Chapter 1. Sequential Circuits

Excitation tables of flip-flops

Analysis of sequential circuits

Implementation of sequential circuits from given state tables

Excitation Tables of Flip-Flops

An excitation table shows the required input for flip-flops to transition between states.

Excitation table for a D flip-flop:

In the excitation table below, q represents the present output, and Q represents the next output.

This table shows that:

- To keep a D flip-flop's output at 0, we input 0.
- To change a D flip-flop's output from 0 to 1, we input 1.
- To change a D flip-flop's output from 1 to 0, we input 0.
- To keep a D flip-flop's output at 1, we input 1.

q Q	D
0 0	0
0 1	1
1 0	0
1 1	1

Excitation Tables of Flip-Flops

Excitation table for an SR flip-flop:

S R	q	Q
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	-

q Q	S R
0 0	0 x
0 1	1 0
1 0	0 1
1 1	x 0

For this transition, both inputs shown below perform the same function.

SR = 00
SR = 01

If S=0, the value of R doesn't matter.
Therefore, SR is written as 0x.

Excitation Tables of Flip-Flops

Excitation table for a T flip-flop:

q Q	T
0 0	0
0 1	1
1 0	1
1 1	0

Excitation table for a JK flip-flop:

q Q	J K	
0 0	0 x	$\Rightarrow$ JK= 00 or JK=01
0 1	1 x	$\Rightarrow$ JK= 10 or JK=11
1 0	x 1	$\Rightarrow$ JK= 01 or JK=11
1 1	x 0	$\Rightarrow$ JK= 00 or JK=10

Analysis of Sequential Circuits

The analysis of a sequential circuit requires three steps:

1. Deriving the equations for the outputs and next states of the flip-flops.
2. Generating a state table that shows the input, output, and next states. This table indicates the data to be stored in the memory components when the next clock pulse is received.
3. Generating a state diagram from the state table.

Analysis of Sequential Circuits

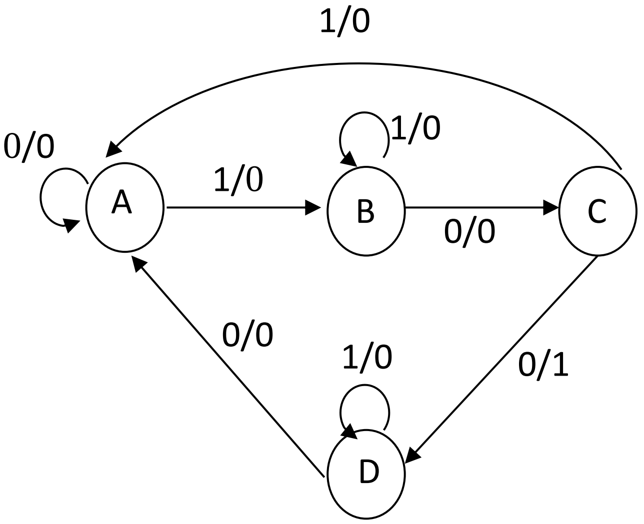
Let's start with some basic terms: state, state table, and state diagram.

The state of a circuit refers to the outputs of the flip-flops used in the circuit. Typically, letters are used as labels for the states (e.g., A = 00 in a circuit with two flip-flops).

Present State	Next State		Output (z)	
	x=0	x=1	x=0	x=1
A	A	B	0	0
B	C	B	0	0
C	D	A	1	0
D	A	D	0	0

