Lecture 5a
Digital Logic - Basic Logic Gates

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Outlines

In this series of lectures we are going to discuss

- in detail the various basic Gates [1]
- designing of boolean logic circuits using the basic gates
- minimizing the boolean expressions

The Basic Digital Gates !!


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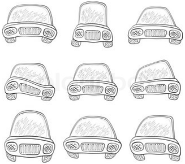
"MY WIFE'S IDEA OF THE FOUR BASIC FOOD GROUPS IS CANNED, FROZEN, FREEZE-DRIED AND CARRY-OUT."

Digital Logic Gates

The Gate

The term **Gate** is used is describe a circuit that performs a basic logic operation.

Input(s) are on the left, andthe output is on the right of each gate (symbol)



The Inverter

Inverters (NOT Gate)

- The inverter (NOT Gate/circuit) performs the operation called *inversion* or *complementation*.
- The inverter changes one logic level to the opposite level.
- In terms of bits, it changes a **1 to a 0** and a **0 to a 1**

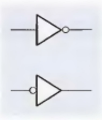


Figure: Distinctive shape sysmbols with negation indicators

The Negation and Polarity Indicators

- The negation indicator is a “bubble” (◦) thta indicates **inversion** or *complementation* when it appears on the input or output of any logic element.

Generally *inputs are on the left of a logic symbol and the output is on the right*

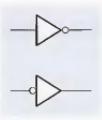


Figure: Distinctive shape sysmbols with negation indicators

The Negation and Polarity Indicators

* When appearing on the input, the bubble means that a 0 is the *active* or *asserted* input state, and the input is called an **active-LOW** input.
* When appearing on the input, the bubble means that a 0 is the *active* or *asserted* output state, and the input is called an **active-HIGH** input.

Inverter Truth Table

When a HIGH level is applied to an inverter input, a LOW level will appear on its output and vice-versa

INPUT (I)	OUTPUT (O)
LOW (0)	HIGH (1)
HIGH (1)	LOW (0)

Inverter Operation

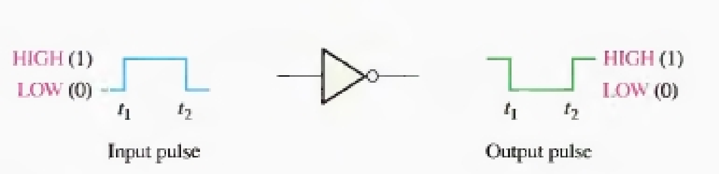


Figure: Inverter operation with a pulse input; t_1 and t_2 indicate the corresponding points on the input and output pulse waveform

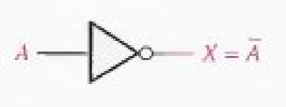
Logic Expression for an Inverter

In **Boolean Algebra**, the **complement** of a variable is designated by a bar over the letter.

$$X = \overline{A}$$

where

- A is the input variable
- X is the output variable



1. If A is 1 then X is 0
2. If A is 0 then X is 1

Example 1

A waveform is applied to an inverter.

Figure: Waveform is applied to input

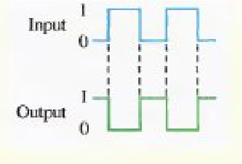


Figure: The output waveform

Example 2

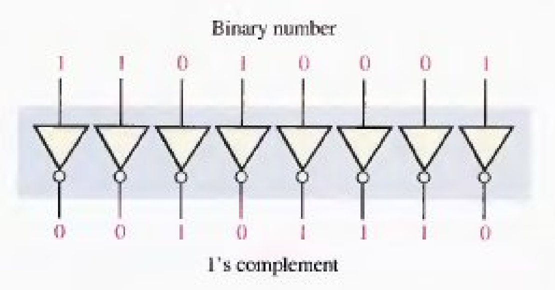


Figure: 1's Complement

The AND Gate

The AND Gate

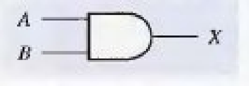
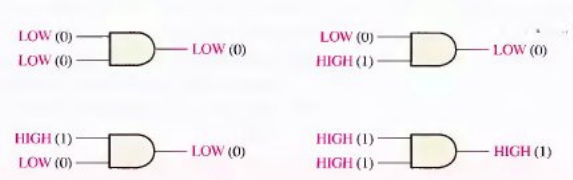


Figure: Symbol of AND Gate

- The AND gate is composed of two or more inputs and a single output.
- An AND gate can have any number of inputs greater than one.

