1. Simplify the following Boolean logic functions to the format in sum of product first and then create a truth table in Excel for each as the verification reference of the circuit design, finally implement by online tools at *https://circuitverse.org/simulator*

   a. $f = (A + \overline{C} + \overline{D})(\overline{B} + \overline{C} + D)(A + \overline{B} + \overline{C})$
   b. $f = (Z + X)(\overline{Z} + \overline{Y})(\overline{Y} + X)$
   c. $f = \overline{(X + Y)}Z + \overline{X}\overline{Y}\overline{Z}$

   Notes:
   - *The simulation tools provide users with a lot of help for circuit designs by clicking "**Help**" button on the tool bar.*
   - *Each design should be exported as "**.cv**" file by "**Export as file**" in "**Project**" tab on the tool bar and submitted with the truth table.*

Ans: a)

Calculation:

a) $(A+\overline{C}+\overline{D})(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})$

$= (\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})A+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{C}+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{D}$

$= (A+\overline{B}+\overline{C})A\overline{B}+(A+\overline{B}+\overline{C})A\overline{C}+(A+\overline{B}+\overline{C})AD+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{C}+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{D}$

$= A\overline{B}A+A\overline{B}\overline{B}+A\overline{B}\overline{C}+(A+\overline{B}+\overline{C})A\overline{C}+(A+\overline{B}+\overline{C})AD+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{C}+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{D}$

$= A\overline{B}+A\overline{B}\overline{B}+A\overline{B}\overline{C}+(A+\overline{B}+\overline{C})A\overline{C}+(A+\overline{B}+\overline{C})AD+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{C}+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{D}$

$= A\overline{B}+A\overline{B}+A\overline{B}\overline{C}+(A+\overline{B}+\overline{C})A\overline{C}+(A+\overline{B}+\overline{C})AD+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{C}+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{D}$

$= A\overline{B}+A\overline{C}+AD+(A+\overline{B}+\overline{C})\overline{C}+(A+\overline{B}+\overline{C})\overline{C}D+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{D}$

$= A\overline{B}+A\overline{C}+AD+(A+\overline{B}+\overline{C})\overline{C}+(\overline{B}+\overline{C}+D)(A+\overline{B}+\overline{C})\overline{D}$

$= A\overline{B}+AD+\overline{C}+\overline{D}\overline{B}A+\overline{D}\overline{B}\overline{B}+\overline{D}\overline{B}\overline{C}$

$= A\overline{B}+AD+\overline{C}+\overline{D}\overline{B}A+\overline{D}\overline{B}+\overline{D}\overline{B}\overline{C}$

$= A\overline{B}+AD+\overline{C}+\overline{D}\overline{B}+\overline{D}\overline{B}\overline{C}$

$= A\overline{B}+AD+\overline{C}+\overline{D}\overline{B}$

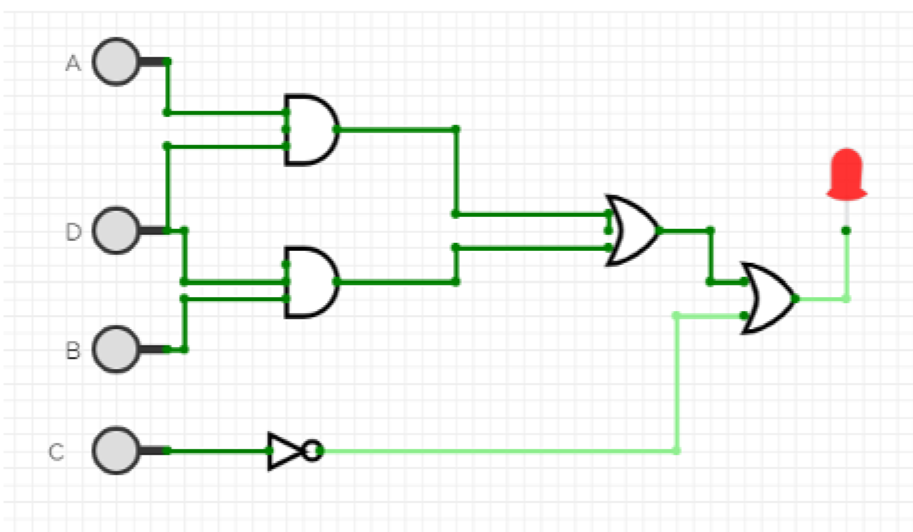
$= AD+\overline{C}+\overline{D}\overline{B}$

$$AD+\overline{C}+\overline{D}\,\overline{B}$$

Truth Table:

