UNIVERSITI TEKNOLOGI MALAYSIA

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SCSR1013 DIGITAL LOGIC

MODULE 3: LOGIC GATES

FACULTY OF COMPUTING

Module 3: Overview

NOT Gate (Inverter)
AND Gate
OR Gate
NAND Gate
NOR Gate
Exclusive-OR (XOR) Gate
Exclusive-NOR (XNOR) Gate

- For each gates, we will emphasize on the following:
  i. Characteristics
  ii. Symbols
  iii. Operator
  iv. Boolean expression
  v. Truth Table
  vi. Timing Diagram

Outline

two logic values either 0 or 1.

0

1

- NOT Gate (Inverter)
- AND Gate
- OR Gate

Basic building block

- NAND Gate
- NOR Gate

- Exclusive-OR (XOR) Gate
- Exclusive-NOR (XNOR) Gate

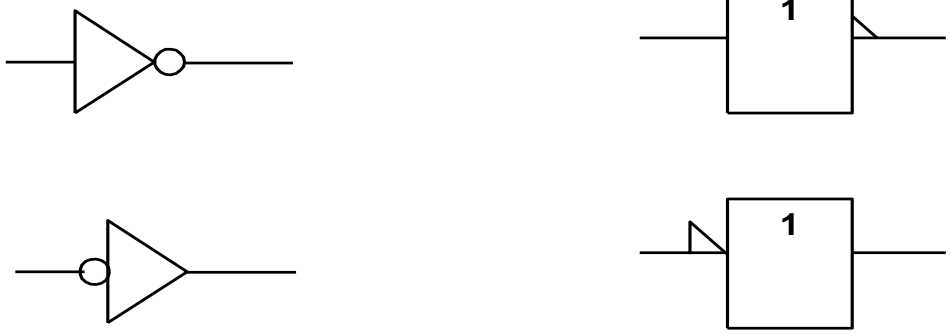
Universal gate using
2 of the basic gates

NOT Gate (Inverter)

- **Characteristics**

  Performs inversion or complementation
  - Changes a logic level to the opposite
  - 0(LOW) ➔ 1(HIGH) ; 1 ➔ 0

Symbols:



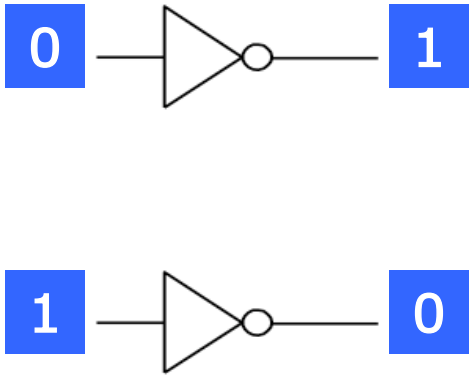
(a) Distinctive shape symbols with negation indicators

(b) Rectangular outline symbols with polarity indicators

Example:

"Output will be 0 if the input is 1"

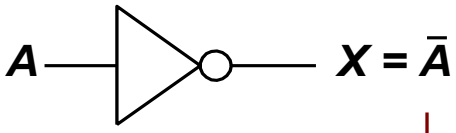
"Output will be 1 if the input is 0"



Continue...

- **Operator**
  - NOT Gate is represented by overbar

- Logic expression



X is the complement of A
X is the inverse of A
X is NOT A

$\bar{A}$

"A bar"
"not A"

$X = \bar{A}$ *or* $X = A'$

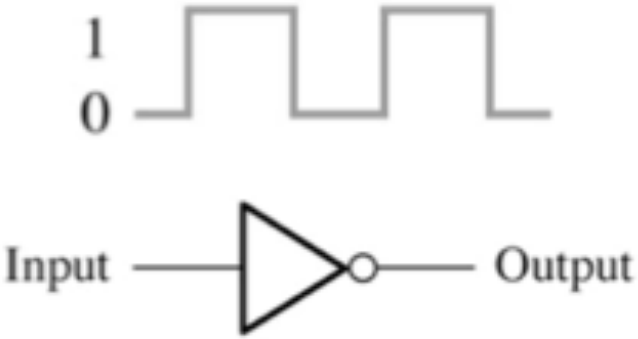
OUTPUT is the complement of INPUT
OUTPUT is the inverse of INPUT
OUTPUT is NOT INPUT

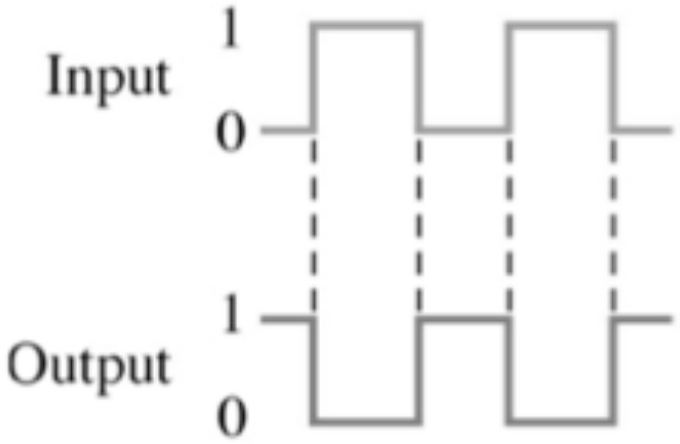
Continue...

- Truth table

A	X
0	1
1	0

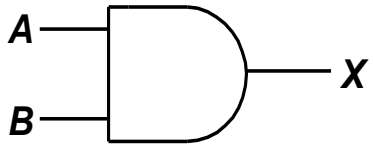
- **Timing diagrams**



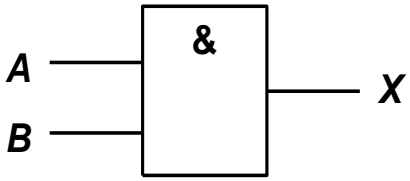


AND Gate

- **Characteristics**
  - Performs 'logical multiplication'
    - If all of the input are HIGH, then the output is HIGH.
    - If any of the input are LOW, then the output is LOW.
      - *AND gate must at least have two (2) INPUTs, and must always have 1 (one) OUTPUT. The AND gate can have more than two INPUTs*
- **Symbols**



