
























- ➔  **Digital Teaching Aid (DED Philippines, 86 p.)**
  -  **(introduction...)**
  -  **Preface**
  -  **Introduction**
  -  **Fundamental Logic Operations - Lesson 1**
    -  **Lesson Plan**
      -  **(introduction...)**
      -  **Introduction**
      -  **TTL circuits**
      -  **Logic operations**
    -  **Handout No. 1**
    -  **Worksheet No. 1**
  -  **Introduction Boolean Algebra - Lesson 2**
    -  **Lesson Plan**
      -  **Introduction**
      -  **Boolean algebra**
      -  **Boolean equations of logic circuits**
      -  **NOR and NAN gates**
      -  **De Morgan's theorems**
    -  **Worksheet No. 2**

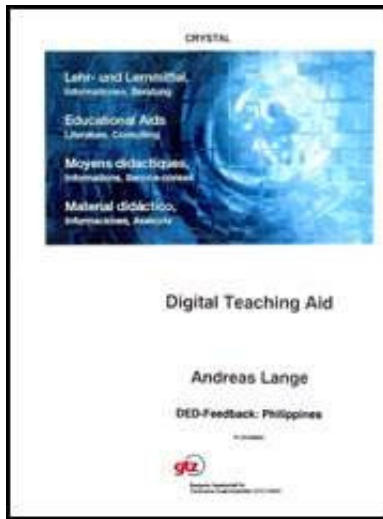
- **Circuit Analysis and Design - Lesson 3**
  - **Lesson Plan**
    - 📄 **(introduction...)**
    - 📄 **Introduction**
    - 📄 **Boolean laws and theorems**
    - 📄 **Sum of product method**
    - 📄 **Design example**
    - 📄 **Handout No. 2**
    - 📄 **Worksheet No. 3**
  - 📄 **First Evaluation**
- **Karnaugh Mapping - Lesson 4**
  - **Lesson Plan**
    - 📄 **(introduction...)**
    - 📄 **Introduction**
    - 📄 **Karnaugh map**
    - 📄 **Truth table to Karnaugh map**
    - 📄 **Pairs, Quads, and Octets**
    - 📄 **Overlapping and Rolling**
  - 📄 **Worksheet No. 4**
- **Karnaugh Mapping II - Lesson 5**
  - **Lesson Plan**
    - 📄 **(introduction...)**
    - 📄 **Introduction**
    - 📄















 **Product of sums method** **Don't care conditions** **Worksheet No. 5** **Coding - Lesson 6** **Lesson Plan** ***(introduction...)*** **Introduction** **ASCII code** **Excess-3 code** **Gray code** **Encoder** **Decoder** **Code converter** **Worksheet No. 6** **Flip-Flops - Lesson 7** **Lesson Plan** ***(introduction...)*** **Introduction** **RS Flip-Flops** **D - Flip-Flop (D-FF)** **JK Flip-Flop (JK-FF)** **Worksheet No. 7** **Second Evaluation**

- **Counter Lesson 8**
  - **Lesson Plan**
    - 📄 **(introduction...)**
    - 📄 **Introduction**
    - 📄 **Asynchronous counter**
    - 📄 **Synchronous counter**
    - 📄 **Seven segment indicator and decoder**
  - 📄 **Worksheet No. 8**
- **Data Processing Circuits - Lesson 9**
  - **Lesson Plan**
    - 📄 **(introduction...)**
    - 📄 **Introduction**
    - 📄 **Multiplexer**
    - 📄 **Demultiplexer**
  - 📄 **Handout No. 3**
  - 📄 **Worksheet No. 9**
  - 📄 **Third Evaluation**
  - 📄 **Answers to Evaluation Problems**

[Home](#) > [ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#)

- 📖 **Digital Teaching Aid (DED Philippines, 86 p.)**
  - ➔ 📄 **(introduction...)**
  - 📄 **Preface**



-  **Introduction**
-  **Fundamental Logic Operations - Lesson 1**
-  **Introduction Boolean Algebra - Lesson 2**
-  **Circuit Analysis and Design - Lesson 3**
-  **First Evaluation**
-  **Karnaugh Mapping - Lesson 4**
-  **Karnaugh Mapping II - Lesson 5**
-  **Coding - Lesson 6**
-  **Flip-Flops - Lesson 7**
-  **Second Evaluation**
-  **Counter - Lesson 8**
-  **Data Processing Circuits - Lesson 9**
-  **Third Evaluation**
-  **Answers to Evaluation Problems**

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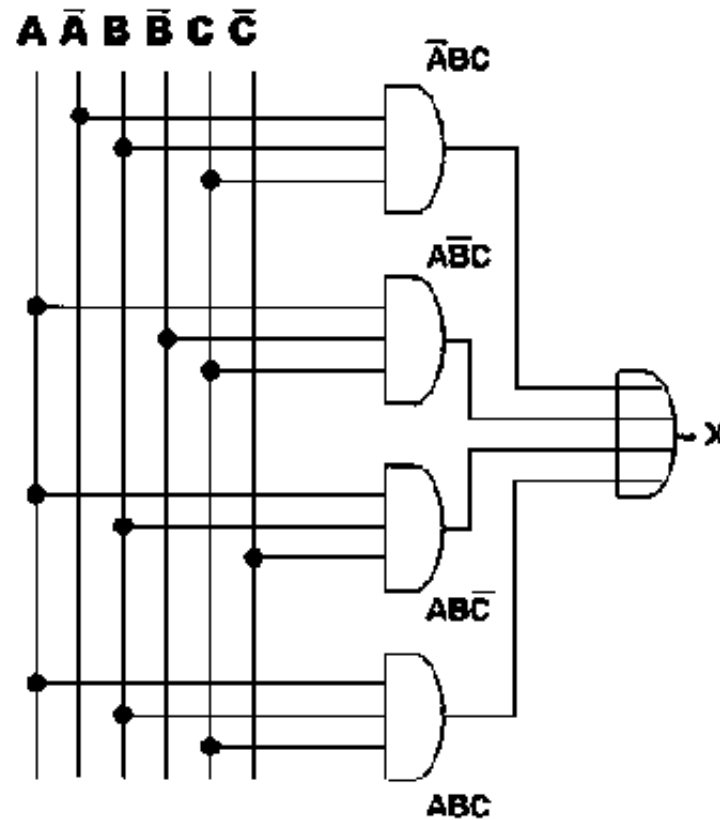
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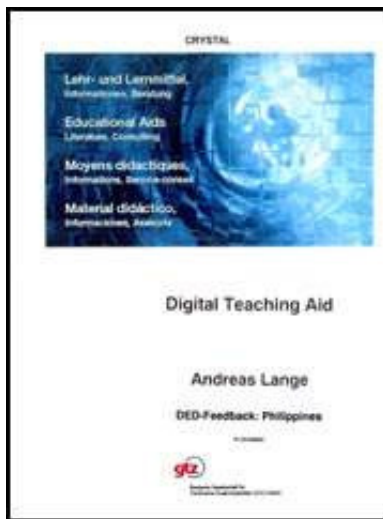


## Figure

### Andreas Lange, DED, 1994 Philippines



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#### Coding - Lesson 6



#### Lesson Plan



*(introduction...)*



Introduction



ASCII code



Excess-3 code



Gray code



Encoder



Decoder



Code converter



Worksheet No. 6

**Digital Teaching Aid (DED Philippinen, 86 p.)**

**Coding - Lesson 6**

## Lesson Plan

### Titel: Coding

### Objectives:

- **Get an idea about the purpose of codes**
- **Understand the principle of decoder, encoder, and code converter**
- **Able to design logic circuits for code conversion**

Time	Method 1	Topic	Way	Remark
		* Review Lesson 5		
		* Introduction		
		* ASCII code		
		- Coding scheme		
		- Parity bit		
		* BCD code		
		* Excess-3 code		
		* Gray code		
		* Encoder		
		- Decimal to BCD encoder		
		* Decoder		
		- BCD to decimal decoder		
		* Code converter		