	A	B	C	D	E
1	**A**	**B**	**C**	**D**	**Output (f)**
2	0	0	0	0	1
3	0	0	0	1	1
4	0	0	1	0	1
5	0	0	1	1	0
6	0	1	0	0	1
7	0	1	1	0	0
8	0	1	1	1	0
9	1	0	0	0	1
10	1	0	0	1	1
11	1	0	1	0	1
12	1	0	1	1	1
13	1	1	0	0	1
14	1	1	0	1	1
15	1	1	1	0	0
16	1	1	1	1	1

Simulator:



b)

Calculation:

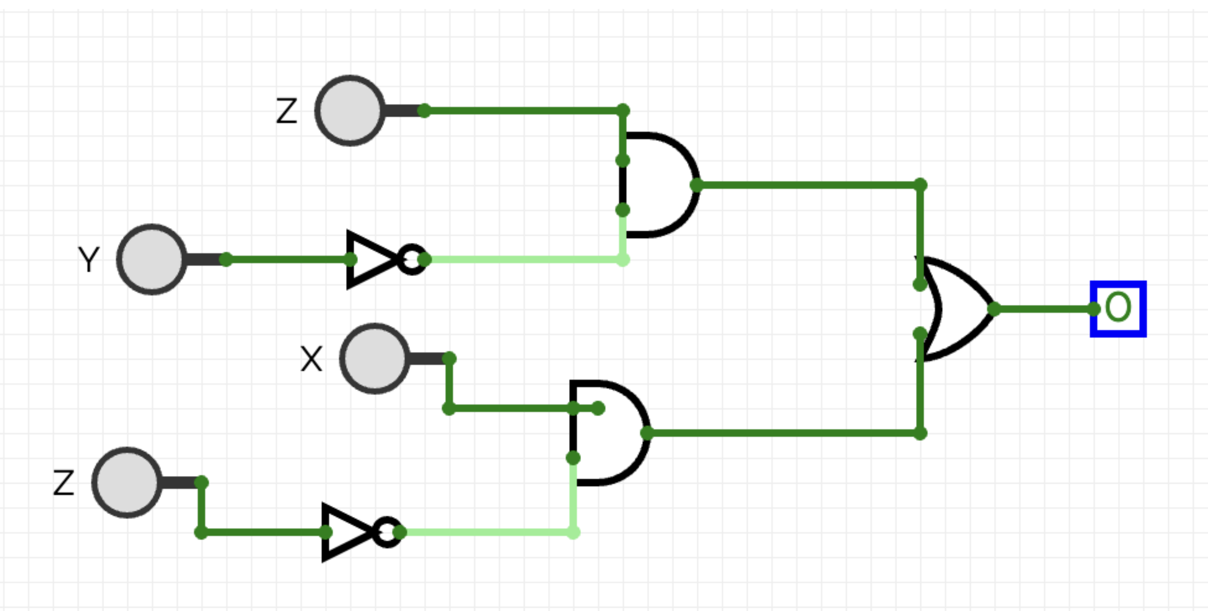
$$
\begin{aligned}
\text{b) } & (z+x)(\bar{z}+\bar{y})(\bar{y}+x) \\
&= (\bar{z}+\bar{y})(\bar{y}+x)z + (\bar{z}+\bar{y})(\bar{y}+x)x \\
&= (\bar{y}+x)z\bar{z} + (\bar{y}+x)z\bar{y} + (\bar{z}+\bar{y})(\bar{y}+x)x \\
&= 0 + (\bar{y}+x)z\bar{y} + (\bar{z}+\bar{y})(\bar{y}+x)x \\
&= (\bar{y}+x)z\bar{y} + (\bar{z}+\bar{y})(\bar{y}+x)x \\
&= z\bar{y}\bar{y} + z\bar{y}x + (\bar{z}+\bar{y})(\bar{y}+x)x \\
&= z\bar{y} + z\bar{y}x + (\bar{z}+\bar{y})(\bar{y}+x)x \\
&= z\bar{y} + (\bar{z}+\bar{y})(\bar{y}+x)x \\
&= z\bar{y} + (\bar{y}+x)x\bar{z} + (\bar{y}+x)x\bar{y} \\
&= z\bar{y} + x\bar{z}\bar{y} + x\bar{z}x + (\bar{y}+x)x\bar{y} \\
&= z\bar{y} + x\bar{z}\bar{y} + x\bar{z} + (\bar{y}+x)x\bar{y} \\
&= z\bar{y} + x\bar{z} + (\bar{y}+x)x\bar{y} \\
&= z\bar{y} + x\bar{z} + x\bar{y}\bar{y} + x\bar{y}x \\
&= z\bar{y} + x\bar{z} + x\bar{y} + x\bar{y}x \\
&= z\bar{y} + x\bar{z} + x\bar{y} + x\bar{y} \\
&= z\bar{y} + x\bar{z} + x\bar{y} \\
&= z\bar{y} + x\bar{z}
\end{aligned}
$$