Note **For a 2-input AND gate, output X is HIGH only when inputs A and B are HIGH; X is LOW when either A or B is LOW, or when both A and B are LOW.**

Logic Levels of AND Gate



A	B	o/p
LOW (0)	LOW (0)	LOW (0)
LOW (0)	HIGH (1)	LOW (0)
HIGH (1)	LOW (0)	LOW (0)
HIGH (1)	HIGH (1)	HIGH (1)

All possible logic levels for a 2-input AND gate.

Operation with Waveform Inputs

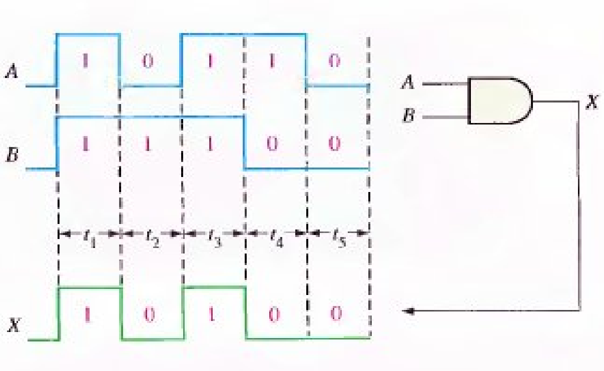
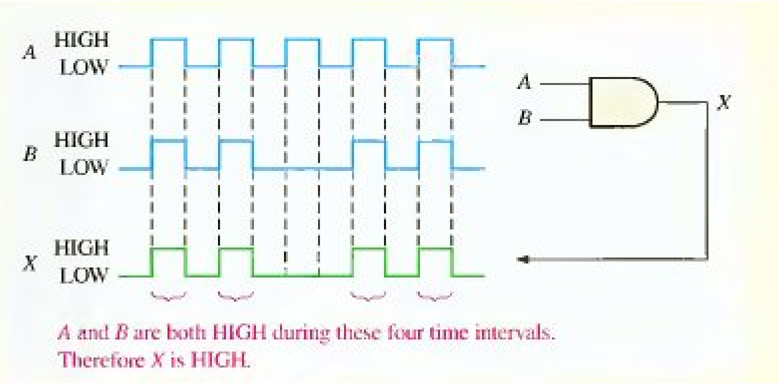
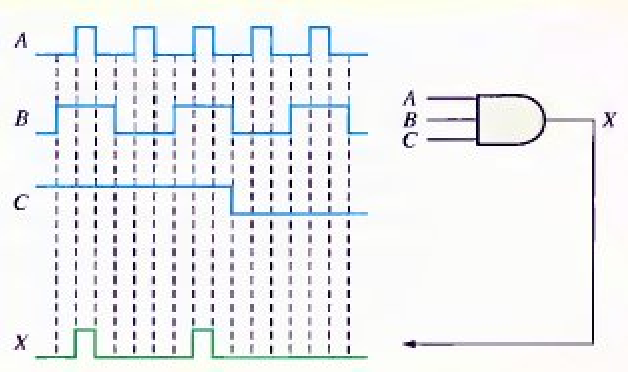


Figure: AND gate operation with a timing diagram showing input and output relationships.

Example with Waveform Inputs



Example with Waveform Inputs



Logic Expressions for an AND Gate

The logical AND function of two variables is represented mathematically either by placing a dot between the two variables, as

$$A.B$$

or as

$$AB$$

.

Example

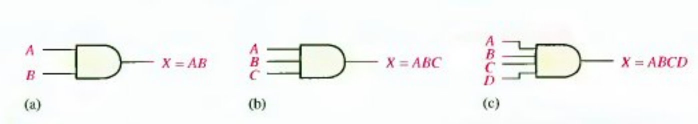


Figure: AND Logic gate symbol with multiple inputs

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

Table: Truth Table of 2-Input AND Gate

Example - Three Input AND Gate

A	B	C	X=ABC
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

Table: Truth Table of 3-Input AND Gate

The total number of input combinations for **n** inputs in $\mathbf{N = 2^n}$

E.g. For $n = 3$, the total number of input combinations are $N = 2^3 = 8$.