		CODE CONVERTER		
		- BCD to Exces-3 code converter		
		* Review Exercise		Worksheet No. 6
	S: Speech D: Discussion Q/A: Question/Answer F: Exercise		B: Boardscript P: Picture Ex: Example HO: Hands-On WS: Worksheet HT: Hand-Out	

## Introduction

### Coding

**Ex: Coding → Alphanumeric information in and out of a computer.**

### ASCII code

### ASCII Code (American Standard Code for Information Interchange)

**ASCII code is a 7 bit code whose format is**

**X6 X5 X4 X3 X2 X1 X0**

**i.e. the letter A is coded as:**

**1 0 0 0 0 1****Coding scheme:**

<b>X6 X5 X4</b>									
<b>X3</b>	<b>X2</b>	<b>X1</b>	<b>X0</b>	<b>010</b>	<b>011</b>	<b>100</b>	<b>101</b>	<b>110</b>	<b>111</b>
0	0	0	0		0		P		P
0	0	0	1		1	A	Q	a	q
0	0	1	0		2	B	R	b	r
.	.	.	.		.	.	.	.	.
.	.	.	.		.	.	.	.	.
.	.	.	.		.	.	.	.	.
1	1	1	1			0			

**Ex; The letter B via ASCII in binary:****1 0 0 0 0 1 0****Parity bit****During sending/transmitting data, 1 bit errors may occur. To catch these errors, a parity bit is usually transmitted along with the original bits:****X7 X6 X5 X4 X3 X2 X1 X0****|**

## parity bit

**A parity checker at the receiving end can test for even or odd parity. I.e the transmitting station will set the parity bit always in that way to put the whole number in even parity. If the parity checker at the receiving end determines odd parity it will report an error message.**

**Now we have 8 bits (1 byte), this is the ideal length because most digital equipment is set up to handle bytes of data.**

## BCD Code (Binary Coded Decimal)

**Each decimal place (0...9) is represented by a binary code.**

Ex: 753

0111 0101 0011

7 5 3

**The BCD code is a 4 bit code which is very common along digital systems.**

## Excess-3 code

**Also an important 4 bit code**

**Ex: Convert a decimal number in excess-3 code:**

12 → excess-3

1

2 *First we add 3 to every decimal digit.*

$$\begin{array}{r} + \quad 3 \\ \hline 4 \end{array} \quad \begin{array}{r} + \quad 3 \\ \hline 5 \end{array}$$

0100 0101 Then we convert the sum in BCD form.  
0100 0101 in excess-3 stands for decimal 12.

**Fig. 6-1: Conversion table, dec → BCD → excess-3**

Decimal	BCD	Excess - 3
0	0000	001 1
1	0001	0100
2	0010	0101
3	0011	0110
4	0100	0111
5	0101	1000
6	0110	1001
7	0111	1010
8	1000	1011
9	1001	1100

## Gray code

**Each Gray code number differs from the preceding number by a single bit.**

**Fig. 6-2: Conversion table, dec → Gray → BCD**

<b>Decimal</b>	<b>Gray</b>	<b>Binary</b>
0	0000	0000
1	0001	0001
2	0011	0010
3	0010	0011
4	0110	0100
5	0111	0101
6	0101	0110
7	0100	0111
8	1100	1000
9	1101	1001

## **Encoder**

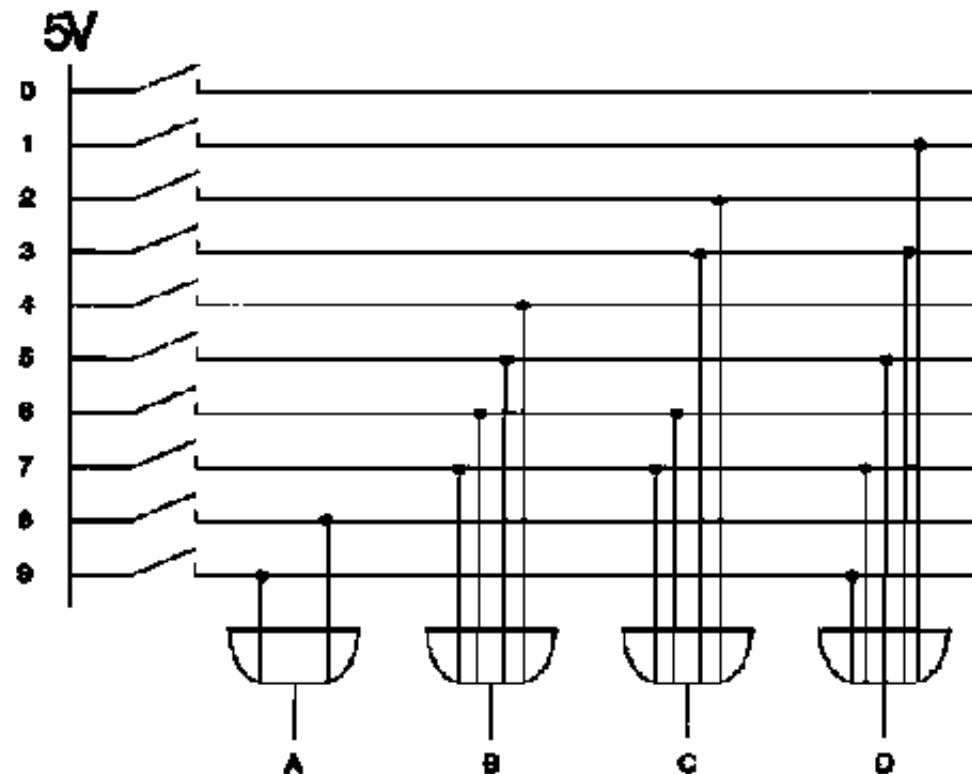
**An encoder converts an active input signal into a coded output signal.**

**Ex: Decimal to BCD encoder**

**(see Fig. 6-3 on the next page) If switch 9 is pressed:**

**A B C D = 1 0 0 1**

**The circuit in Fig. 6-3 is also available as TTL device 74147.**



**Fig. 6-3: Decimal to BCD encoder**

## Decoder

**A decoder converts a coded input signal into an active output signal.**

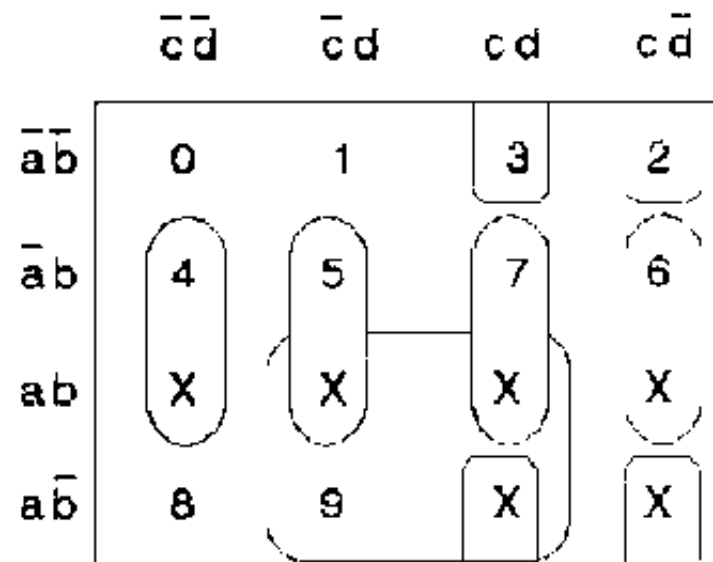
**Ex; Develop a decoder circuit which converts BCD code into decimal.**