(a) Distinctive shape



(b) Rectangular outline with the AND (&) qualifying symbol

- Operator

$$0.0=0$$
$$0.1=0$$
$$1.0=0$$
$$1.1=1$$

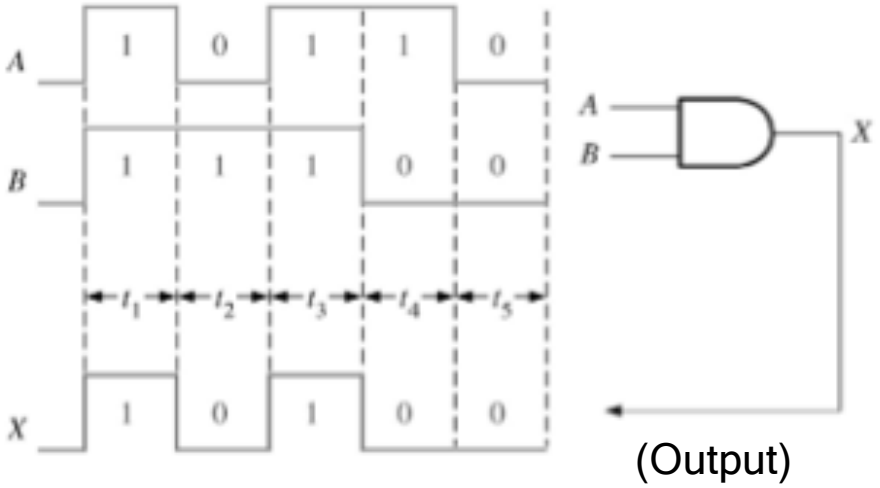
- Logic operation

$$X=A\bullet B$$

- Truth table

A B	X = A . B
0 0	0
0 1	0
1 0	0
1 1	1

- Timing Diagram



Extra

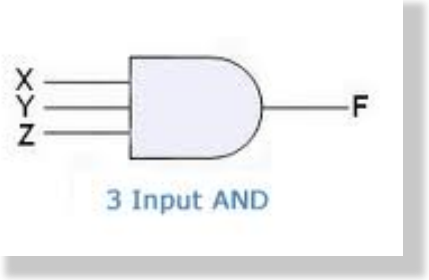
Exercise 3.1:

(a) Develop the truth table for a 3-input AND gate.

(b) Determine the total number of possible input combinations for a 4-input AND gate.

Solution:

(a) Possible input combinations = $2^3 = 8$



INPUTS			OUTPUT
A	B	C	X
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

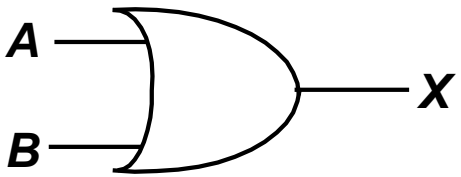
(Output 1 when all inputs 1)

(b) Possible input combinations
$= 2^4 = 16$

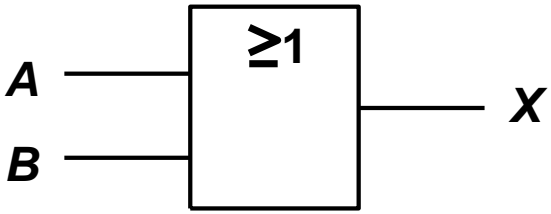
OR Gate

- Performs '*logical addition*'
  - If any of the input are HIGH, then the output is HIGH.
  - If all of the input are LOW, then the output is LOW

- Symbols used:



(a) Distinctive shape



(b) Rectangular outline with the OR (≥1) qualifying symbol

Operator

OR operator can be represented by a plus sign "+"

OR gate performs Boolean addition

Boolean addition follows the basic rules as follows:

0 + 0 = 0

0 + 1 = 1

1 + 0 = 1

1 + 1 = 1

Logical Expression

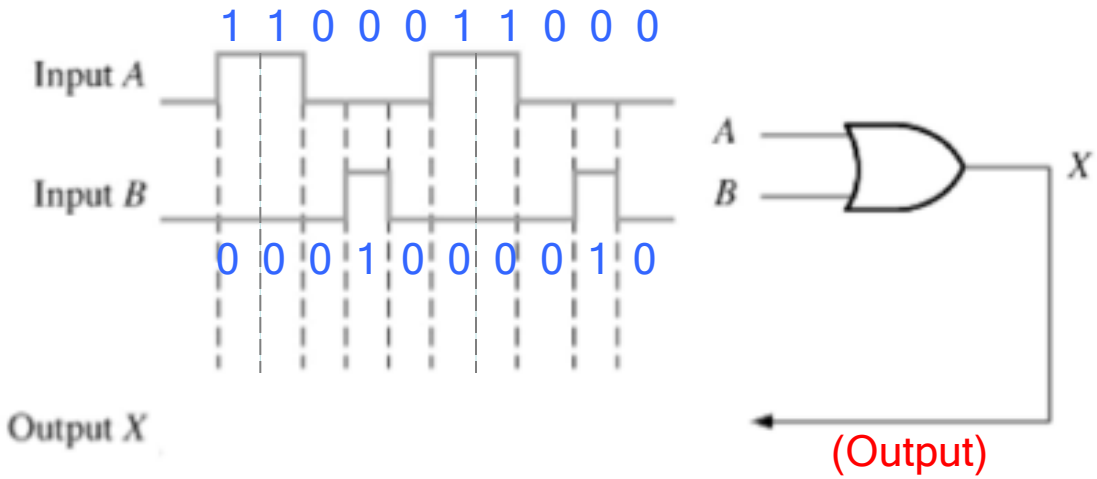
$X = A + B$

Continue...

Truth Table

A B	X = A + B
0 0	0
0 1	1
1 0	1
1 1	1

Timing Diagram (DIY)

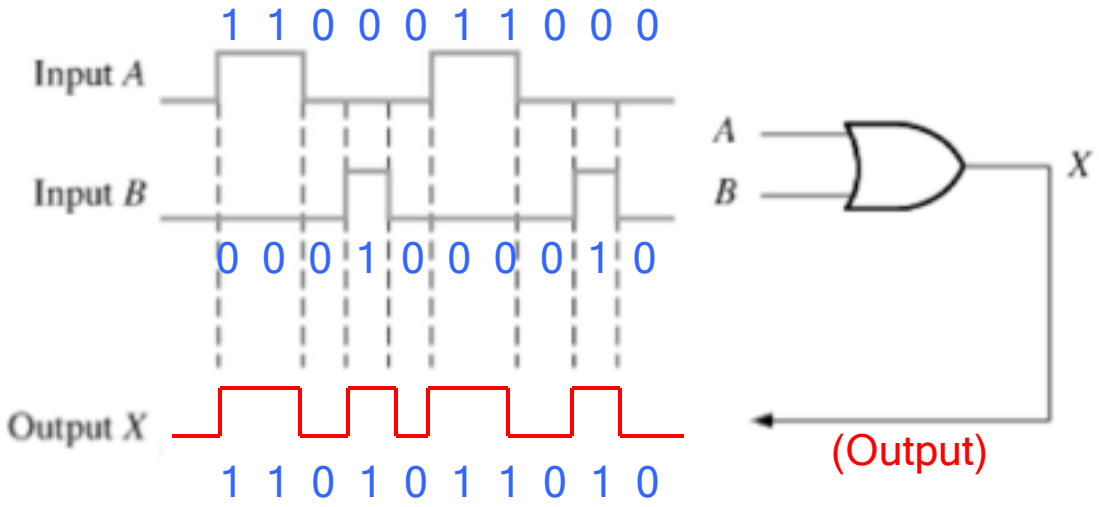


Exercise 3.2:
Draw the output waveform.