Application

The AND Gate follows the same basic rules of **Boolean multiplication**

$$\begin{aligned} 0.0 &= 0 \\ 0.1 &= 0 \\ 1.0 &= 0 \\ 1.1 &= 1 \end{aligned}$$

Application

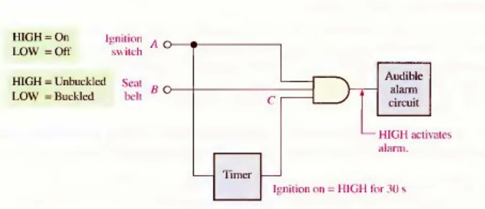


Figure: A Seat Belt Alarm System

- When the ignition is turned on, a timer is started that produces a HIGH on input C for 30sec
- If the ignition is *on* **AND** seat belt is *unbuckeled* **AND** timer *is running* - the output of AND gate is HIGH and the timer is **ON**

The OR Gate

The OR Gate

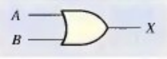


Figure: OR Gate

- The OR gate is composed of two or more inputs and a single output.
- An OR gate can have any number of inputs greater than one.

Note **For a 2-input OR gate, output X is HIGH when either input A or input B is HIGH, or when both A and B are HIGH; X is LOW only when both A and B are LOW.**

Logic Levels of OR Gate

A	B	o/p
LOW (0)	LOW (0)	LOW (0)
LOW (0)	HIGH (1)	HIGH (1)
HIGH (1)	LOW (0)	HIGH (1)
HIGH (1)	HIGH (1)	HIGH (1)

All possible logic levels for a 2-input OR gate.

Operation with Waveform Inputs

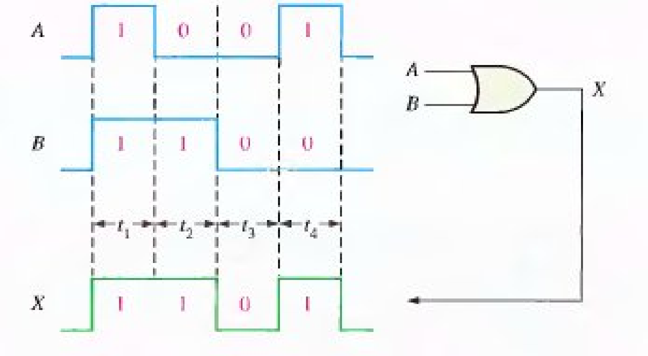
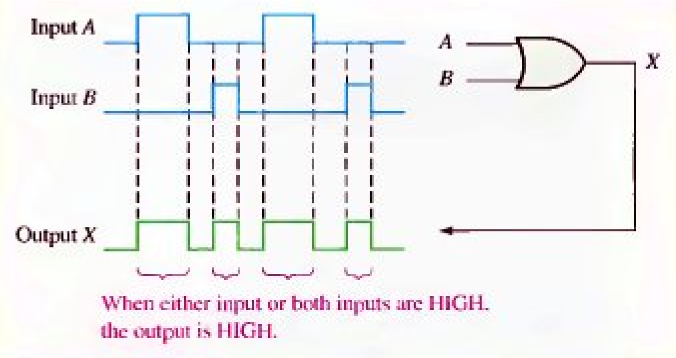
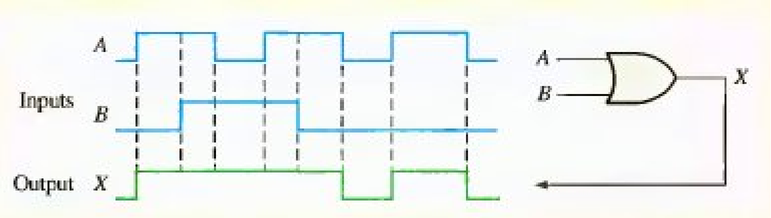


Figure: OR gate operation with a timing diagram showing input and output relationships.

Example with Waveform Inputs



Example with Waveform Inputs



Logic Expressions for an OR Gate

The logical OR function of two variables is represented mathematically as

$$A + B$$

.

Example

Figure: OR Logic gate symbol with multiple inputs

A	**B**	$\mathbf{X = A + B}$
0	0	0
0	1	1
1	0	1
1	1	1

Table: Truth Table of 2-Input OR Gate

Example - Three Input OR Gate

A	**B**	**C**	$\mathbf{X = A + B + C}$
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Table: Truth Table of 3-Input OR Gate

The total number of input combinations for **n** inputs in $\mathbf{N = 2^n}$

E.g. For $n = 3$, the total number of input combinations are $N = 2^3 = 8$.

