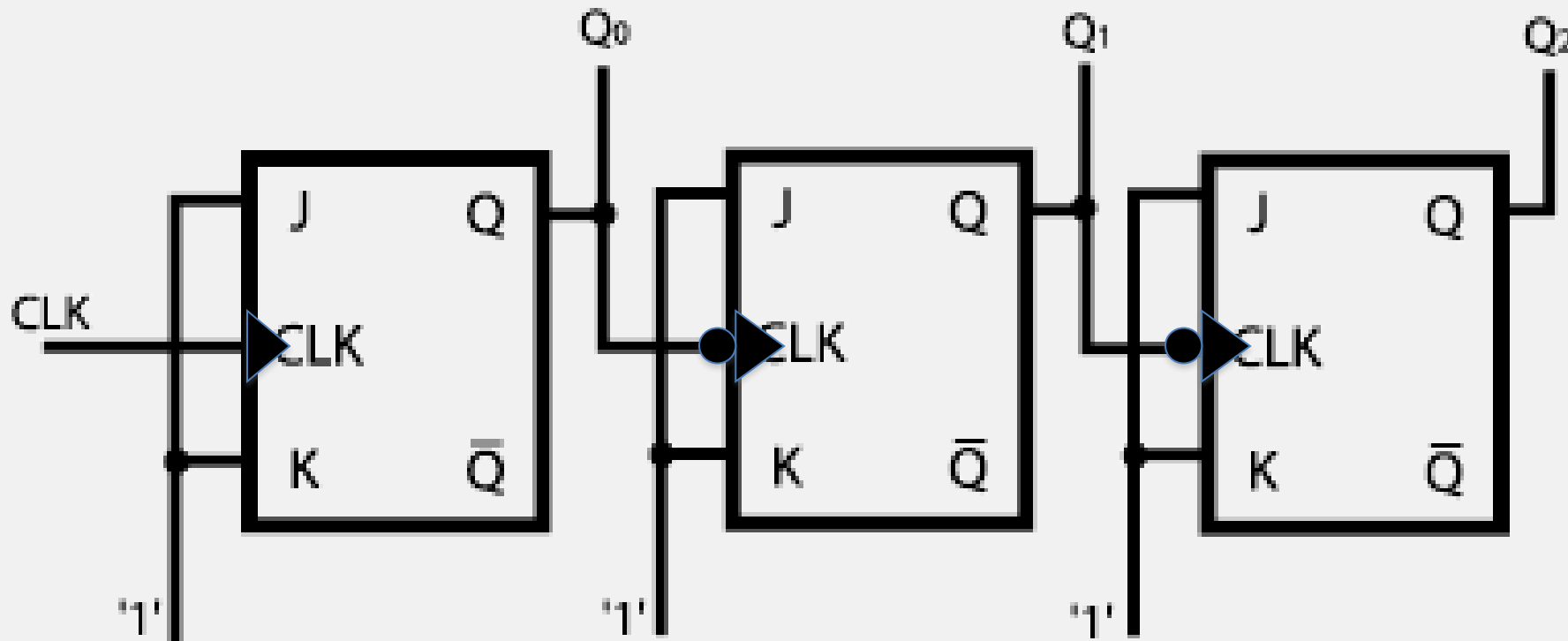
3-bit Binary Ripple Counter

- Idea:
 - to connect the output of one flip-flop to the C input of the next high-order flip-flop
- We need "complementing" flip-flops
 - We can use T flip-flops to obtain complementing flip-flops or
 - **JK flip-flops with its inputs are tied together** or
 - D flip-flops with complement output connected to the D input.

