# [Introduction to Computer Architecture'21] Combinational and Sequential Circuits Revision 2 - solution

*Engr. Ahmad M. Abdel-Hafeez*

## Tips:

### How to solve a Combinational circuit problem:

1. Determine the number of inputs
2. Determine the number of outputs
3. Build the truth table (# of rows = # of combinations = $2^{\#\text{ of inputs}}$)
4. Produce the output(s)
5. Use K-Map (or anyway related) to simplify the output function
6. Design the output function if it's not given

### How to solve a Sequential circuit problem:

1. Determine the number of external inputs
2. Determine the number of external outputs
3. Determine the number of flip-flops = max number of bits in states or need to store
4. Determine the number of D-flip-flop inputs (D-flip-flop stores 1 bit and has 1 input only)
5. Determine the number of outputs (D-flip-flop has 2 outputs only A and A complement)
6. Build the truth/state table (# of rows = # of combinations = $2^{\#\text{ of total inputs}}$)
    a. Total inputs = # of external inputs + # of D-flip-flop inputs
7. Produce the output(s) (such as $A_{n+1}$, $B_{n+1}$, …etc.)
8. Use K-Map (or anyway related) to simplify the next state output function and external output(s)
9. Build the state diagram if it's not given
10. Design the output function if it's not given

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**Question 1:** Design a 2's complement circuit for 3-bit input, for input zero let its 2's complement is also zero.

Solution:

1. It's combinational circuit problem (no need to store bit(s))
2. # of inputs = 3
3. # of outputs = 3
4. # of rows (combinations) = $2^3$ = 8
5. Build the truth table

| X | Y | Z | A | B | C |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 1 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 | 0 |
| 1 | 0 | 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 | 0 | 1 |

6. Use K-Map to produce/simplify the output function
   A = X`Z + X`Y + XY`Z`
   B = Y`Z + YZ`
   C = Z
7. Design this circuit according to #6

**Question 2:** Implement the following function using suitable multiplexer F (A, B, C, D) = ∑ (0, 3, 5, 6, 8, 9, 14, 15)

Solution:

8x1 mux (*the number of its selection lines equals the number of input variables - 1*): A, B and C on **selections** and D on **inputs** as follows: I0= D', I1= D, I2= D, I3= D', I4= 1, I5= 0, I6= 0 and I7= 1

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**Question 3:** Implement practically the following function using a suitable multiplexer F (W, X, Y, Z) = (0, 1, 3, 4, 8, 9, 15)

Solution:

8x1 mux: W, X and Y on **selections** and Z on **inputs** as follows: I0= 1, I1= Z, I2= Z', I3= 0, I4= 1, I5= 0, I6= 0 and I7= Z

**Question 4:** Implement the full subtractor using suitable multiplexers.

Solution:

for the truth table of the full subtractor use **two** 4x1 muxs one for **B borrow** and one for **D difference**.

| X | Y | Z | B | D |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 |
| 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 |

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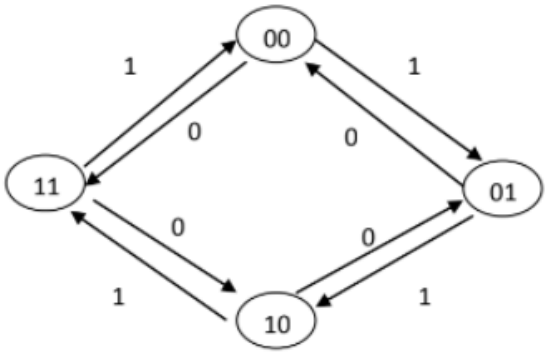
**Question 5:** Design the following a sequential circuit using two D flipflops A and B and one external input x according to the following state diagram.




Solution:

1. # of external inputs = 1
2. # of external outputs = 0
3. # of flip-flops = max number of bits in states or need to store = 2
4. # of D-flip-flop inputs = 2
5. Determine the number of outputs = 4 (2 for each D flip-flop)
6. Build the truth/state table (# of rows = # of combinations = $2^{\#\text{ of total inputs}}$)
   a. Total inputs = # of external inputs + # of D-flip-flop inputs = 3
   b. # of number of rows = 8

| X | $A_n$ | $B_n$ | $A_{n+1}$ | $B_{n+1}$ |
|---|---|---|---|---|
| 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 0 | 0 |
| 0 | 1 | 0 | 0 | 1 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 0 |
| 1 | 1 | 0 | 1 | 1 |
| 1 | 1 | 1 | 0 | 0 |