Application

The OR Gate has the same basic rules of **Boolean additon**

$$\begin{aligned} 0+0 &= 0 \\ 0+1 &= 1 \\ 1+0 &= 1 \\ 1+1 &= 1 \end{aligned}$$

Application

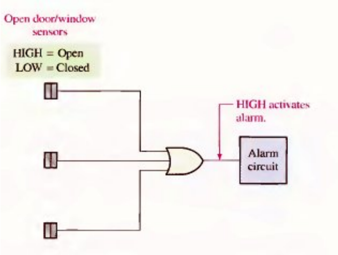


Figure: An Open Window-Door System

- This system could be used for one room in a home-a room with two windows and a door having magnetic switches.
- It activates when one of the windows or the door is opened.

The NAND Gate

The NAND Gate

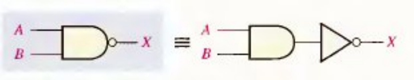


Figure: NAND Gate

- The NAND gate is composed of two or more inputs and a single output.
- An NAND gate can have any number of inputs greater than one.

Note **For a 2-input NAND gate, output X is LOW only when inputs A and B are HIGH; X is HIGH when either A or B is LOW, or when both A and B are LOW.**

Logic Levels of NAND Gate

A	B	o/p
LOW (0)	LOW (0)	HIGH (1)
LOW (0)	HIGH (1)	HIGH (1)
HIGH (1)	LOW (0)	HIGH (1)
HIGH (1)	HIGH (1)	LOW (0)

All possible logic levels for a 2-input NAND gate.

Operation with Waveform Inputs

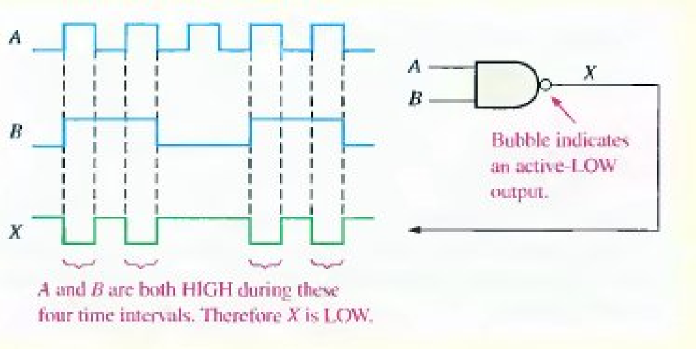


Figure: NAND gate operation with a timing diagram showing input and output relationships.

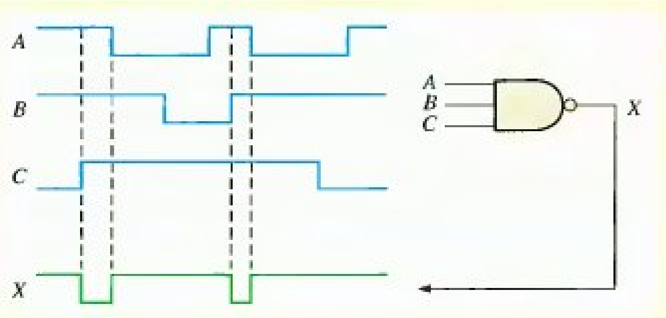
Logic Expressions for an NAND Gate

The logical AND function of two variables is represented mathematically as

$$X = \overline{AB}$$

.

Example with Waveform Inputs



Negative-OR Equivalent Operation of a NAND Gate

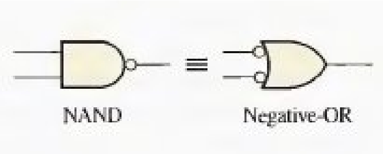
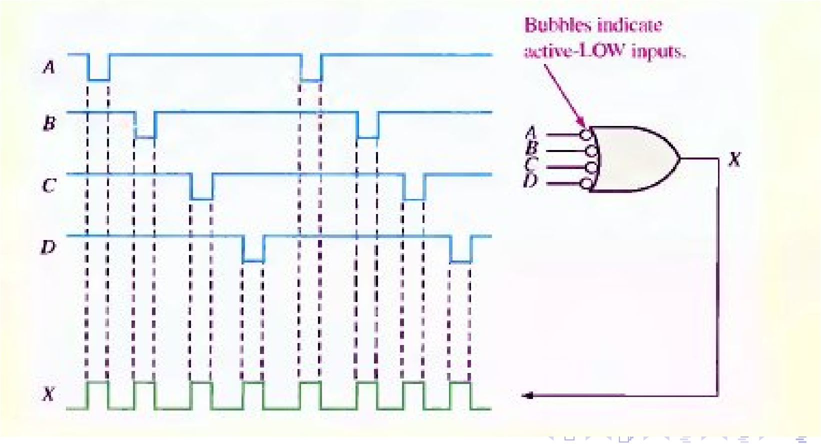


Figure: Standard symbols representing the two equivalent operation of a NAND gate.