***Fig. 6-4: Truth table, BCD → decimal***

a	b	c	d	
↗3	↗2	↗1	↗0	Dec

0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9

**To optimize the circuit we use a Karnaugh map for simplification:**



**Fig. 6-5: Karnaugh map**

**For every number in the Karnaugh map we can write an equation:**

$$X_0 = \bar{a}\bar{b}\bar{c}\bar{d}$$

$$X_1 = \bar{a}\bar{b}cd$$

$$X_2 = \bar{b}c\bar{d}$$

$$X_3 = \bar{b}cd$$

$$X_4 = b\bar{c}\bar{d}$$

$$X_5 = b\bar{c}d$$

$$X_6 = bcd$$

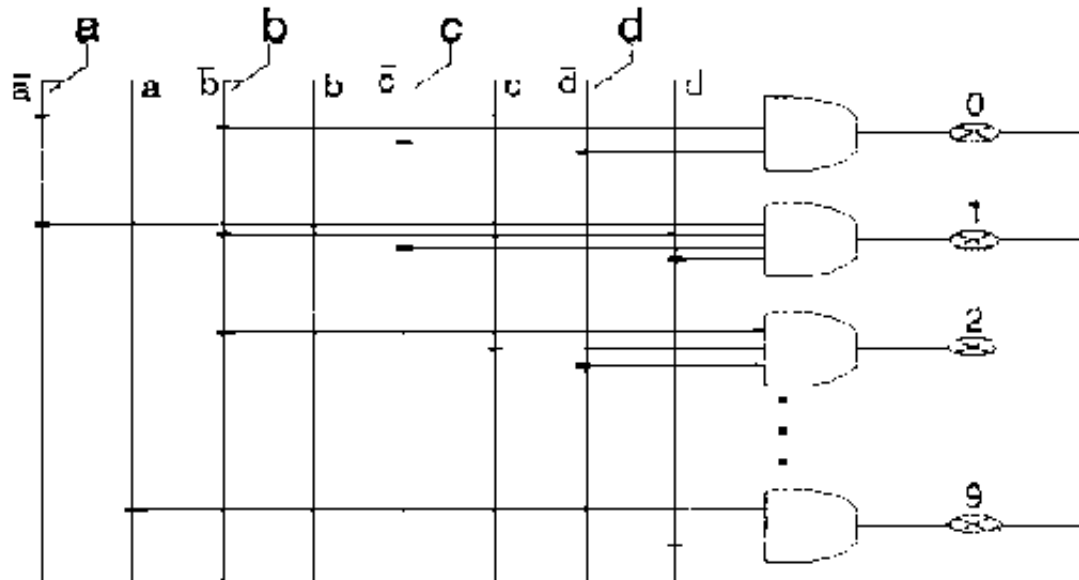
$$X_7 = bcd$$

$$X_8 = a\bar{b}\bar{c}\bar{d}$$

$$X_9 = ad$$

**Now we can draw the logic circuit:**

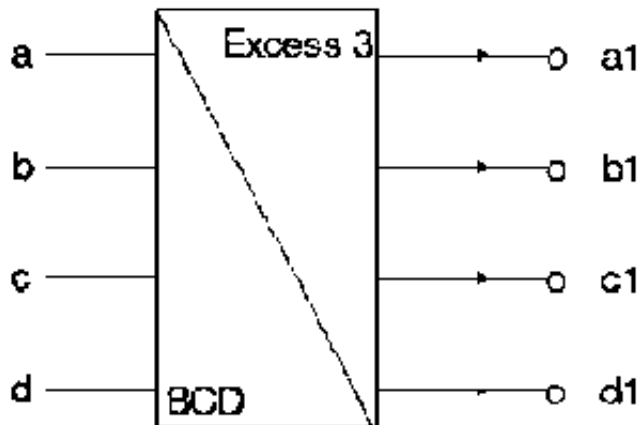




**Fig. 6-6: Decoder circuit, BCD → decimal**

**Code converter**

**Code converter are logical networks which convert codes into another.**



**Fig. 6-7: TTL device, BCD → excess-3 converter**

**Fig. 6-8: Conversion table, dec  $\rightarrow$  BCD  $\rightarrow$  excess-3**

Dec	BCD				Excess - 3			
	a	b	c	d	a <sub>1</sub>	b <sub>1</sub>	c <sub>1</sub>	d <sub>1</sub>
0	0	0	0	0	0	0	1	1
1	0	0	0	1	0	1	0	0
2	0	0	1	0	0	1	0	1
3	0	0	1	1	0	1	1	0
4	0	1	0	0	0	1	1	1
5	0	1	0	1	1	0	0	0
6	0	1	1	0	1	0	0	1
7	0	1	1	1	1	0	1	0
8	1	0	0	0	1	0	1	1
9	1	0	0	1	1	1	0	0

**Worksheet No. 6**

**No. 1** Develop a decoder circuit for the conversion of the Gray code into the decimal system. Use a Karnaugh map to get a simplified circuit!

Gray code				decimal
d	c	b	a	
0	0	0	0	0

0	0	0	1	1
0	0	1	1	2
0	0	1	0	3
0	1	1	0	4
0	1	1	1	5
0	1	0	1	6
0	1	0	0	7
1	1	0	0	8
1	1	0	1	9
X	X	X	X	
.	.	.	.	
.	.	.	.	

**No. 2 Develop a code converter for the conversion of the excess 3 code into the 8421 code (BCD).**

**Complete the truth table!**

**Use Karnaugh maps to get a simplified circuit!**

Excess 3 code					8421 code			
dec	d	c	b	a	d1	c1	b1	a1
0	0	0	1	1	0	0	0	0

1	0	1	0	0	0	0	0	1
2	0	1	0	1	0	0	1	0
3	0	1	1	0	0	0	1	1
4	0	1	1	1	0	1	0	0
5	1	0	0	0	0	1	0	1
6	1	0	0	1	0	1	1	0
7	1	0	1	0	0	1	1	1
8	1	0	1	1	1	0	0	0
9	1	1	0	0	1	0	0	1
	1	1	0	1	1	0	1	0
	1	1	1	0	1	0	1	1
	1	1	1	1	1	1	0	0
	0	0	0	0	1	1	0	1
	0	0	0	1	1	1	1	0
	0	0	1	0	1	1	1	1

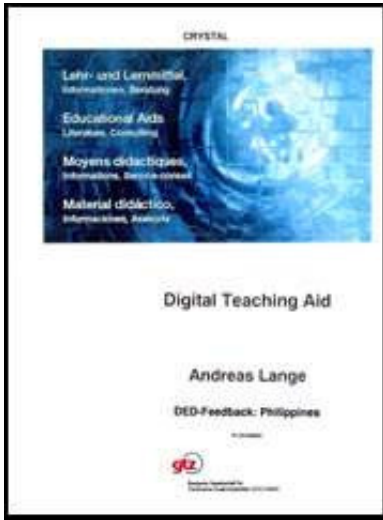
**The lower six rows are redundant.**









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**Flip-Flops - Lesson 7**  
**Lesson Plan**

-  **(introduction...)**
-  **Introduction**
-  **RS Flip-Flops**
-  **D - Flip-Flop (D-FF)**
-  **JK Flip-Flop (JK-FF)**
-  **Worksheet No. 7**

**Digital Teaching Aid (DED Philippines, 86 p.)**

**Flip-Flops - Lesson 7**

**Lesson Plan**

**Titel: Flip-Flops**

**Objectives:**

- **Understand the Flip-Flop principle**
- **Know the three basic Flip-Flops (RS, D, JK)**
- **Able to analyze timing diagrams**

<b>Time</b>	<b>Method</b>	<b>Topic</b>	<b>Way</b>	<b>Remark</b>
		* Review Lesson 6		
		* Introduction		

		* RS Flip-Flops		
		* Clocked RS-FF		
		* Timing diagram		
		* D-FF		
		* FF switching time		
		* JK-FF		
		* JK-MS-FF		
		* Review exercise		Worksheet No. 7
	S: Speech D: Discussion Q/A: Question/Answer F: Exercise		B: Boardscript P: Picture Ex: Example HO: Hands-On WS: Worksheet HT: Hand-Out	