$Z\overline{Y}+X\overline{Z}$

Truth Table:

	A	B	C	D
1	**X**	**Y**	**Z**	**Output (f)**
2	0	0	0	0
3	0	0	1	1
4	0	1	0	0
5	0	1	1	0
6	1	0	0	1
7	1	0	1	1
8	1	1	0	1
9	1	1	1	0
10				

Simulator:



c)

Calculation:

c) $f = \overline{(x+y)}z + \bar{x}\bar{y}\bar{z}$

$= \overline{x+y}z + \bar{x}\bar{y}\bar{z}$

$= \bar{x}\bar{y}z + \bar{x}\bar{y}\bar{z}$

$= \bar{x}\bar{y}(z + \bar{z})$

$= \bar{x}\bar{y}1$

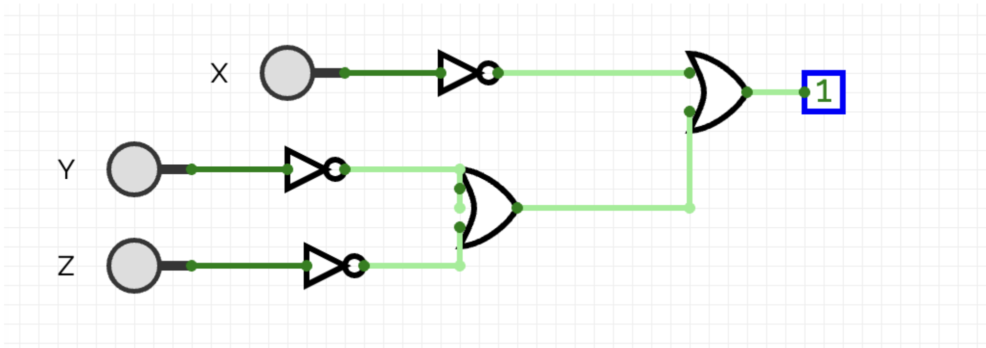
$= \bar{x}\bar{y}$

$$\overline{X} + \overline{Y} + \overline{Z}$$

Truth Table:

	A	B	C	D
1	**X**	**Y**	**Z**	**Output (f)**
2	0	0	0	1
3	0	0	1	1
4	0	1	0	0
5	0	1	1	0
6	1	0	0	0
7	1	0	1	0
8	1	1	0	0
9	1	1	1	0

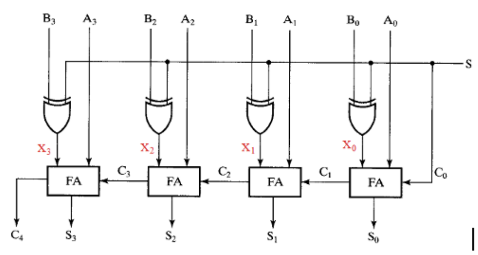
Simulator:



2. Design signal bit full adder based on the truth table and circuit on chapter 3 lecture handouts first and then create 4-bit "Adder-Subtractor circuit" as follows to implement arithmetic addition and subtraction operations.

   - If $S = 0$ in the circuit, then $X_3 = B_3, X_2 = B_2, X_1 = B_1$ and $X_0 = B_0$, so the adder circuit simply adds A and B when $C_0 = S = 0$ (carry in = 0).

   - If $S = 1$, then $X_3 = \overline{B_3}, X_2 = \overline{B_2}, X_2 = \overline{B_2}$ and $X_0 = \overline{B_0}$. Since $C_0 = S = 1$, the - circuit is equivalent to adding the 2's complement of B to A, that is, implementing subtraction operation "A-B".



Verify your design with the following testcases by the conversion from decimal to binary as inputs A and B

(a) A + B = 7 + (-3) = 4 (b) A - B = -6 - (-1) = -5

Notes:

- *The design should be exported as ".cv" file by "**Export as file**" in "**Project**" tab on the tool bar and submitted with the truth table.*

https://circuitverse.org/users/37864/projects/4-bit-binary-adder-subtracter-f689d4dd-24df-4fd2-852c-57d4b220dc95

(click on the input to set as 0 or 1)

Note: I used this link https://circuitverse.org/users/37864/projects/4-bit-binary-adder-subtracter-f689d4dd-24df-4fd2-852c-57d4b220dc95 to verify the design.