Truth Table

A B	X = A + B
0 0	0
0 1	1
1 0	1
1 1	1

Timing Diagram (DIY)



Extra

Self-Test:

a) Input of a NOT gate is A. If A is LOW, the output is HIGH

b) If all inputs of an AND gate are LOW, then the output is LOW

c) If any input of an OR gate is LOW, then the output is HIGH

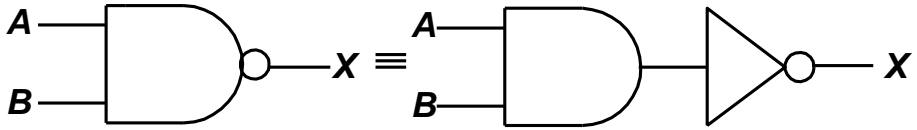
d) If A = HIGH, B = LOW, is the logical operation $X = A \bullet B = A + B$ true? NO

e) From d), what we can do to get X = HIGH ? Invert B

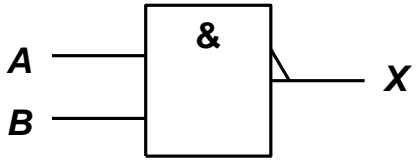
f) Rewrite the new logical operation from e): $X = A \bullet \overline{B} = A + \overline{B}$

NAND Gate

- NAND ➔ NOT-AND ⇨combines the AND gate and an inverter
- Used as a universal gate
  - Combinations of NAND gates can be used to perform AND, OR and inverter operations
  - If all or any of the input are LOW, then the output is HIGH.
  - If all of the input are HIGH, then the output is LOW
- Symbol used:



(a) Distinctive shape: 2 input NAND gate and its NOT/AND equivalent



(b) Rectangular outline: 2 input NAND gate with polarity indicator

Operator

NAND operator can be represented by a dot with an overbar symbol

$$\overline{0.0} = \overline{0} = 1$$
$$\overline{0.1} = \overline{0} = 1$$
$$\overline{1.0} = \overline{0} = 1$$
$$\overline{1.1} = \overline{1} = 0$$

Truth Table

INPUTS A	INPUTS B	AB	OUTPUT $\overline{AB} = X$
0	0	0	$\overline{0.0} = \overline{0} = 1$
0	1	0	$\overline{0.1} = \overline{0} = 1$
1	0	0	$\overline{1.0} = \overline{0} = 1$
1	1	1	$\overline{1.1} = \overline{1} = 0$

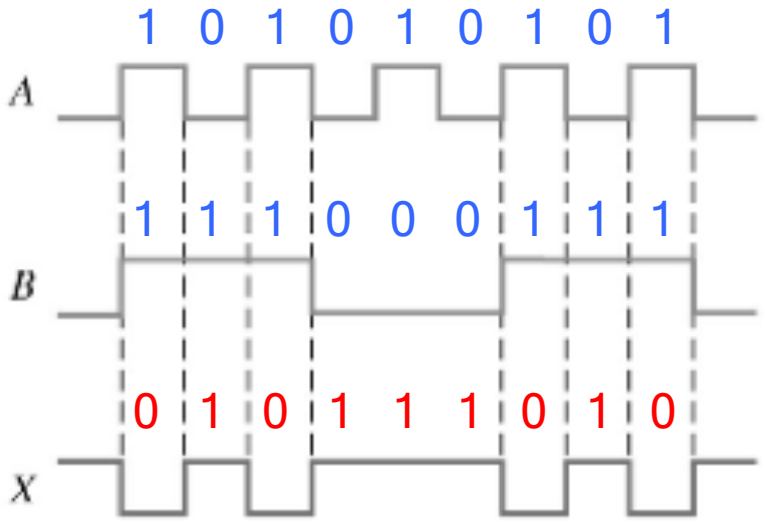
Logical Expression

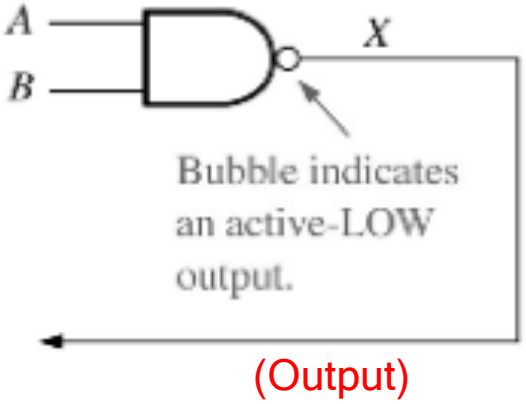
$$X = \overline{A \bullet B}$$

Continue...

Timing Diagram (DIY)

$$X = \overline{A \bullet B}$$

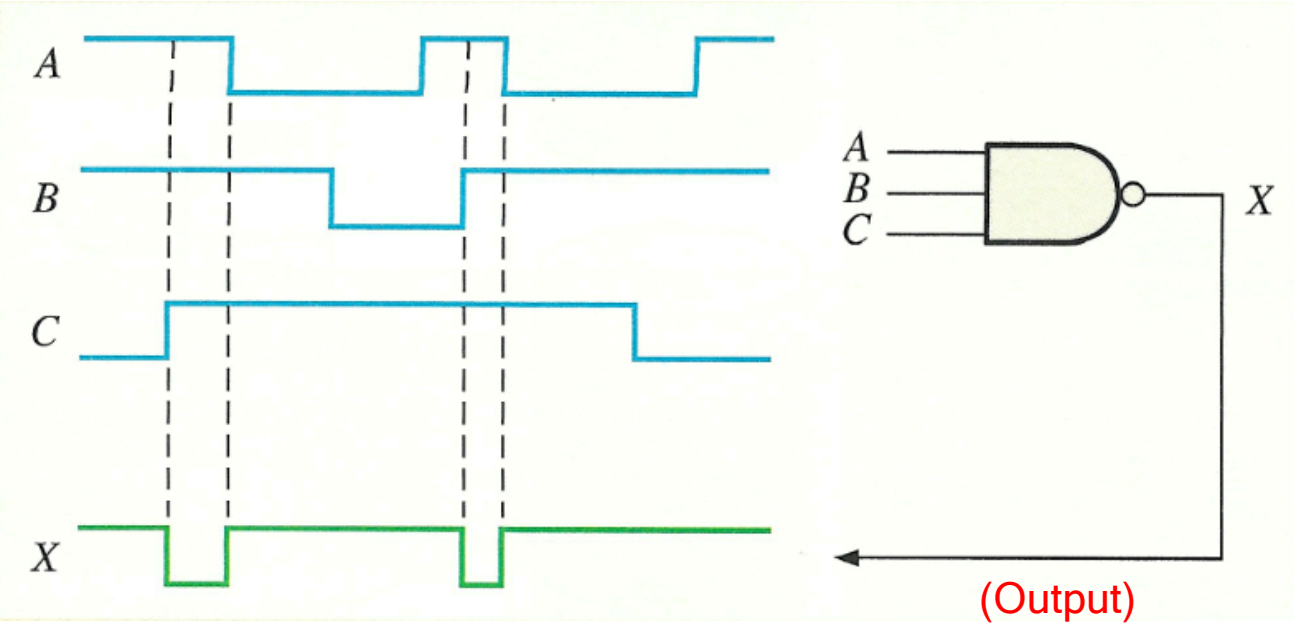




Extra

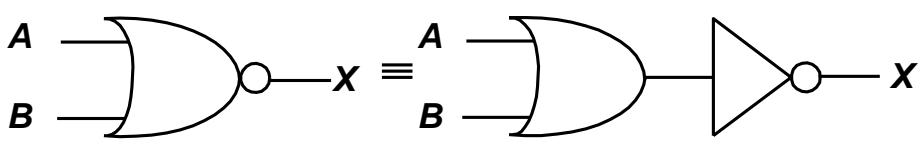
Exercise 3.3:

Show the output waveform for the 3-input NAND gate below with its proper time relationship to the inputs.