0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1
0	0	0	0

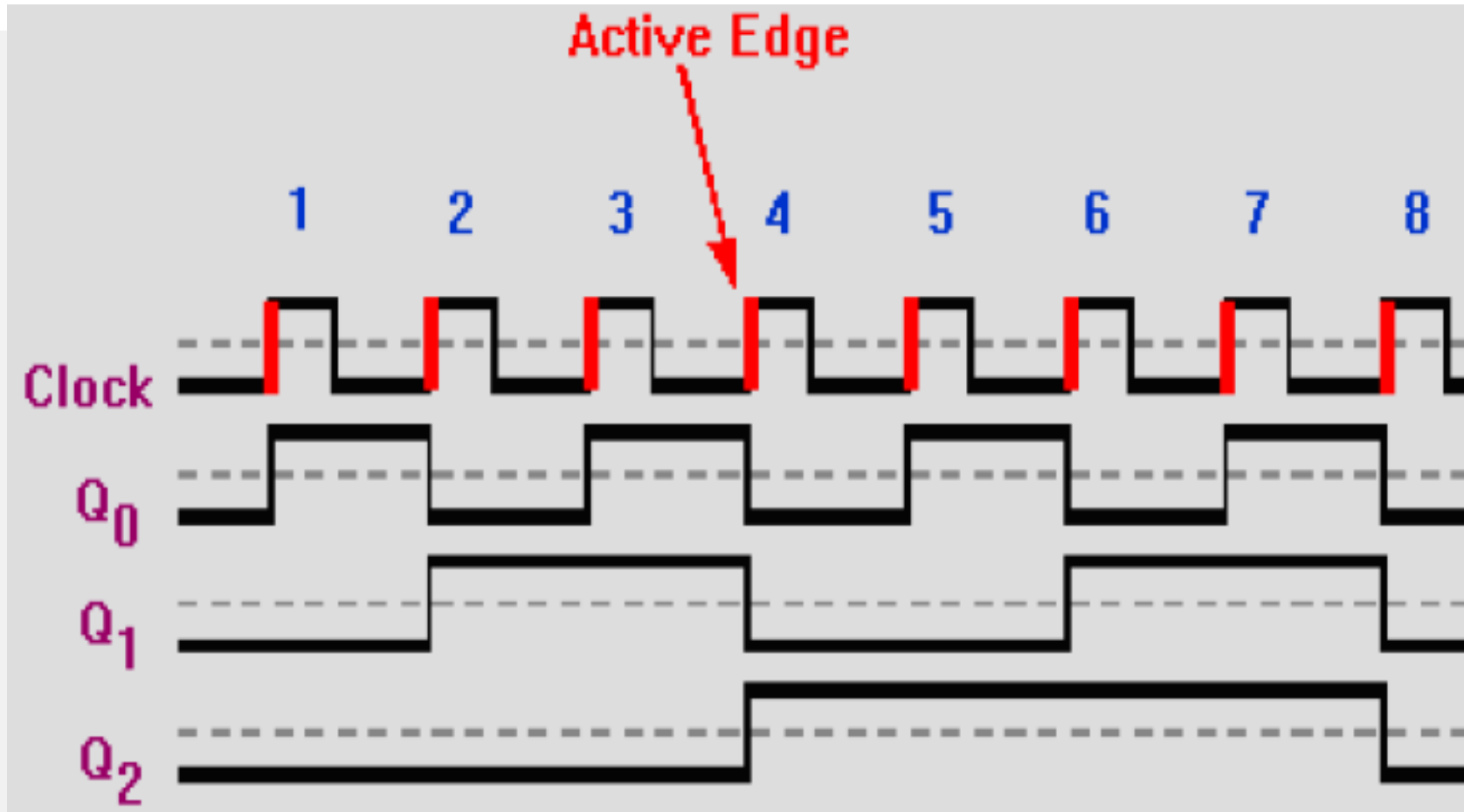
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Asynchronous Counters 3-bit binary up counter