## Introduction

### Flip-Flops

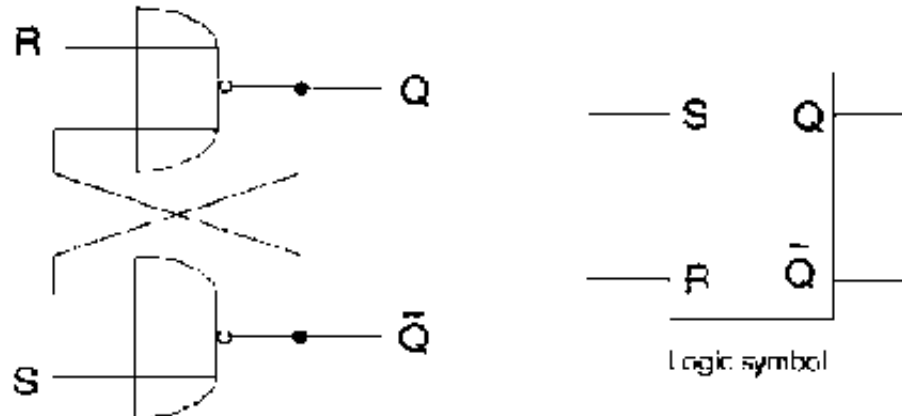
**Sometimes there is a need of digital devices or circuits whose output will remain unchanged, once set, even if there is a change in input.**

### RS Flip-Flops

**A Flip-Flop is a bistable electronic circuit that has two stable states.**

⇒ **Output is either 0 or 5V dc**

**The Flip-Flop can be regarded as a memory device. It can be used to store one binary digit at the output.**



**Fig. 7-1: RS Flip-Flop, logic circuit and device symbol**

**HO: What is the truth table for the circuit above?**

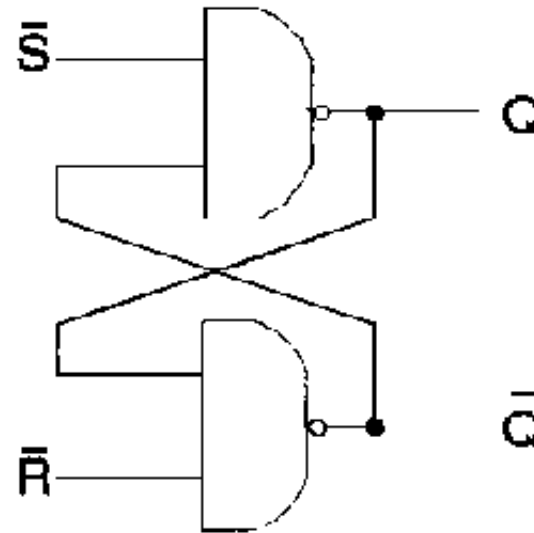
**Solution:**

**Fig. 7-2: Truth table, RS Flip-Flop**

<b>R</b>	<b>S</b>	<b>Q</b>	<b>Action</b>
0	0	Last value	No change
0	1	1	Set
1	0	0	Reset
1	1	?	Forbidden

**If both inputs (R, S) are high at once, the output can not be determined before; therefore, it is a forbidden state.**

**Ex: Create a RS Flip-Flop with NAND gates.**

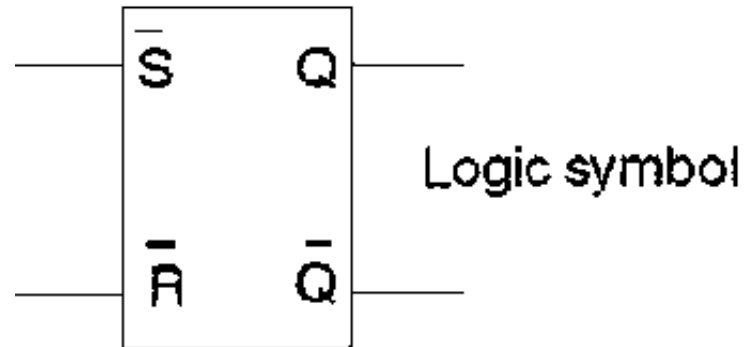


$\bar{R}$	$\bar{S}$	Q
1	1	Last value
1	0	1
0	1	0
0	0	? (forbidden)

**Fig. 7-3: RS Flip-Flop with NAND gates**

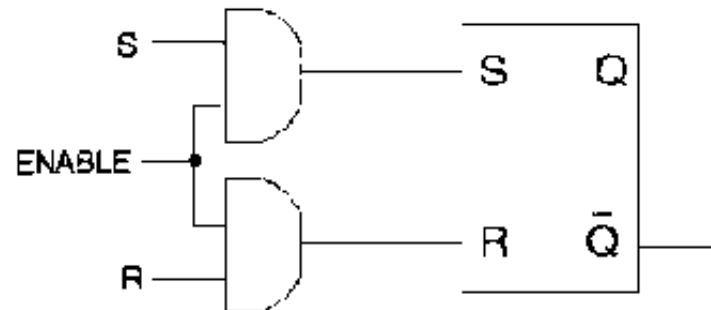


**Note:** The inputs (R, S) are indicated with an overbar so they are inverted.



**Fig. 7-4: Logic symbol, RS Flip-Flop with inverted inputs**

### Clocked RS Flip-Flop

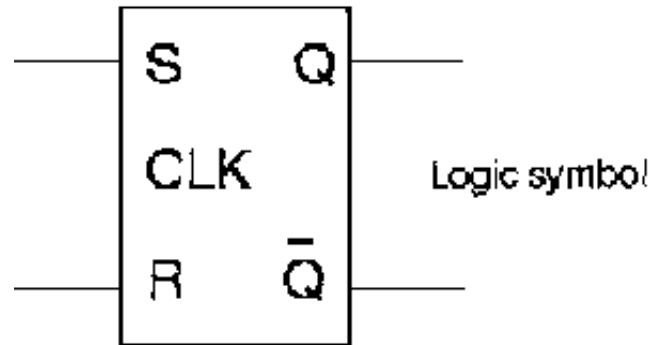


**Fig. 7-5: Clocked RS Flip-Flop**

**This Flip-Flop can be enabled or disabled.**

**ENABLE → low: R and S will have no effect on the output**

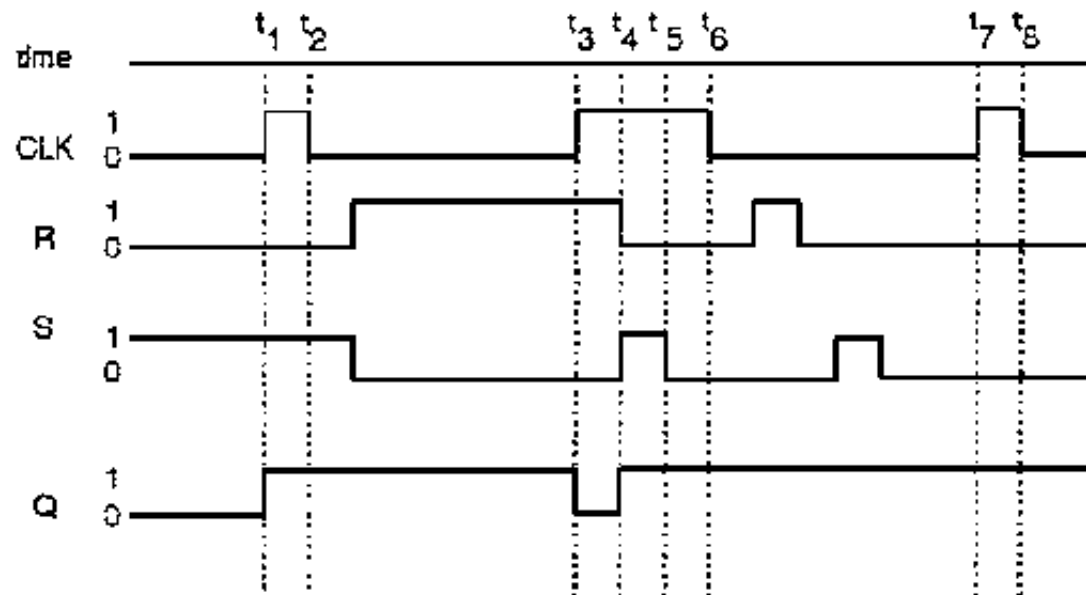
**ENABLE → high: R and S inputs will be directly transmitted to the output**



**Fig. 7-6: Logic symbol, Clocked RS Flip-Flop**

## Timing diagram

A timing diagram is a drawing to determine the time dependent actions of logic devices.