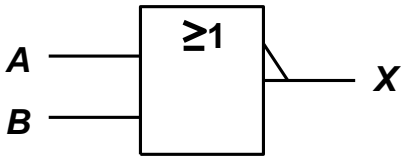


NOR Gate

- NOR ➔ NOT-OR ⇨combines the OR gate and an inverter
- Used as a universal gate
  - Combinations of NOR gates can be used to perform AND, OR and inverter operations
  - If all or any of the input are HIGH, then the output is LOW.
  - If all of the input are LOW, then the output is HIGH
- Symbol used:



(a) Distinctive shape: 2 input NOR gate and its NOT/OR equivalent



(b) Rectangular outline with the OR (≥1) qualifying symbol

Continue...

Operator

NOR operator can be represented by a plus with an overbar symbols

$$\overline{0+0} = \overline{0} = 1$$
$$\overline{0+1} = \overline{1} = 0$$
$$\overline{1+0} = \overline{1} = 0$$
$$\overline{1+1} = \overline{1} = 0$$

Logical Expression

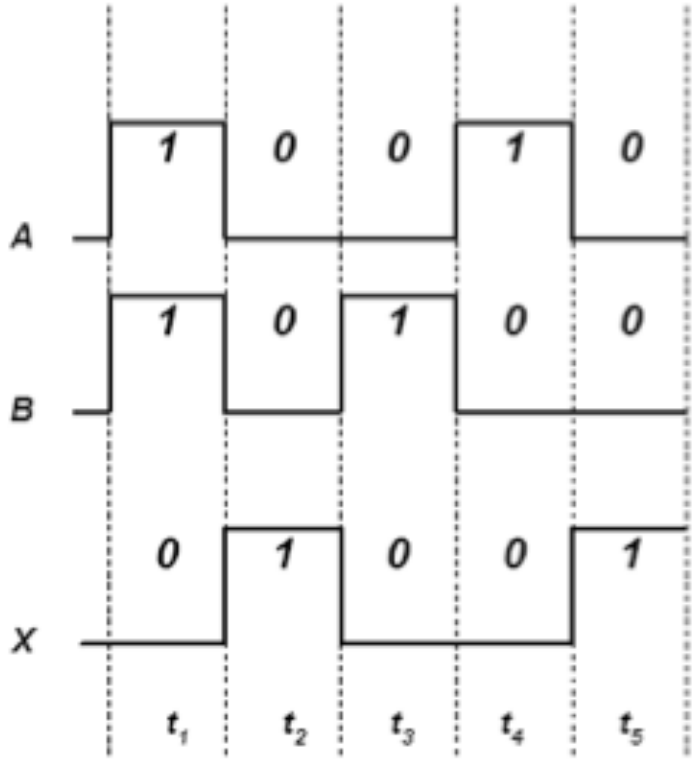
$$X = \overline{A+B}$$

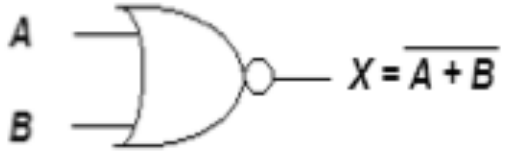
Truth Table

INPUTS		OUTPUT	
A	B	$A+B \longrightarrow$	$\overline{A+B} = X$
0	0	0	$\overline{0+0} = \overline{0} = 1$
0	1	1	$\overline{0+1} = \overline{1} = 0$
1	0	1	$\overline{1+0} = \overline{1} = 0$
1	1	1	$\overline{1+1} = \overline{1} = 0$

Continue...

Timing Diagram (DIY)

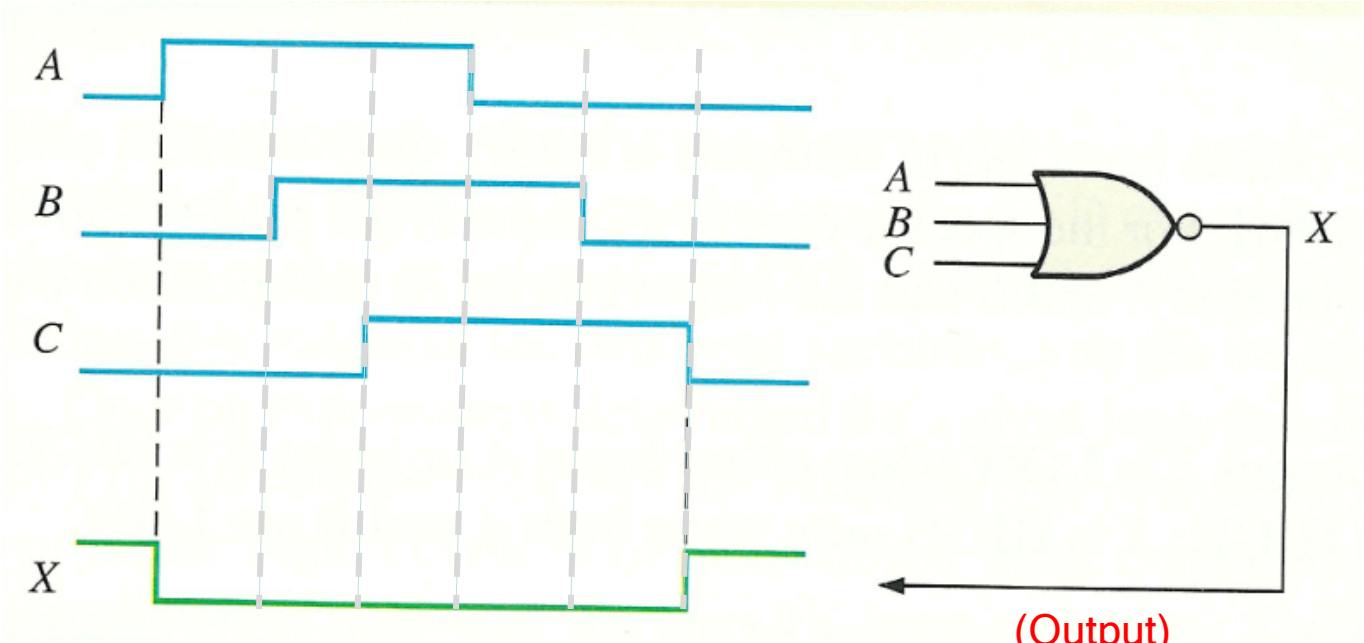




Extra

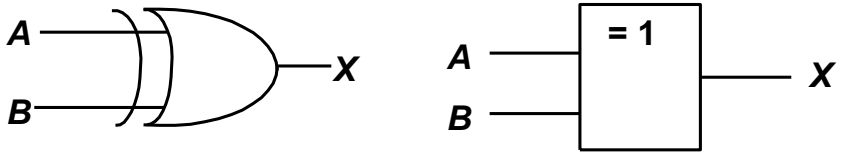
Exercise 3.4:

Show the output waveform for the 3-input NOR gate below with its proper time relationship to the inputs.