A State Table

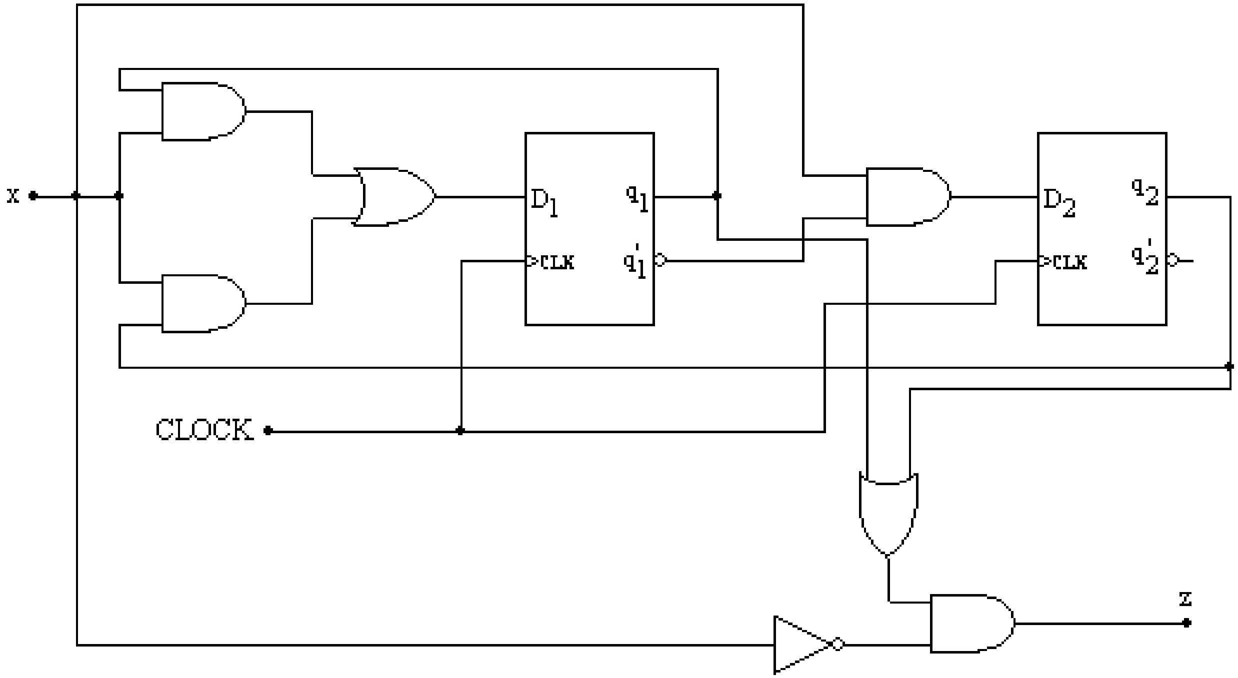
States



A State Diagram

Analysis of Sequential Circuits

Example:

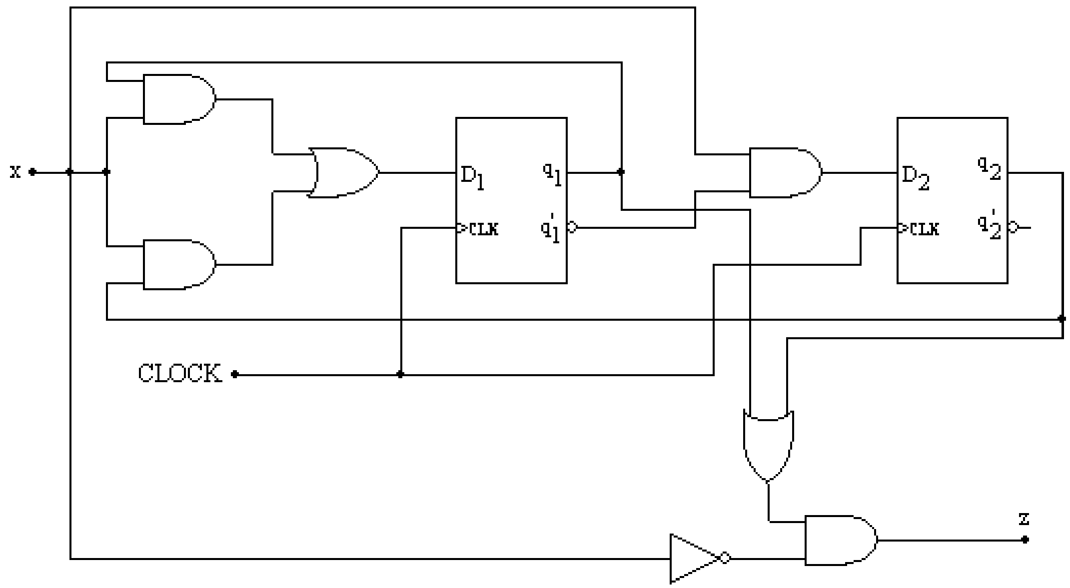


In the given circuit, we can identify the input, the output, and the number of memory components used.

This circuit has a single input and a single output, with two flip-flops used as memory components.

Example (2^{nd} Page):

In the first step, we need to derive the state equations.



Characteristic equation of a D flip-flop is: Q = D. So, $Q_1 = D_1$ and $Q_2 = D_2$.

$D_1 = x.q_1+x.q_2 = x.(q_1+q_2)$

$D_2 = x.q_1'$

So, $Q_1 = x.(q_1+q_2)$ and $Q_2 = x.q_1'$

The output $z = x'.(q_1+q_2)$

Example (3^{rd} Page):

In the second step, we generate the state table using the state equations derived in the first step.