7. Produce the output(s) (such as $A_{n+1}$, $B_{n+1}$, …etc.)
8. Use K-Map (or anyway related) to simplify the next state output function and external output(s)
   $A_{n+1} = X \odot A_n \odot B_n$
   $B_{n+1} = B_n`$
9. Build the characteristic table

| X | $A_{n+1}$ | $B_{n+1}$ |
|---|---|---|
| 0 | $A_n \odot B_n$ | $B_n`$ |
| 1 | $A_n \oplus B_n$ | $B_n`$ |

10. Design the output function according to #8

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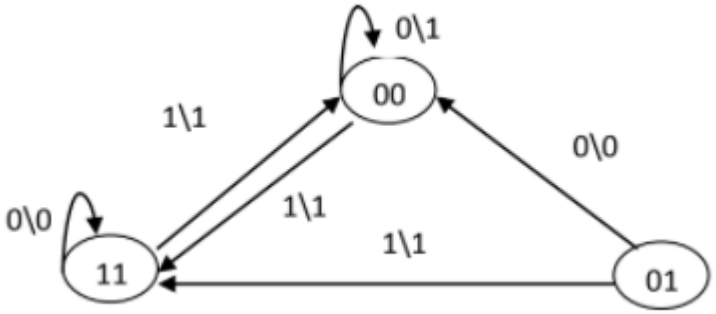
**Question 6:** Design the following a sequential circuit using D flipflops.




Solution:

1. # of external inputs = 1
2. # of external outputs = 1
3. # of flip-flops = max number of bits in states or need to store = 2
4. # of D-flip-flop inputs = 2
5. Determine the number of outputs = 4 (2 for each D flip-flop)
6. Build the truth/state table (# of rows = # of combinations = $2^{\#\text{ of total inputs}}$)
    a. Total inputs = # of external inputs + # of D-flip-flop inputs = 3
    b. # of number of rows = 8

| X | $A_n$ | $B_n$ | $A_{n+1}$ | $B_{n+1}$ | Y |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 0 | X | X | X |
| 0 | 1 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 | 1 | 1 |
| 1 | 0 | 1 | 1 | 1 | 1 |
| 1 | 1 | 0 | X | X | X |
| 1 | 1 | 1 | 0 | 0 | 1 |

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7. Produce the output(s) (such as $A_{n+1}$, $B_{n+1}$, …etc.)
8. Use K-Map (or anyway related) to simplify the next state output function and external output(s)
   $A_{n+1} = X \odot A_n$
   $B_{n+1} = X \odot A_n$
   $Y = X + B_n`$
9. Build the characteristic table

| **X** | **$A_{n+1}$** | **$B_{n+1}$** |
|---|---|---|
| 0 | $A_n$ | $A_n$ |
| 1 | $A_n`$ | $A_n`$ |

10. Design the output function according to #8

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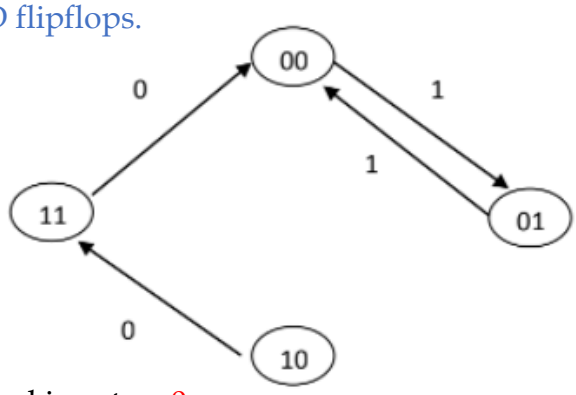
**Question 7:** Design and implement the following a sequential circuit with external output Y using D flipflops.




Solution:

1. # of external inputs = 0
2. # of external outputs = 1
3. # of flip-flops = max number of bits in states or need to store = 2
4. # of D-flip-flop inputs = 2
5. Determine the number of outputs = 4 (2 for each D flip-flop)
6. Build the truth/state table (# of rows = # of combinations = $2^{\#\text{ of total inputs}}$)
   a. Total inputs = # of external inputs + # of D-flip-flop inputs = 2
   b. # of number of rows = 4

| $A_n$ | $B_n$ | $A_{n+1}$ | $B_{n+1}$ | Y |
|---|---|---|---|---|
| 0 | 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 0 |
| 1 | 1 | 0 | 0 | 0 |

7. Produce the output(s) (such as $A_{n+1}$, $B_{n+1}$, …etc.)
8. Use K-Map (or anyway related) to simplify the next state output function and external output(s)
   $A_{n+1} = A_n \bullet B_n`$
   $B_{n+1} = B_n`$
   $Y = A_n`$
9. Design the output function according to #8

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**If you have any question, email us:**

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