XOR Gate

- **Characteristics**
  - Combines basic logic circuits of AND, OR and Inverter.
  - Has only 2 inputs
  - Used as a universal gate
    - Can be connected to form an adder that allows a computer to do perform addition, subtraction, multiplication and division in ALU (Arithmetic and Logic Unit).
    - If both of the input are at the same logic level, then the output is LOW.
    - If both of the input are at opposite logic levels, then the output is HIGH
- **Symbol**



(a) Distinctive shape **(b) Rectangular outline**

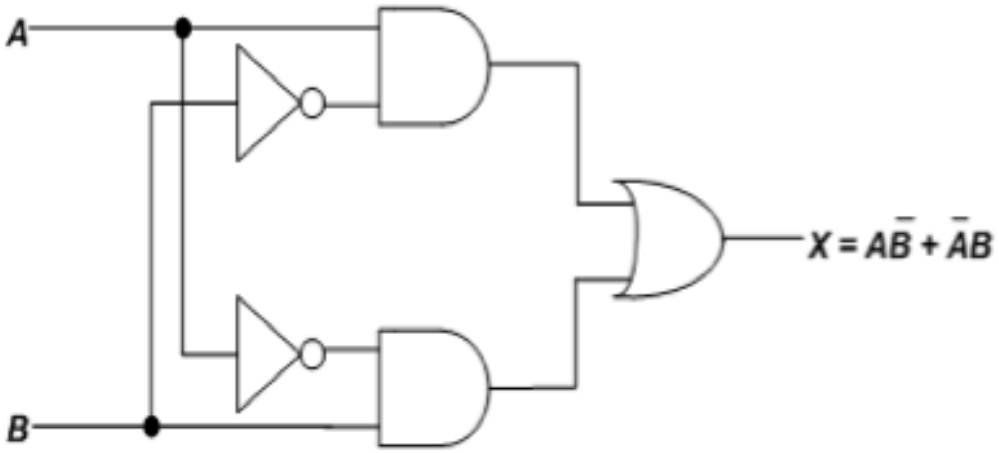
Continue...

Operator

XOR operator can be represented by a $\oplus$ symbol

Logical Expression

$$X = A \oplus B$$
$$= A\bar{B} + \bar{A}B$$



XOR is a combination of 2 AND gates, 1 OR gate, and 2 NOT gates (inverter)

Continue...

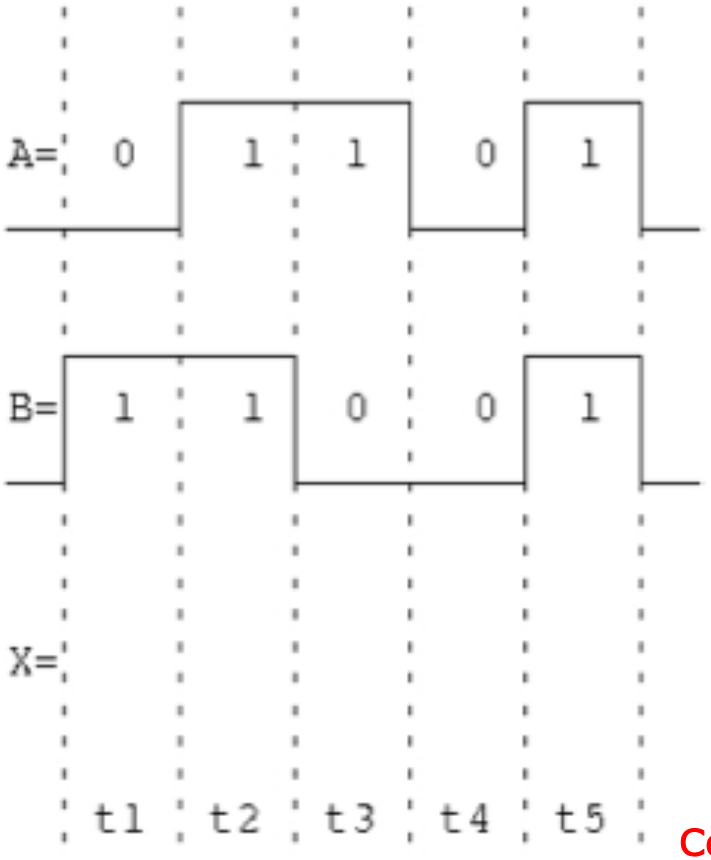
Timing Diagram (DIY)