The De' Morgan Boolean Law (for NAND Gates)

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

Example with Waveform Inputs



Truth Table for 2-input NAND Gate

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

Table: Truth Table of 2-Input NAND Gate

Example - Three Input NAND Gate

A	B	C	$X = \overline{ABC}$
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Table: Truth Table of 3-Input NAND Gate

Application

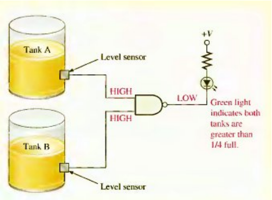


Figure: A Water tankIndicator

- If tank A and tank B are above one-quarter full, the LED is on.

The NOR Gate

The NOR Gate

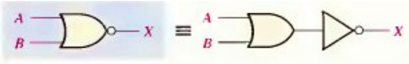
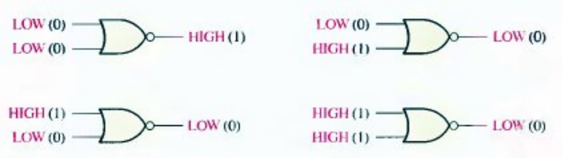


Figure: NOR Gate

- The NOR gate is composed of two or more inputs and a single output.
- An NOR gate can have any number of inputs greater than one.

Note **For a 2-input NOR gate, output X is LOW when either input A or input B is HIGH, or when both A and B are HIGH; X is HIGH only when both A and B are LOW.**

Logic Levels of NOR Gate



A	B	o/p
LOW (0)	LOW (0)	HIGH (1)
LOW (0)	HIGH (1)	LOW (0)
HIGH (1)	LOW (0)	LOW (0)
HIGH (1)	HIGH (1)	LOW (0)

All possible logic levels for a 2-input NOR gate.

Operation with Waveform Inputs

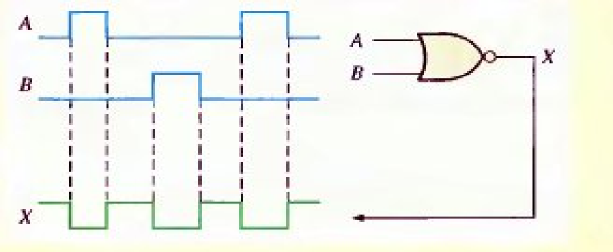


Figure: NOR gate operation with a timing diagram showing input and output relationships.

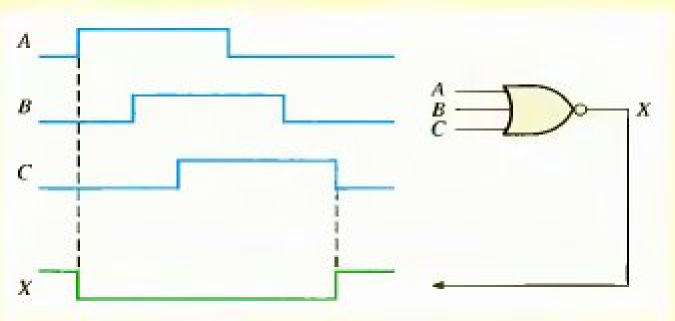
Logic Expressions for an NOR Gate

The logical NOR function of two variables is represented mathematically as

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

.

Example with Waveform Inputs



Negative-AND Equivalent Operation of a NOR Gate

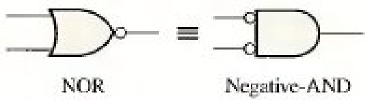


Figure: Standard symbols representing the two equivalent operation of a NOR gate.