$Q_1 = x.(q_1+q_2)$

$Q_2 = x.q_1'$

$z = x'.(q_1+q_2)$

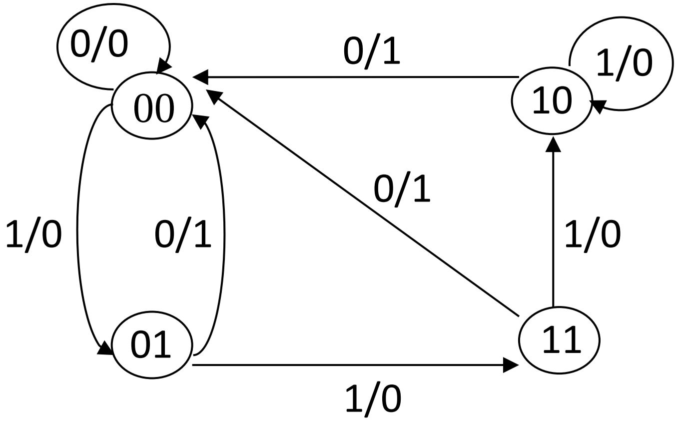
Present State			Next State		Output
q_1	q_2	x	Q_1	Q_2	z
0	0	0	**0**	**0**	**0**
0	0	1	**0**	**1**	**0**
0	1	0	**0**	**0**	**1**
0	1	1	**1**	**1**	**0**
1	0	0	**0**	**0**	**1**
1	0	1	**1**	**0**	**0**
1	1	0	**0**	**0**	**1**
1	1	1	**1**	**0**	**0**

Present State (q_1 q_2)	Next State (Q_1Q_2) x = 0	Next State (Q_1Q_2) x = 1	Output (z) x = 0	Output (z) x = 1
(A) 0 0	**0 0**	**0 1**	**0**	**0**
(B) 0 1	**0 0**	**1 1**	**1**	**0**
(C) 1 0	**0 0**	**1 0**	**1**	**0**
(D) 1 1	**0 0**	**1 0**	**1**	**0**

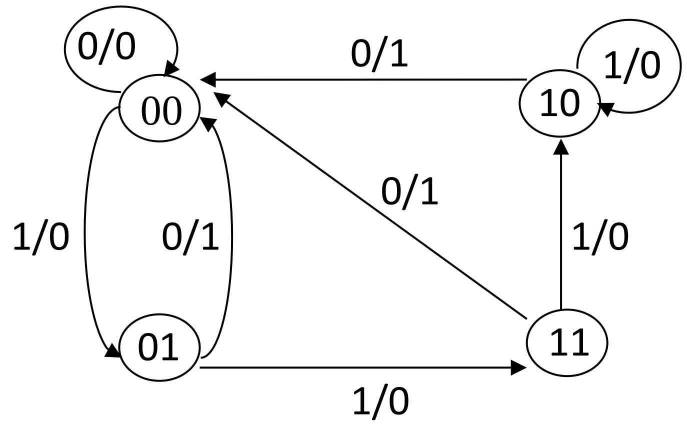
Example (4th Page):

In the last step, we generate the state diagram.

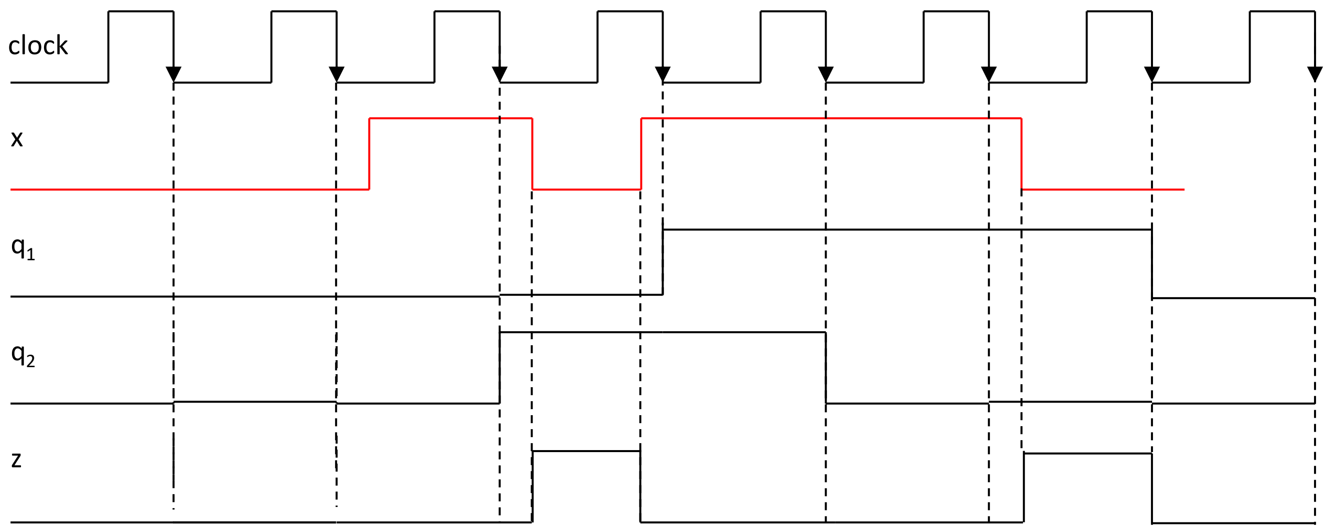
Present State (q_1 q_2)	Next State (Q_1Q_2) x = 0	Next State (Q_1Q_2) x = 1	Output (z) x = 0	Output (z) x = 1
(A) 0 0	**0 0**	**0 1**	**0**	**0**
(B) 0 1	**0 0**	**1 1**	**1**	**0**
(C) 1 0	**0 0**	**1 0**	**1**	**0**
(D) 1 1	**0 0**	**1 0**	**1**	**0**