Ans:

Convert Decimals to Binary:

Test Case 1: A + B = 7 + (-3) = 4

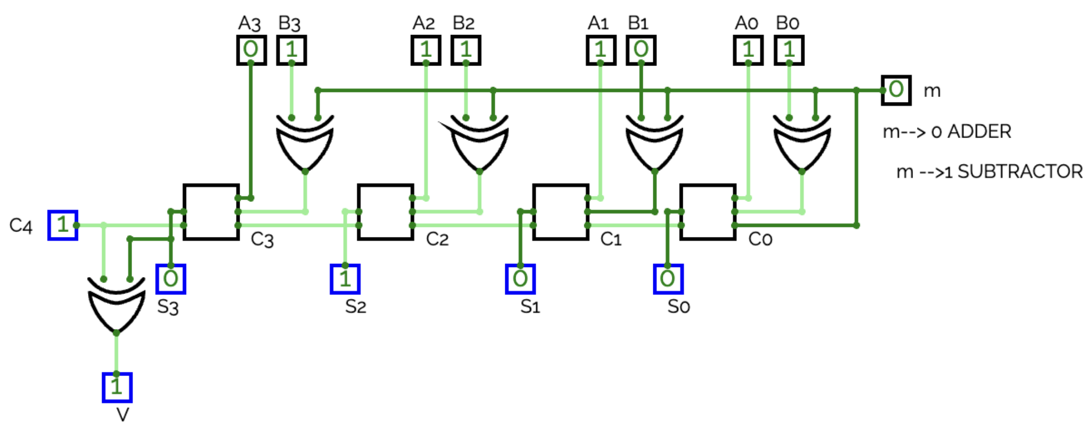
1) Convert A and B to 4-bit binary numbers:
- A = 7 in decimal is 0111 in binary
- B = -3 in two's complement is 1101 in binary.

Test Case 2: A - B = -6 -(-1) = -5

2) Convert A and B to 4-bit binary numbers:
- A = -6 in two's complement is 1010 in binary.
- B = -1 in two's complement is 1111 in binary.

Verify the Adder/Subtractor:
Test Case 1 : A + B

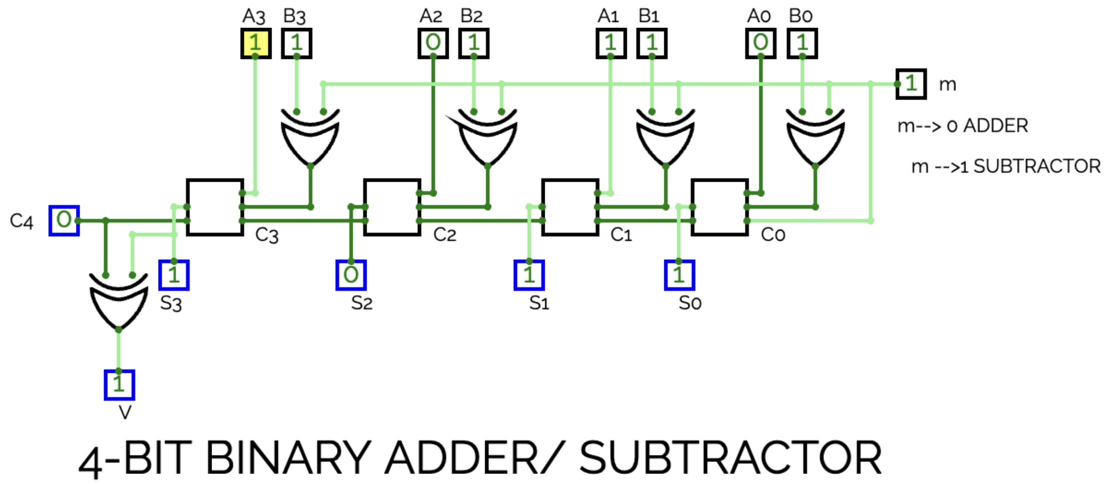
1) Setting the inputs:
- A3 A2 A1 A0 = 0111
- B3 B2 B1 B0 = 1101
- Mode m = 0 for addition



2) The outputs S3 S2 S1 S0. For 7 + (-3), the expected result is 0100 or 4 in decimal.