**Fig. 7-7: Timing diagram of a clocked RS Flip-Flop**

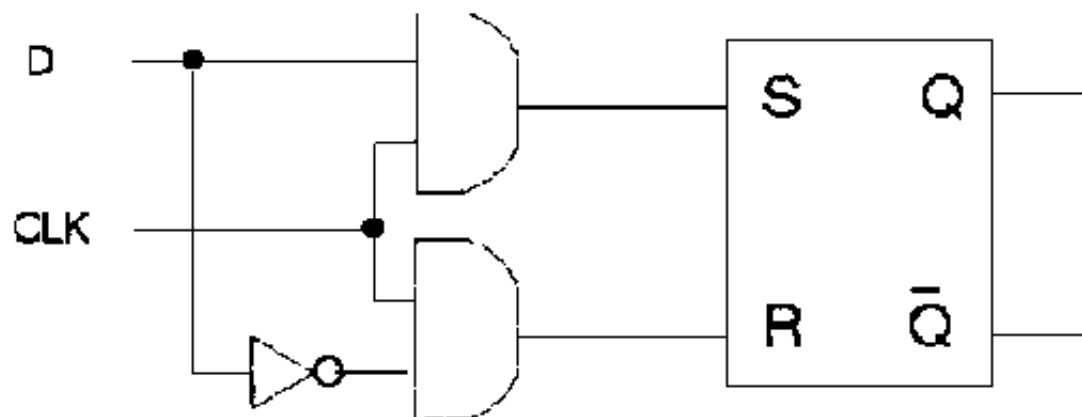
**Fig. 7-7** shows that the inputs (R, S) effect the output (Q) only when the clock

**signal (CLK) is high.**

## **RS Flip-Flop application: Bounce free switch**

### **D - Flip-Flop (D-FF)**

**The generation of two signals to drive a Flip-Flop is a disadvantage in many applications. This has led to the D-FF, a circuit that needs only a single data input.**



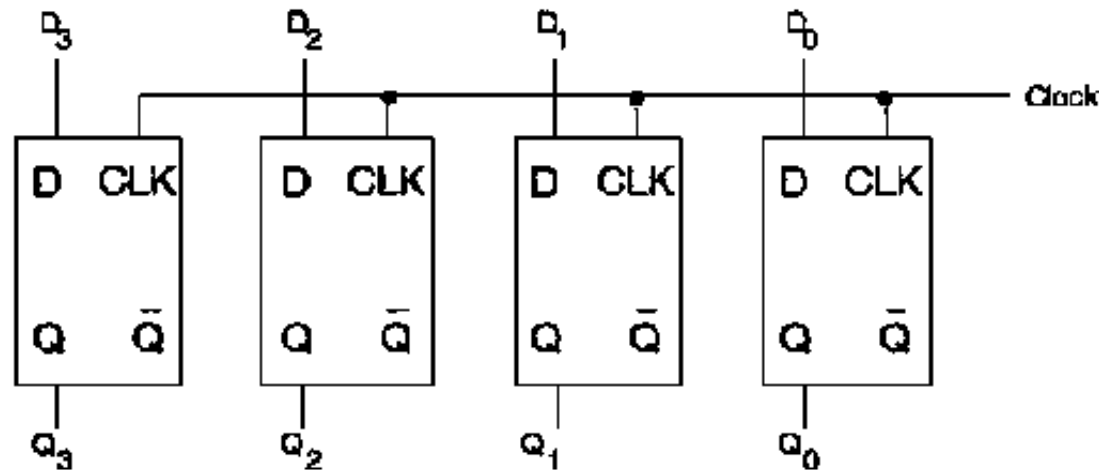
CLK	D	Q
0	X	last state
1	0	0
1	1	1

**Fig. 7-8: D Flip-Flop, logic circuit and truth table**

**CLK → low: D can change without effect on the output**

**CLK → high: Q is forced to equal the value of D**

**Ex: Create a 4 bit data memory with D-latches (D-FF).**



**Fig. 7-9: Data storage with D-FF**

**In Fig. 7-9, when the clock goes high, input data is loaded into the Flip-Flops and appears at the output.**

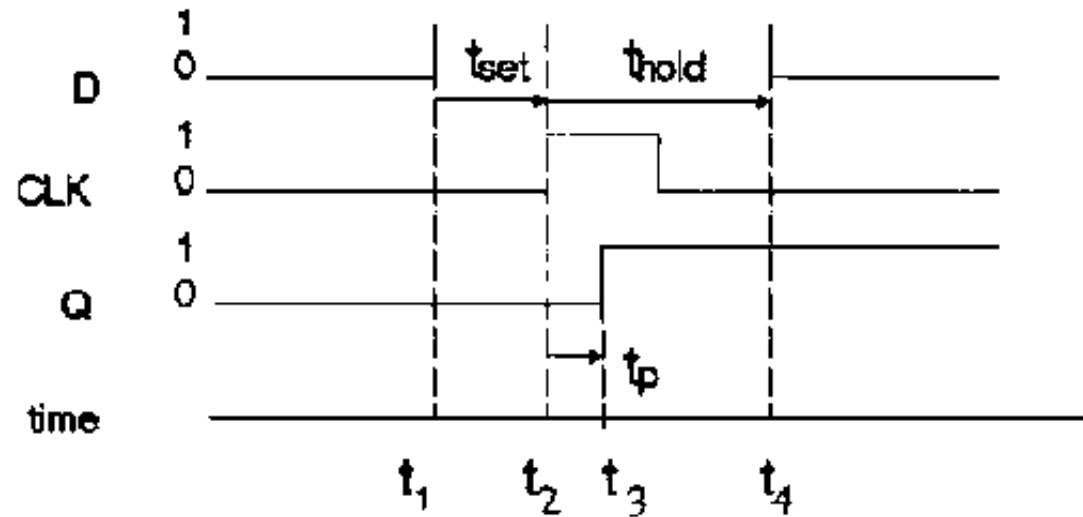
**Suppose the data input is:**

$$\mathbf{D_3 D_2 D_1 D_0 = 1 0 1 0}$$

**When the clock goes high this 4 bit word is loaded into the D-latches, resulting in an output of:**

$$\mathbf{Q_3 Q_2 Q_1 Q_0 = 1 0 1 0}$$

## Flip-Flop switching time



**Fig. 7-10: Timing diagram, FF switching time**

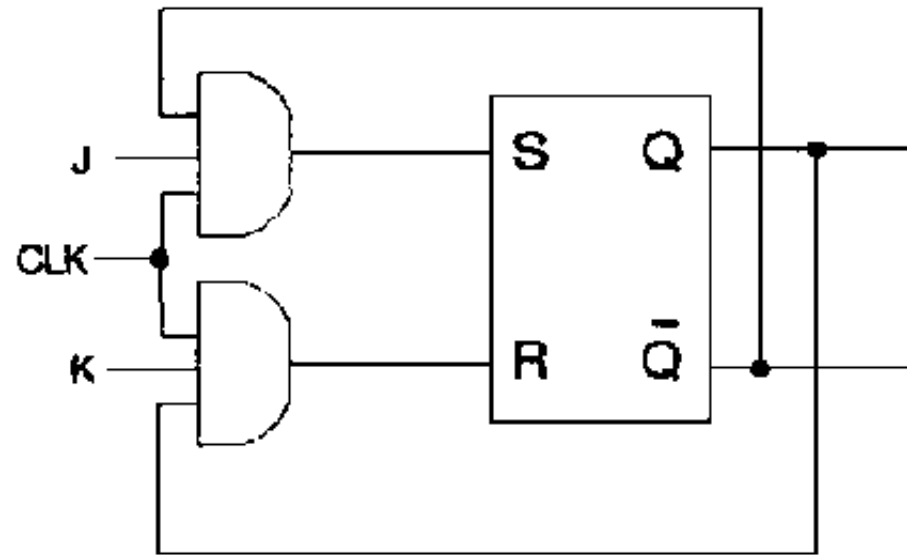
$t_{set}$ : Minimum of time that the data bit must be present before the clock edge hits (because of stray capacitance)

$t_{hold}$ : The data bit has to be hold long enough for the internal transistors to switch.