Example (5th Page):



Let’s analyze the behavior of the circuit using the timing diagram below.



Implementation of Sequential Circuits from Given State Tables

Example: Let's implement a sequential circuit from the state table given below.

Present State	Next State		Output (z)	
	x=0	x=1	x=0	x=1
A	A	B	0	0
B	C	B	0	0
C	D	A	1	0
D	A	D	0	0

The state table has four states, which means we need to use two flip-flops. We can label the states as A, B, C, and D.

State	$y_1 y_2$
A	0 0
B	0 1
C	1 0
D	1 1

or

State	$y_1 y_2$
A	0 0
B	0 1
C	1 1
D	1 0

Alternatively, we can label the states in different ways.

Example (2^{nd} Page):

State	$y_1 y_2$
A	0 0
B	0 1
C	1 0
D	1 1

Present State	Next State x=0	Next State x=1	Output (z) x=0	Output (z) x=1
A	A	B	0	0
B	C	B	0	0
C	D	A	1	0
D	A	D	0	0

Present State ($y_1 y_2$)	Next State ($Y_1 Y_2$) x=0	Next State ($Y_1 Y_2$) x=1	Output (z) x=0	Output (z) x=1
0 0	0 0	0 1	0	0
0 1	1 0	0 1	0	0
1 0	1 1	0 0	1	0
1 1	0 0	1 1	0	0

Example (3rd Page):

State Table

Present State (y_1y_2)	Next State (Y_1Y_2) x=0	Next State (Y_1Y_2) x=1	Output (z) x=0	Output (z) x=1
0 0	0 0	0 1	0	0
0 1	1 0	0 1	0	0
1 0	1 1	0 0	1	0
1 1	0 0	1 1	0	0

Truth Table

Present State $x\ y_1\ y_2$	Next State $Y_1\ Y_2$	Inputs of Flip-Flops $J_1\ K_1$	Inputs of Flip-Flops $J_2\ K_2$	Output z
0 0 0	**0 0**	0 x	0 x	0
0 0 1	**1 0**	1 x	x 1	0
0 1 0	**1 1**	x 0	1 x	1
0 1 1	**0 0**	x 1	x 1	0
1 0 0	0 1	0 x	1 x	0
1 0 1	0 1	0 x	x 0	0
1 1 0	0 0	x 1	0 x	0
1 1 1	1 1	x 0	x 0	0

q Q	J K
0 0	0 x
0 1	1 x
1 0	x 1
1 1	x 0

Example (4^{th} Page):

Present State $x\ y_1\ y_2$	Next State $Y_1\ Y_2$	Inputs of Flip-Flops $J_1\ K_1$	Inputs of Flip-Flops $J_2\ K_2$	Output z
0 0 0	**0 0**	0 x	0 x	0
0 0 1	**1 0**	1 x	x 1	0
0 1 0	**1 1**	x 0	1 x	1
0 1 1	**0 0**	x 1	x 1	0
1 0 0	0 1	0 x	1 x	0
1 0 1	0 1	0 x	x 0	0
1 1 0	0 0	x 1	0 x	0
1 1 1	1 1	x 0	x 0	0

J_2

$x \backslash y_1y_2$	00	01	11	10
0	0	x	x	1
1	1	x	x	0

$J_2 = xy_1' + x'y_1 = x \oplus y_1$

K_2

$x \backslash y_1y_2$	00	01	11	10
0	x	1	1	x
1	x	0	0	x

$K_2 = x'$

J_1

$x \backslash y_1y_2$	00	01	11	10
0	0	1	x	x
1	0	0	x	x

$J_1 = x'y_2$

K_1

$x \backslash y_1y_2$	00	01	11	10
0	x	x	1	0
1	x	x	0	1

$K_1 = xy_2' + x'y_2 = x \oplus y_2$

From the truth table;
$z = x'y_1y_2'$

Example (5th Page):

$J_1 = x'y_2$

$K_1 = xy_2' + x'y_2 = x \oplus y_2$

$J_2 = xy_1' + x'y_1 = x \oplus y_1$

$K_2 = x'$