Truth Table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

$X = A\bar{B} + \bar{A}B$

X-OR truth table

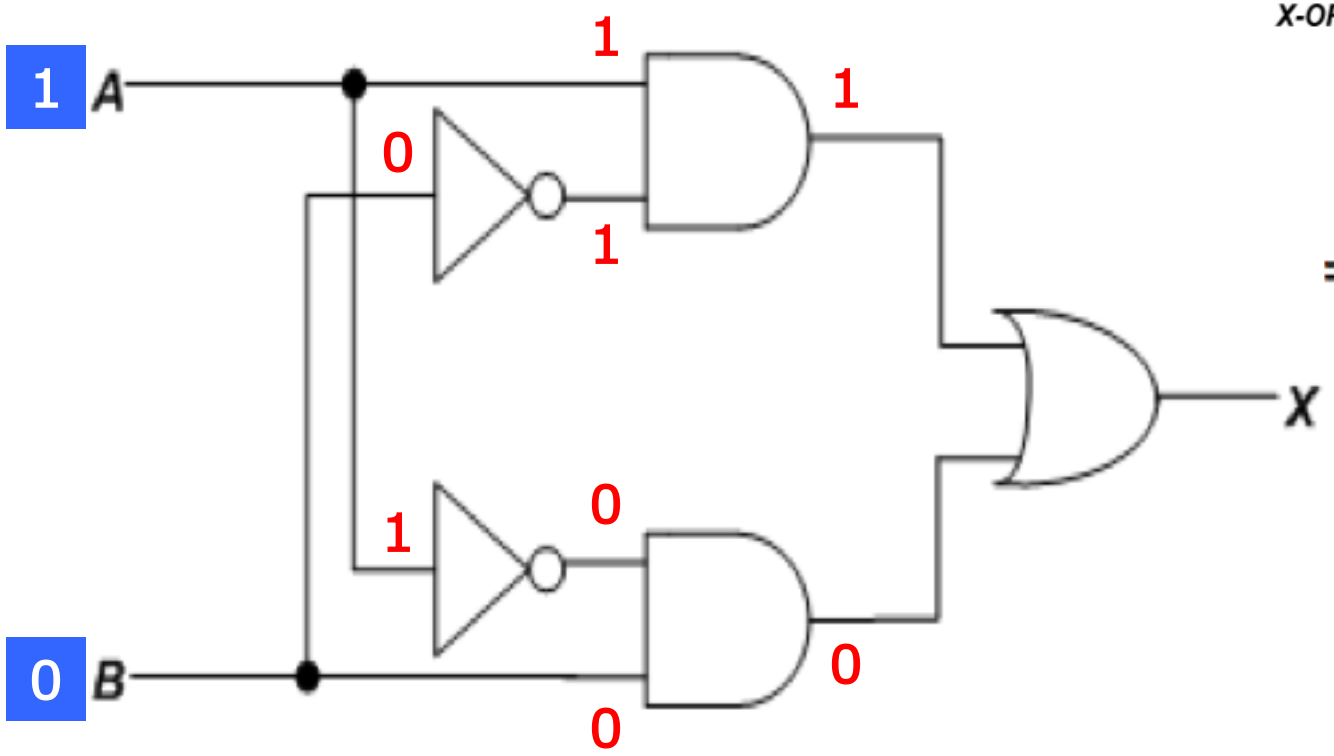


Continue...

Truth Table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

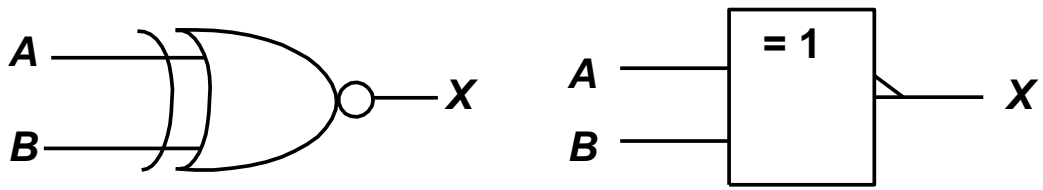
X-OR truth table



$$=A\overline{B}+\overline{A}B$$

XNOR Gate

- Has only 2 inputs, but output of XNOR is the opposite of XOR
  - If both of the input are at the same logic level, then the output is HIGH.
  - If both of the input are at opposite logic levels, then the output is LOW.
- Symbol used:



(a) Distinctive shape

(b) Rectangular outline

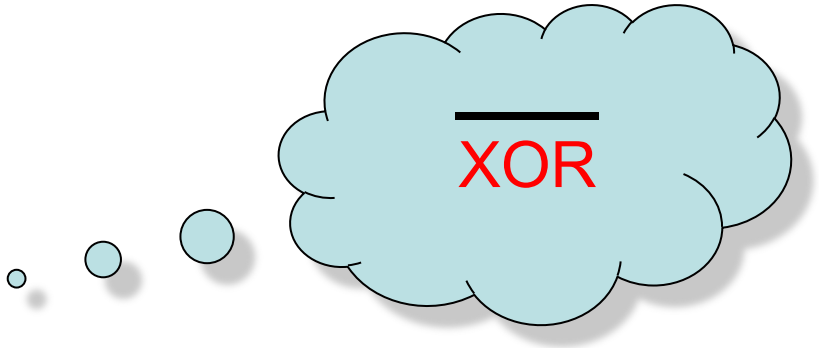
Continue...

Operator

XNOR operator can be represented by a $\odot$ symbol

Logical Expression

$$X = A \odot B$$
$$= \overline{A \oplus B}$$
$$= \overline{A\bar{B} + \bar{A}B}$$
$$= AB + \overline{\bar{A}\bar{B}}$$

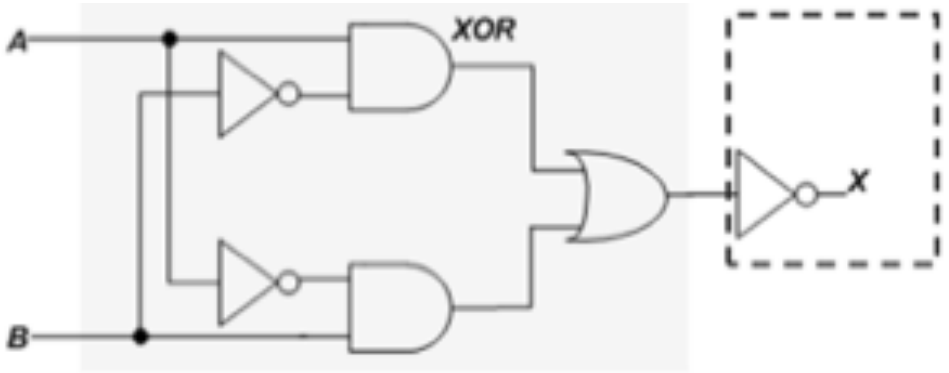


Continue...

XNOR Implementation

- There are two ways in implementing XNOR Gate:
  - The first implementation by **complementing (inverting)** XOR circuit

1



$$X = A\overline{B} + \overline{A}B$$

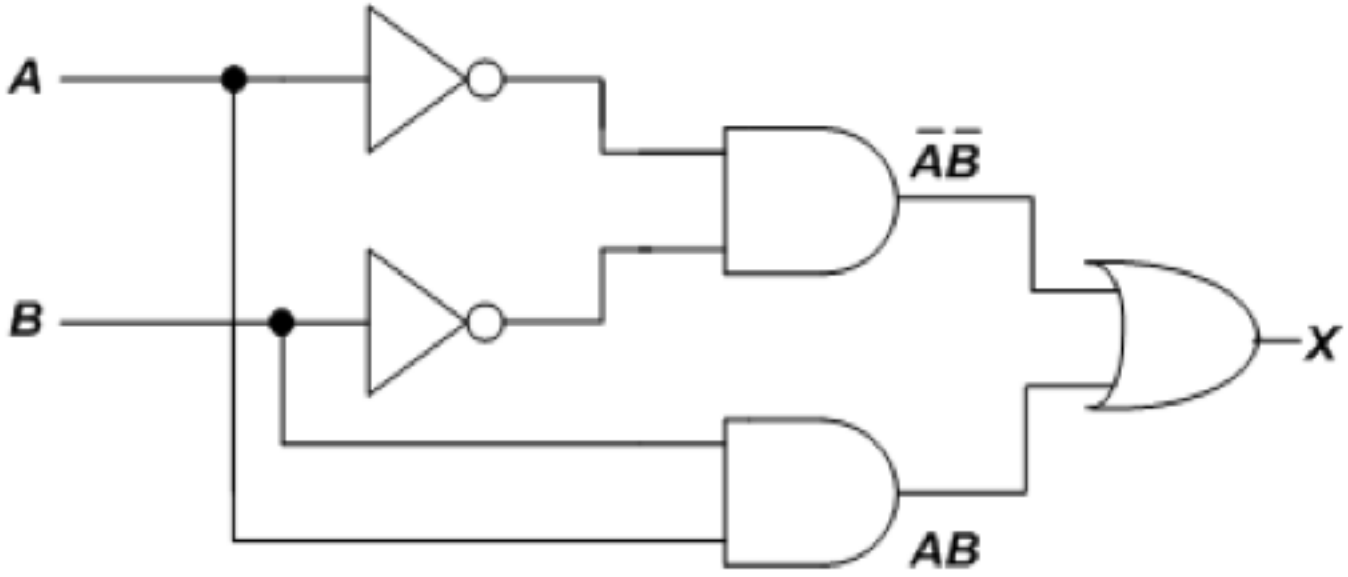
$$X = \overline{A\overline{B} + \overline{A}B}$$

Continue...