The De' Morgan Boolean Law (for NOR Gates)

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

Truth Table for 2-input NOR Gate

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

Table: Truth Table of 2-Input NOR Gate

Example - Three Input NOR Gate

A	**B**	**C**	$\mathbf{X} = \overline{\mathbf{A} + \mathbf{B} + \mathbf{C}}$
0	0	0	1
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	0

Table: Truth Table of 3-Input NOR Gate

Application

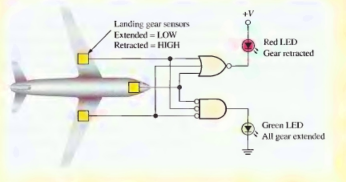


Figure: An Aircraft Landing Gears Status Indicator

- A green LED display turns on if all three gears are properly extended when the "gear down" switch has been activated in preparation for landing.
- A red LED display turns on if any of the gears fail to extend properly prior to landing.

Note Implement two circuits for the above

The Exclusive-OR Gate

The Exclusive-OR (XOR) Gate

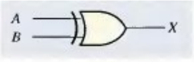
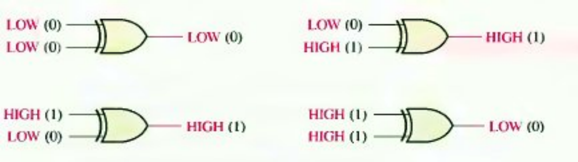


Figure: Exclusive-OR (XOR) Gate

- The XOR gate is composed of two or more inputs and a single output.
- An XOR gate can have any number of inputs greater than one.

Note **For an exclusive-OR gate. output X is HIGH when input A is LOW and input B is HIGH, or when input A is HIGH and input B is LOW: X is LOW when A and B are both HIGH or both LOW.**

Logic Levels of XOR Gate



A	B	o/p
LOW (0)	LOW (0)	LOW (0)
LOW (0)	HIGH (1)	HIGH (1)
HIGH (1)	LOW (0)	HIGH (1)
HIGH (1)	HIGH (1)	LOW (0)

All possible logic levels for a 2-input XOR gate.

Operation with Waveform Inputs

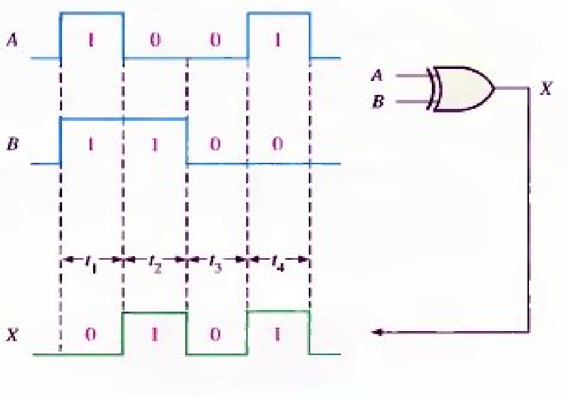


Figure: XOR gate operation with a timing diagram showing input and output relationships.

Logic Expressions for an XOR Gate

Logic Expression

The logical XOR function of two variables is represented mathematically as

$$X = A \oplus B$$

.

Equivalent AND-OR XOR Gates

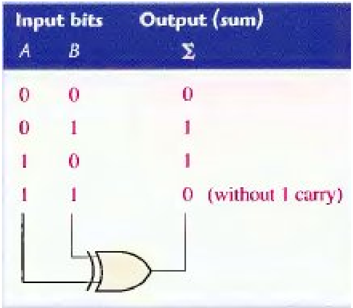
$$A \oplus B = \overline{A}.B + A.\overline{B}$$

Truth Table for 2-input XOR Gate

A	**B**	$\mathbf{X} = \mathbf{A} \oplus \mathbf{B}$
0	0	0
0	1	1
1	0	1
1	1	0

Table: Truth Table of 2-Input XOR Gate

Application



Input bits		Output (sum)
A	B	Σ
0	0	0
0	1	1
1	0	1
1	1	0 (without 1 carry)

Figure: XOR as Binary Adder withot Carry

Application

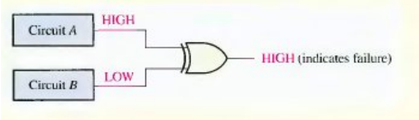


Figure: Circuit Failure Status Indicator

- A certain system contains two identical circuits operating in parallel.
- As long as both are operating properly, the outputs of both circuits are always the same.
- If one of the circuits fails, the outputs will be at opposite levels at some time.