$t_p$ : Switching time, diodes and transistors cannot switch states immediately. (some nanoseconds)

## **JK Flip-Flop (JK-FF)**

**Flip - Flops can be used to build counters, JK-FF are the ideal elements for that purpose.**



**Fig. 7-11: JK-FF, logic circuit**

**Ex: What is the truth table for the circuit above?**

**Fig. 7-12: Truth table, JK-FF**

CLK	J	K	Q
X	0	0	<b>last state</b>
	0	1	<b>0</b>
	1	0	<b>1</b>
	1	1	<b>toggle</b>

J and K → Both AND gates are disabled, clock pulses have no effect. Q retains its last value.

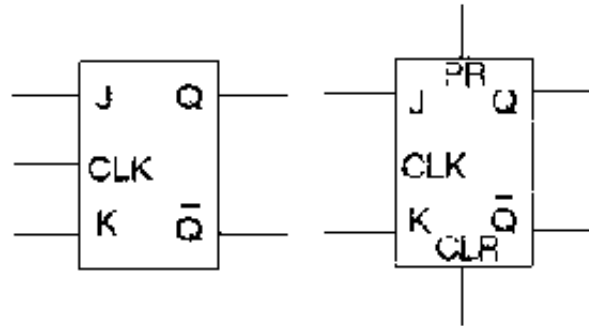
J → low, K The upper gate is disabled, only reset is possible (unless Q is already reset).

→ high:

J → high, K The lower gate is disabled, only set is possible (unless Q is already high).

→ low:

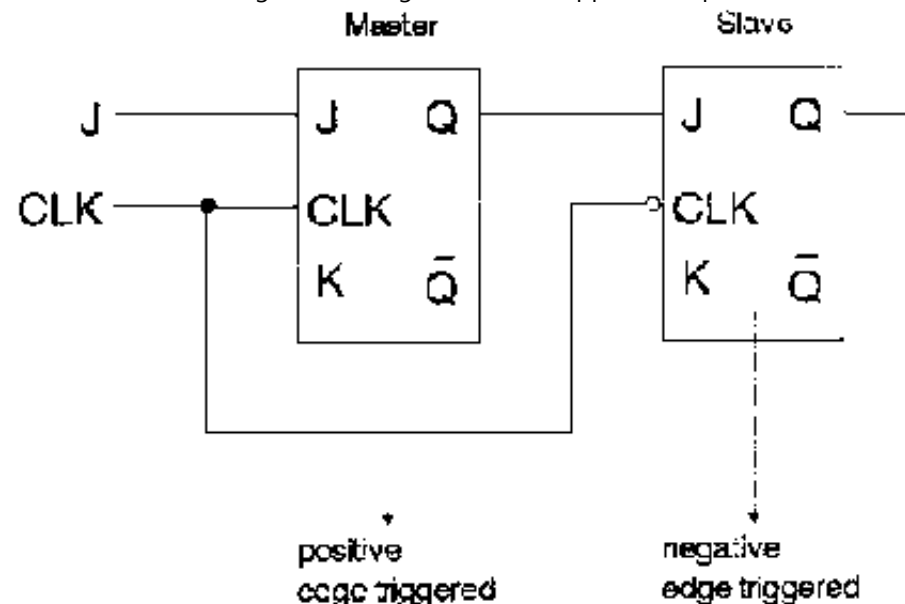
J and K → Set or reset is possible, the Flip-Flop will "toggle" on the next positive clock edge. Toggle means to switch to the opposite state.



**Fig. 7-13: JK-FF's, logic symbols**

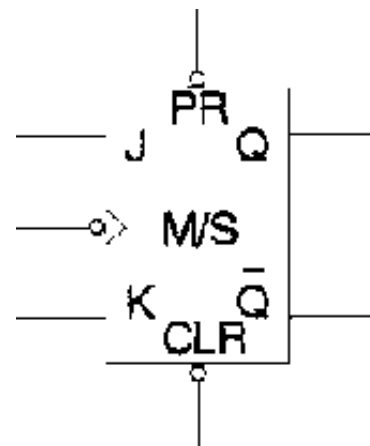
**Preset (PR) and Clear (CLR) are input signals to get a definite start point.**

### **JK Master-Slave FF (JK-MS-FF)**



**Fig. 7-14: JK-MS-FF, logic circuit**

**Regardless what the master does, the slave copies it. The slave copies the master on the negative clock edge. This circuit provides a way to avoid racing.**



**Fig. 7-15: JK-MS-FF, logic symbol**



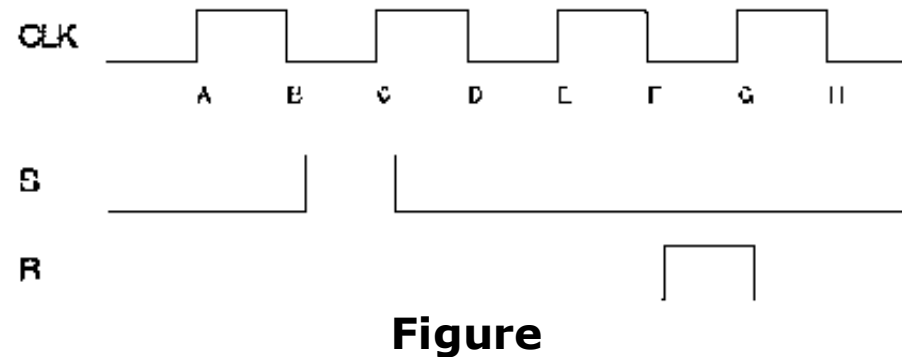
## Available as TTL device: 74 LS 76

### Worksheet No. 7

**No. 1** A JK master slave FF has its inputs tied to + 5V, and a series of pulses are applied to its CLK input Describe the Q output.

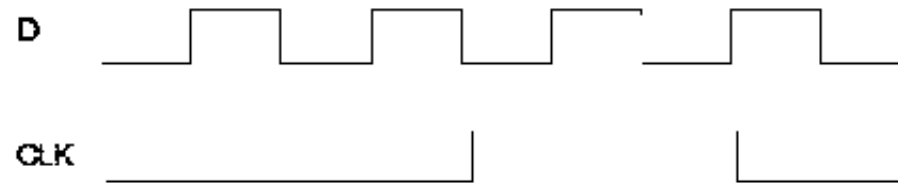


**No. 2** The signal drives a clocked RS - FF. If Q is low before point A in time: At what point does Q becomes a 1? What does Q reset to 0?



**No. 3** Use the information in the preceding problem and draw the waveform Q.

**No. 4** The signal drives a D-FF. What is the value of stored in the FF after the clock pulse is over?

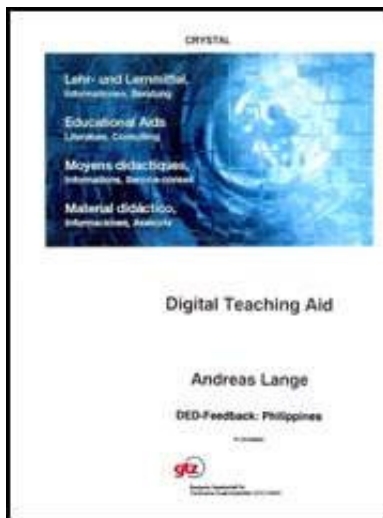


Figure

**No. 5** A normal JK-FF,  $J = K = 1$ . A 1 MHz is applied to the CLK input it has a propagation delay  $t_p$  of 50 ns. Draw the input squarewave and the out put expected at Q. Be sure to show the propagation delay time.