Second implementation is by directly implementing the following expression:

2

$$X = AB + \overline{A}\,\overline{B}$$



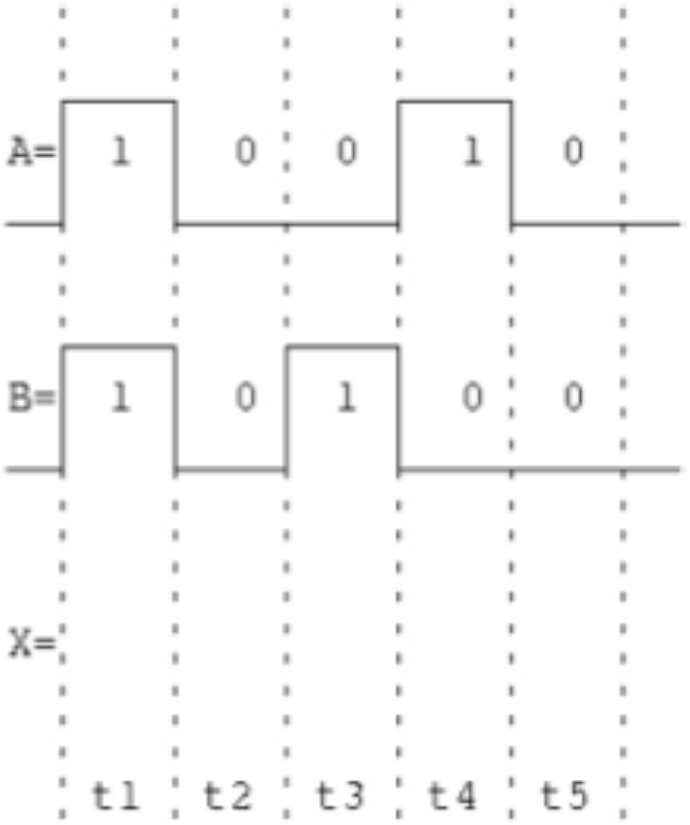
Continue...

Truth Table

A	B	X
0	0	1
0	1	0
1	0	0
1	1	1

$= AB + \overline{A}\overline{B}$

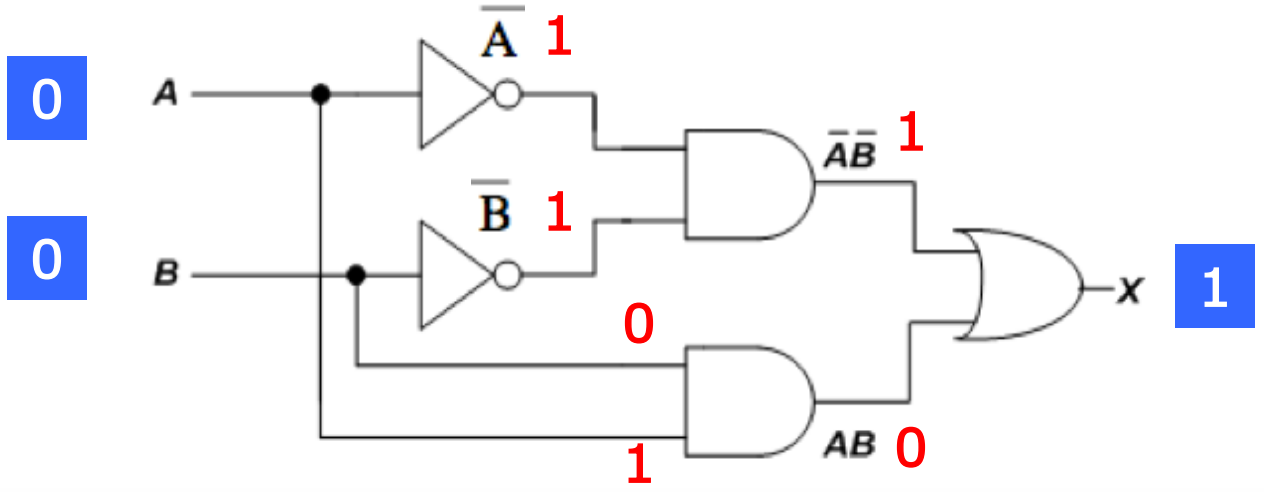
Timing Diagram (DIY)



The characteristic of the above circuit can be proven by the following truth table

Example:

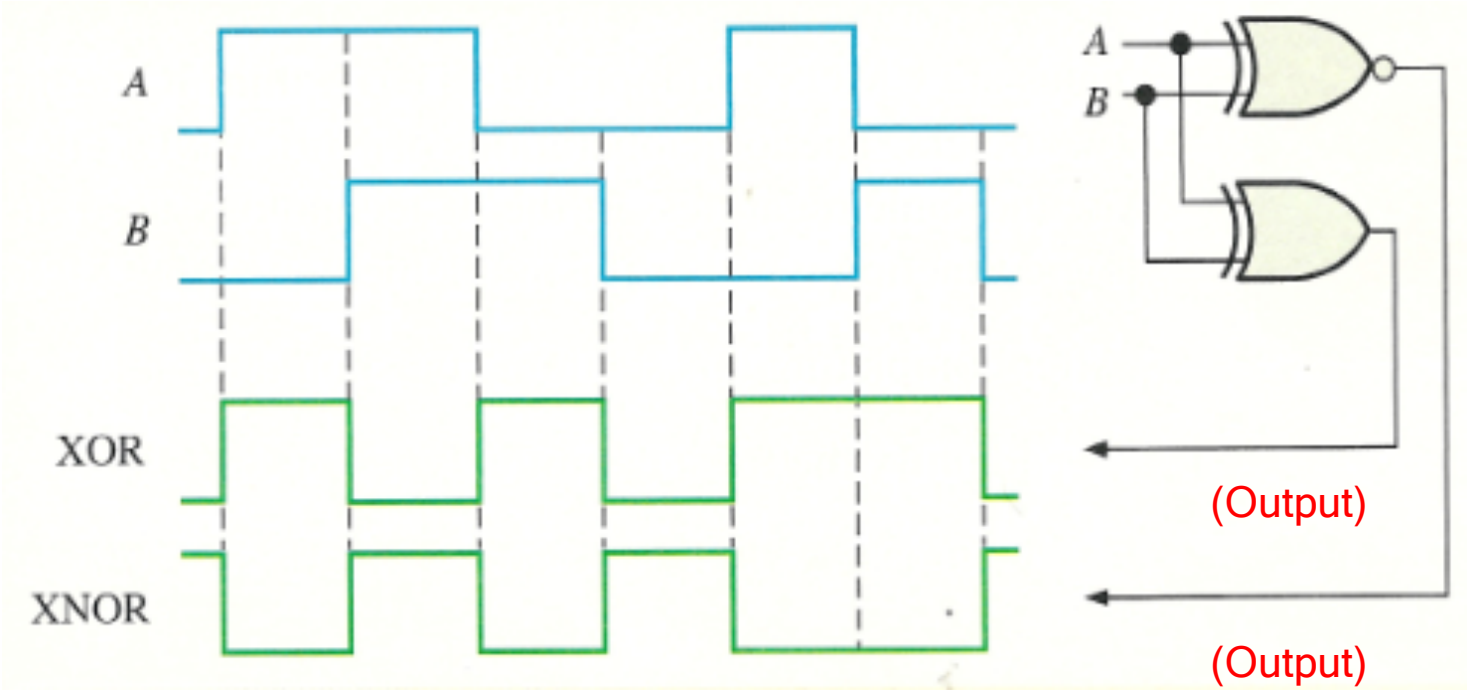
A	B	AB	$\overline{A}\ \overline{B}$	$X = AB + \overline{A}\ \overline{B}$
0	0	0	1	1
0	1	0	0	0
1	0	0	0	0
1	1	1	0	1