The Exclusive-NOR Gate

The Exclusive-NOR (XNOR) Gate

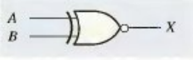


Figure: Exclusive-OR (XOR) Gate

- The XNOR gate is composed of two or more inputs and a single output.
- An XNOR gate can have any number of inputs greater than one.

Note **For an exclusive-NOR gate, output X is LOW when input A is LOW and input B is HIGH, or when A is HIGH and B is LOW; X is HIGH when A and B are both HIGH or both LOW.**

Logic Levels of XNOR Gate

A	B	o/p
LOW (0)	LOW (0)	HIGH (1)
LOW (0)	HIGH (1)	LOW (0)
HIGH (1)	LOW (0)	LOW (0)
HIGH (1)	HIGH (1)	HIGH (1)

All possible logic levels for a 2-input XNOR gate.

Operation with Waveform Inputs

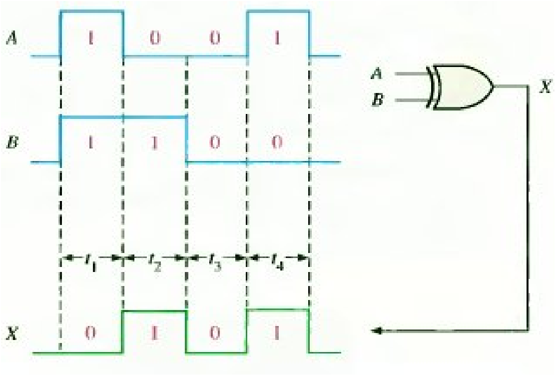


Figure: XNOR gate operation with a timing diagram showing input and output relationships.

Logic Expressions for an XNOR Gate

Logic Expression

The logical XNOR function of two variables is represented mathematically as

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

.

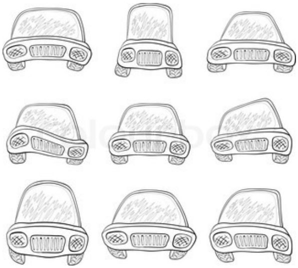
Equivalent AND-OR XOR Gates

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

Truth Table for 2-input XNOR Gate

A	**B**	$\mathbf{X} = \mathbf{A} \oplus \mathbf{B}$
0	0	1
0	1	0
1	0	0
1	1	1

Table: Truth Table of 2-Input XNOR Gate



Dual Inline Packages (DIP)

Digital Integrated Circuits

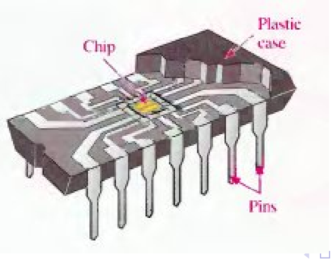
Digital Integrated Circuits

- A monolithic **integrated circuit (IC)** is an electronic circuit that is constructed entirely on a single chip of silicon
- All the components that make up the circuit - transitors, diodes, resistors and capacitors - are an integral part of that single chip
- Fixed-function logic and programmable logic are two categories of digital ICs.
- In fixed-function logic, the logic functions are set by the manufacturer and cannot be altered.

IC Packages

- Integrated Circuit (IC) packages are classified according to the way they are mounted on printed circuit (PC) boards as either *through-hole* mounted or *surface* mounted
- The through-hole type packages have pins (leads) that are inserted through holes in the PC board.
- The pins can be soldered to conductors on the opposite side,
- The most common type of through-hole package is the *dual in-line package* (**DIP**)

Dual Inline Packages (DIP)



Pin Numbering

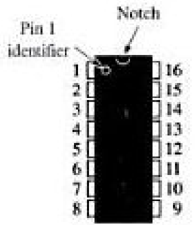


Figure: Pin Numbering for DIP

Digital IC Packages

Inverters (IC 7404)

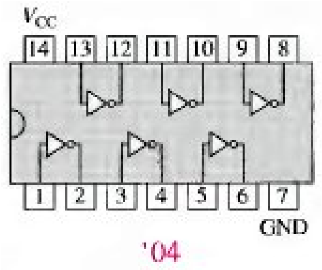


Figure: IC 7404 - Inverter DIP

2-Input AND (IC 7408)

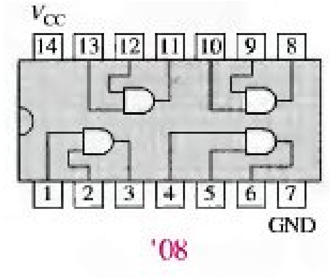


Figure: IC 7408 - 2-Input AND DIP

3-Input AND (IC 7411)