Test case 2: A - B

1) Setting the inputs:
- A3 A2 A1 A0 = 1010
- B3 B2 B1 B0 = 1111
- Mode m = 1 for subtraction



2) The outputs S3 S2 S1 S0. For -6 -(-1), the expected result is 1011 or -5 in two's complement representation.

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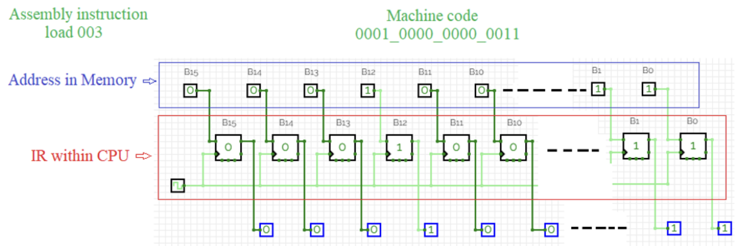
3. The following circuit is to simulate the MARIE assembly instruction "load 003", which means that it moves this instruction saved in the certain location of the memory to the instruction register (IR) using 16 D-Flip Flops within CPU.



Based on the above circuit, please implement the following MARIE assembly instructions by translating assembly code to machine code depending on the given lookup table in chapter 4 lecture handouts

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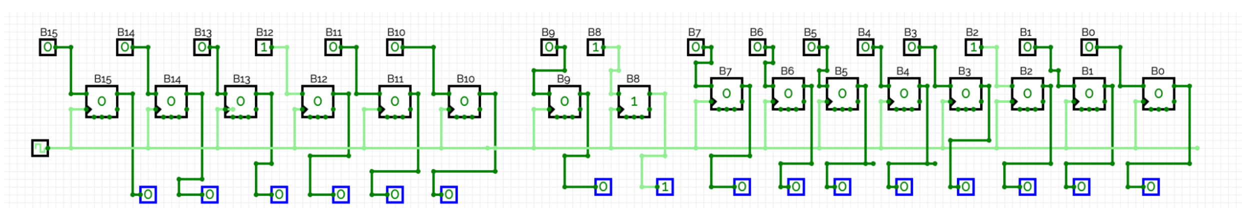
Load 104	*(0001_0001_0000_0100)*
Add 105	*(0001_0001_0000_0101)*
Store 106	*(0001_0001_0000_0110)*
Halt	*(0111_0000_0000_0000)* → *check binary code for Halt*

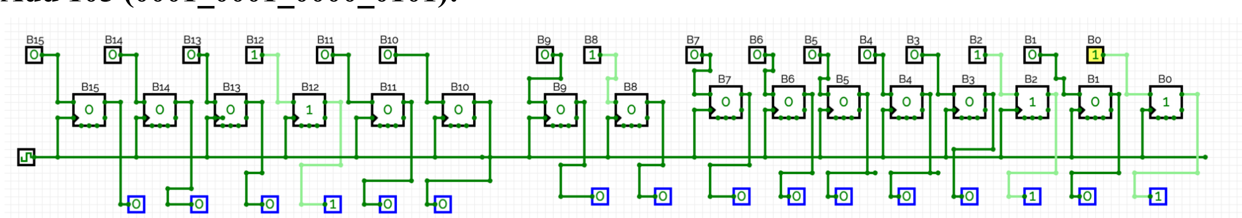
Notes:

- *The design should be exported as ".cv" file by "**Export as file**" in "**Project**" tab on the tool bar and submitted with the truth table.*

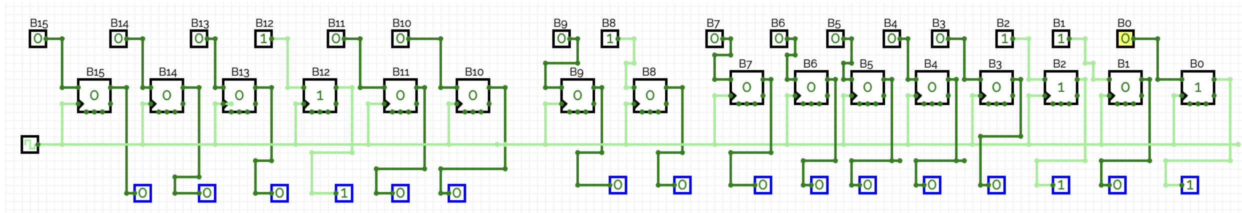
Ans: Load 104 (0001_0001_0000_0100):



Add 105 (0001_0001_0000_0101):



Store 106(0001_0001_0000_0110):



Halt (0111_0000_0000_0000):