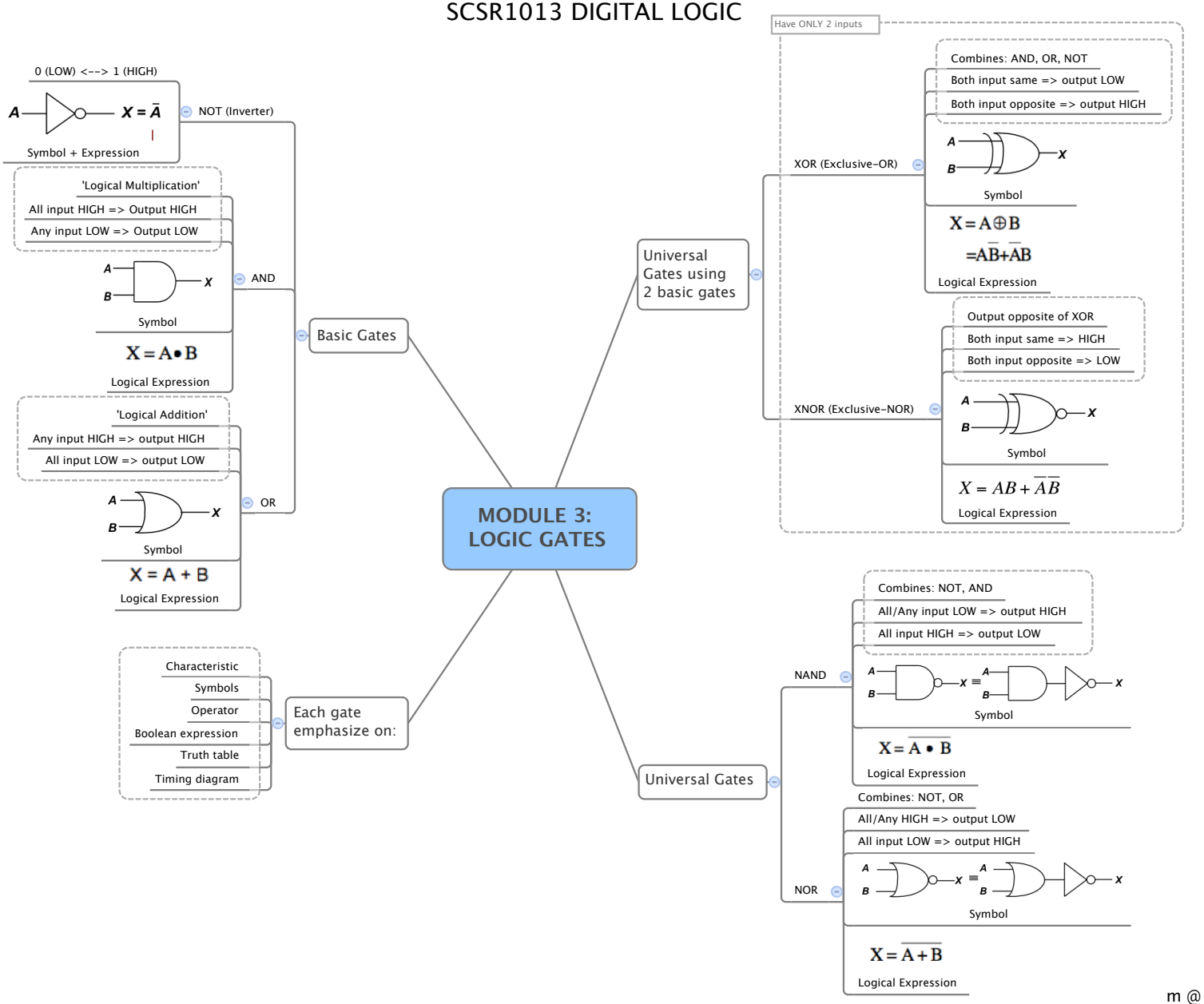


Extra

Exercise 3.5:

Determine the output waveforms for the XOR gate and XNOR gate, given the input waveforms, A and B.




MODULE 3: LOGIC GATES
Basic Gates
NOT (Inverter)
0 (LOW) <--> 1 (HIGH)
A
X = Ā
Symbol + Expression
AND
'Logical Multiplication'
All input HIGH => Output HIGH
Any input LOW => Output LOW
A
B
X
Symbol
X = A • B
Logical Expression
OR
'Logical Addition'
Any input HIGH => output HIGH
All input LOW => output LOW
A
B
X
Symbol
X = A + B
Logical Expression
Each gate emphasize on:
Characteristic
Symbols
Operator
Boolean expression
Truth table
Timing diagram
Universal Gates using 2 basic gates
Have ONLY 2 inputs
XOR (Exclusive-OR)
Combines: AND, OR, NOT
Both input same => output LOW
Both input opposite => output HIGH
A
B
X
Symbol
X = A⊕B
=AB̄+ĀB
Logical Expression
XNOR (Exclusive-NOR)
Output opposite of XOR
Both input same => HIGH
Both input opposite => LOW
A
B
X
Symbol
X = AB + ĀB̄
Logical Expression
Universal Gates
NAND
Combines: NOT, AND
All/Any input LOW => output HIGH
All input HIGH => output LOW
A
B
X
≡
A
B
X
Symbol
X = (A • B)̄
Logical Expression
NOR
Combines: NOT, OR
All/Any HIGH => output LOW
All input LOW => output HIGH
A
B
X
≡
A
B
X
Symbol
X = (A + B)̄
Logical Expression

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