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Sequential Circuits



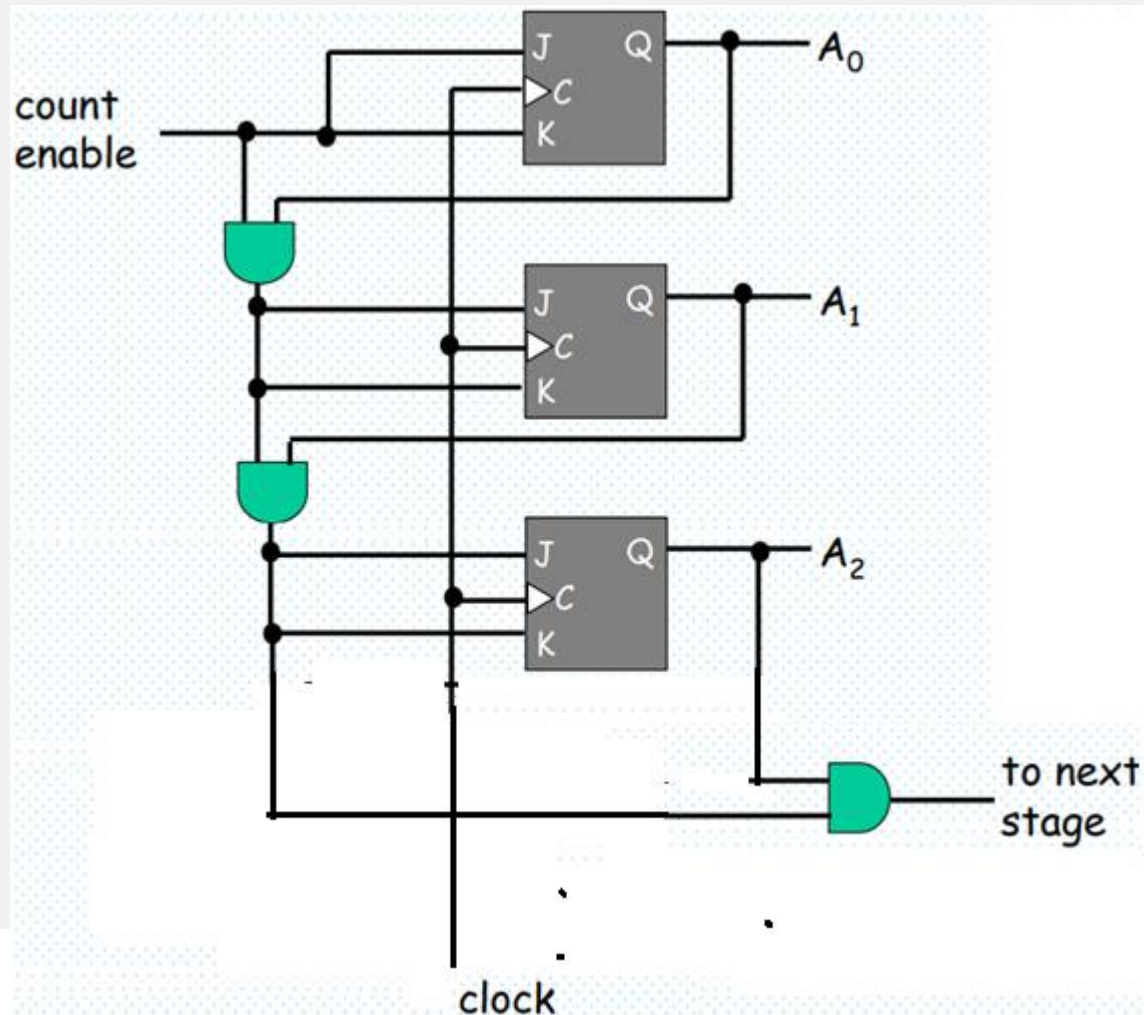
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Synchronous Counters

- There is a common clock
 - that triggers all flip-flops simultaneously
 - If $T = 0$ or $J = K = 0$ the flip-flop does not change state.
 - If $T = 1$ or $J = K = 1$ the flip-flop does change state.
- Design procedure is so simple
 - no need for going through sequential logic design process
 - A_0 is always complemented
 - A_1 is complemented when $A_0 = 1$
 - A_2 is complemented when $A_0 = 1$ and $A_1 = 1$
 - so on

	A ₂	A ₁	A ₀
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1
0	0	0	0

Synchronous Counters 3-bit binary up counter



End of lecture 10

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