[Home](#) > [ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#)



## Digital Teaching Aid (DED Philippines, 86 p.)

 *(introduction...)*

 Preface

 Introduction

 Fundamental Logic Operations - Lesson 1


 Introduction Boolean Algebra - Lesson 2







 Circuit Analysis and Design - Lesson 3

 First Evaluation

 Karnaugh Mapping - Lesson 4

 Karnaugh Mapping II - Lesson 5

 Coding - Lesson 6

- ➔  **Flip-Flops - Lesson 7**
-  **Second Evaluation**
-  **Counter - Lesson 8**
-  **Data Processing Circuits - Lesson 9**
-  **Third Evaluation**
-  **Answers to Evaluation Problems**

## Second Evaluation

**No. 1 In a workshop two machines are driven by an electric motor**

Power consumption: motor A = 1 KW

motor B = 2 KW

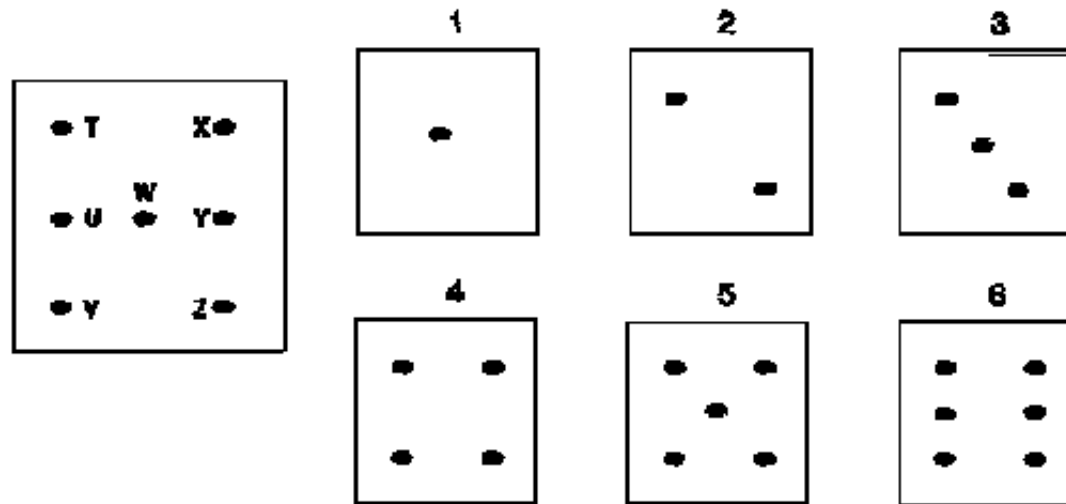
**For a new machine of which its motor C receives the power of 4 KW, the maximum main power of  $P_{max} = 4$  KW is sufficient only if the two other machines (A and B) are not switched on. Design a circuit which supplies a warning signal Q if a power higher than 4 KW is taken from the main power system by the three machines.**

- Truth table
- Karnaugh map
- Logic circuit

**No. 2 For a display of the figures 1-6, in the well known spot configuration of a game die, design the code conversion circuit. At the input the figures are binary coded.**

## T, U, V, W, X, Y, Z are output variables (LED's)

- Truth table
- Karnaugh map
- Logic circuit



Figure

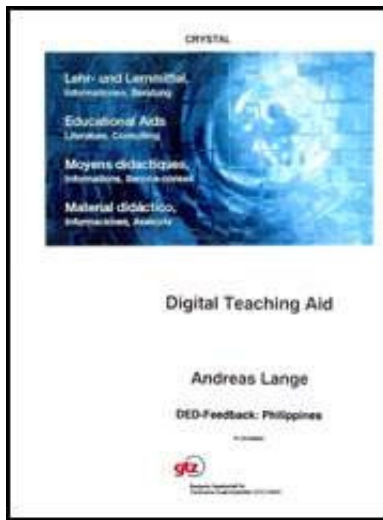
### No. 3 Design a JK Flip Flop with NAND and AND gates.

- Logic circuit
- Truth table

### No. 4 Design a D Flip Flop. Use only NAND gates.

- Logic circuit
- Truth table

[Home](#) > [ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#)



## Digital Teaching Aid (DED Philippines, 86 p.)

### Counter - Lesson 8

#### Lesson Plan

 (*introduction...*)

 Introduction

 Asynchronous counter

 Synchronous counter

 Seven segment indicator and decoder

 Worksheet No. 8

## Digital Teaching Aid (DED Philippines, 86 p.)

### Counter - Lesson 8

#### Lesson Plan

#### Titel: Counter

#### Objectives:

- Understand the principle of asynchronous and synchronous counter
- Able to design asynchronous counter
- Know the seven segment principle

<b>Time</b>	<b>Method</b>	<b>Topic</b>	<b>Way</b>	<b>Remark</b>
		* Review Lesson 7		
		* Introduction		
		* Asynchronous counter		
		- Timing diagram		
		- Truth table		
		- Countdown mode		
		* Synchronous counter		
		* Seven Segment Indicator and Decoder		
		- Common anode indicator		
		- Common cathode indicator		
		- Seven segment decoder		
		* Review Exercise		Worksheet No. 8
	S: Speech D: Discussion Q/A: Question/Answer F: Exercise		B: Boardscript P: Picture Ex: Example HO: Hands-On WS: Worksheet	

## **Introduction**

### **Counter**

**Counters are beside the logic operations the basic elements of all digital controls.**

**Since the clock pulses occur at known intervals, the counter can be used as an instrument for measuring time and therefore period or frequency.**

**On principle there are two counting organisations:**

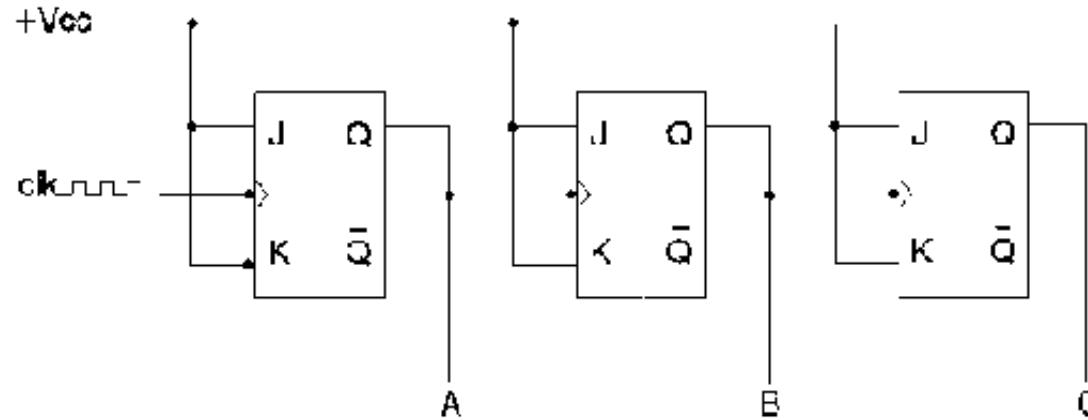
**- Asynchronous (serial, ripple) counter**

**Each Flip-Flop is triggered by the previous Flip-Flop, and thus the counter has a cumulative settling time. (Delay time,  $t_p$ )**

**- Synchronous (parallel) counter**

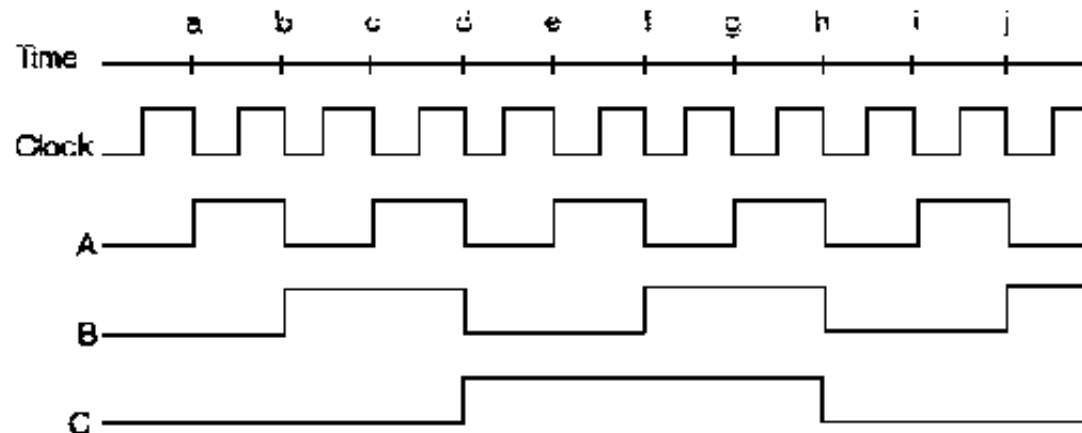
**Here, every Flip-Flop is triggered by the clock (synchronous), and thus the settling time is simply equal to the delay time of a single Flip-Flop.**