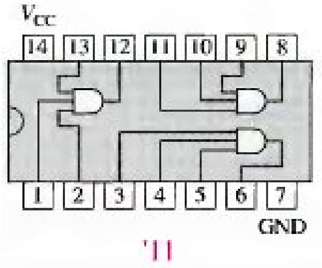


Figure: IC 7411 - 3-Input AND DIP

4-Input AND (IC 7421)

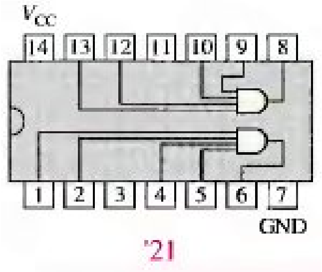


Figure: IC 7421 - 4-Input AND DIP

2-Input OR (IC 7432)

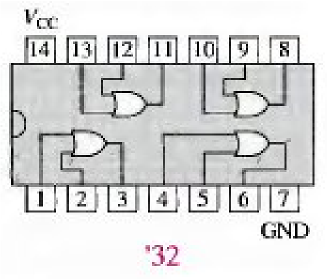


Figure: IC 7432 - 2-Input OR DIP

2-Input NAND (IC 7400)

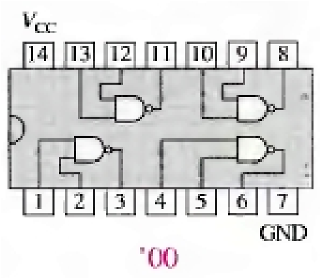


Figure: IC 7400 - 2-Input NAND DIP

3-Input NAND (IC 7410)

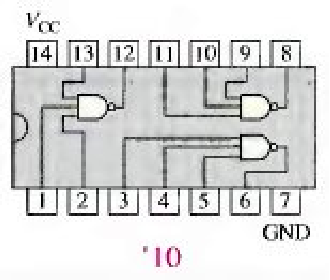


Figure: IC 7410 - 3-Input NAND DIP

4-Input NAND (IC 7420)

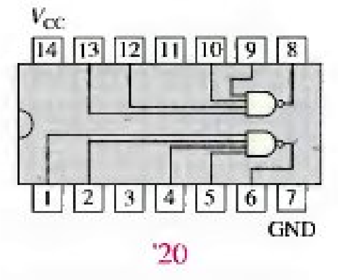


Figure: IC 7420 - 4-Input NAND DIP

8-Input NAND (IC 7430)

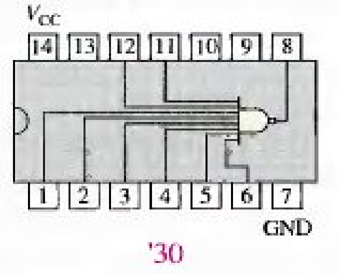


Figure: IC 7430 - 8-Input NAND DIP

2-Input N0R (IC 7402)

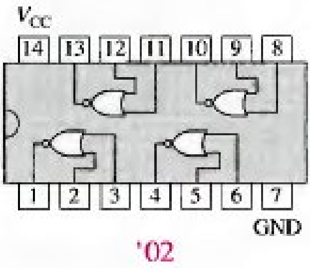


Figure: IC 7402 - 2-Input NOR DIP

3-Input N0R (IC 7427)

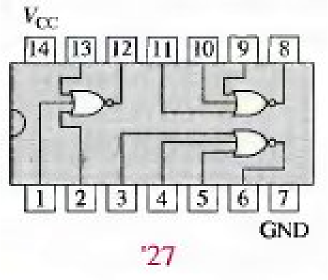


Figure: IC 7427 - 3-Input NOR DIP

2-Input X0R (IC 7486)

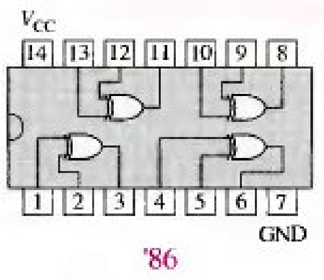


Figure: IC 7486 - 2-Input XOR DIP

References

[1] Thomas L. Floyd.
Digital Fundamentals, 8th edition.
Pearson Education Inc., 2003.

QUESTIONS !!!