### **Asynchronous counter**



**Fig. 8-1: Asynchronous counter with JK-MS-FF in toggle mode**

**To understand how this counter works lets have a look at the timing diagram:**



**Fig. 8-2: Timing diagram, asynchronous mod 8 counter**

**The frequency of waveform C is one half that at B, but is only one-eighth the clock frequency.**

**The FF's are negative edge triggered, hence output signals change only at the falling side of the clock pulse.**



**Fig. 8-3: Truth table, asynchronous mod 8 counter**

CLK transition	C	B	A
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1
0	0	0	0

**A three Flip-Flop counter is often referred to as a mod 8 (modulus 8) counter since it has 8 states.**

$2^3 = 8$  output conditions *(The exponent equals to the number of Flip-Flops)*

**The largest decimal number which is represented by a 3 Flip-Flop counter is:**

$$2^3 - 1 = 7$$

In general:  $2^n - 1$

### Count Down mode

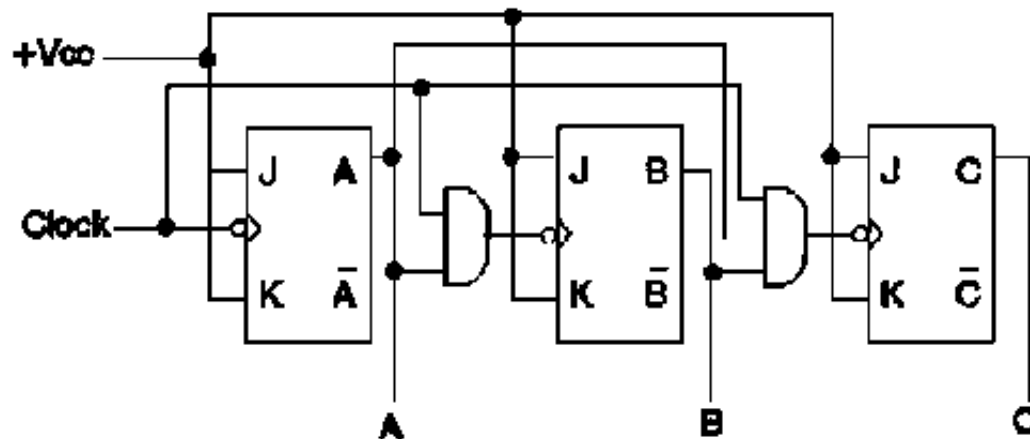
**Switching the clock inputs of each Flip-Flop to the  $\bar{Q}$  outputs causes the counting sequence to start at 111 down to 000.**

**HO: How many Flip-Flops are required to construct a mod-128 counter? A mod-32? What is the largest decimal number that can be stored in a mod-64 counter?**

**Solution:**

- \* mod-128 must have 7 Flip-Flops ( $2^7 = 128$ )
- \* mod-32 must have 5 Flip-Flops
- \* mod-64, the largest decimal number is 63

**Synchronous counter**



***Fig. 8-4: Synchronous counter, with JK-MS-FF in toggle mode***

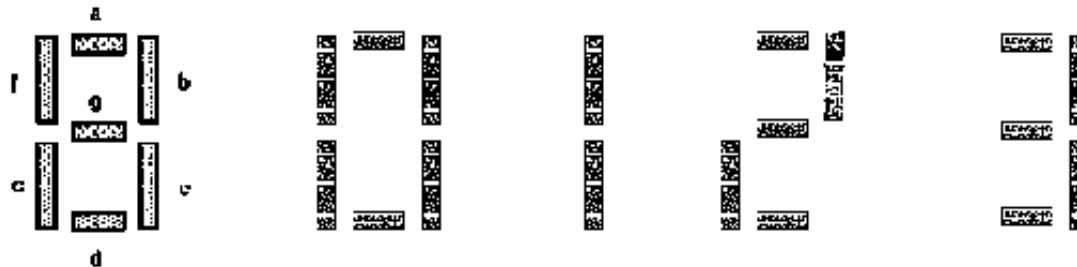
**The negative clock transition is the mechanism that toggles each FF. Therefore, whenever a Flip-Flop changes state, it toggles at exactly the same time as all the other Flip-Flops. In other words, all Flip-Flops change state in synchronism. This**

**advantage needs an increase in hardware (additional gates), hence the asynchronous counter is the cheaper solution for time uncritical applications.**

## **Seven segment indicator and decoder**

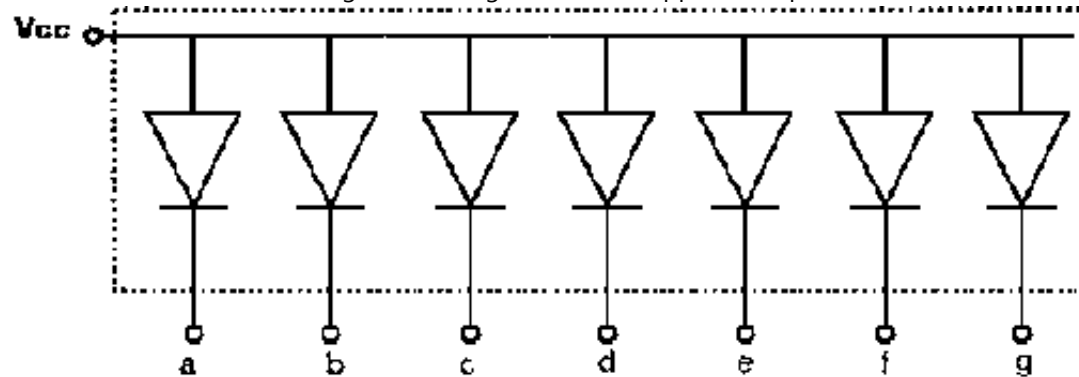
### **Seven segment indicators**

**Seven segment indicators are made by seven LED's. LED's are light emitting diodes. (LED function: Free electrons recombine with holes near the junction. As the free electrons "fall" from a higher energy level to lower one, they give up energy in form of heat and light)**



***Fig. 8-5: seven LED's labeled a through g***

**Depending on which LED's are light up it is possible to indicate decimal numbers from 0 to 9.**

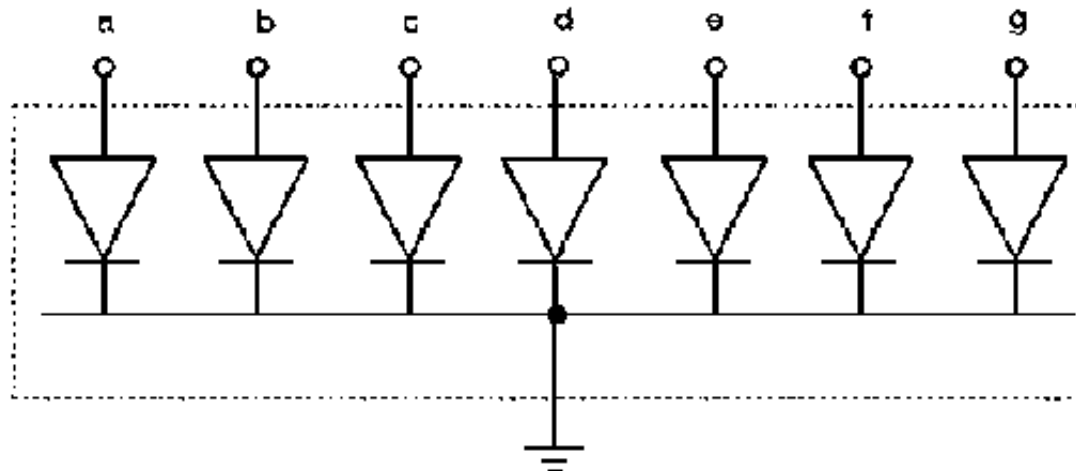


**Fig. 8-6: Seven segment indicator, common anode type**

**Two types of indicators are available:**

- common anode
- common cathode

**The diodes are controlled by ground (common anode) or by 5V (common cathode).**



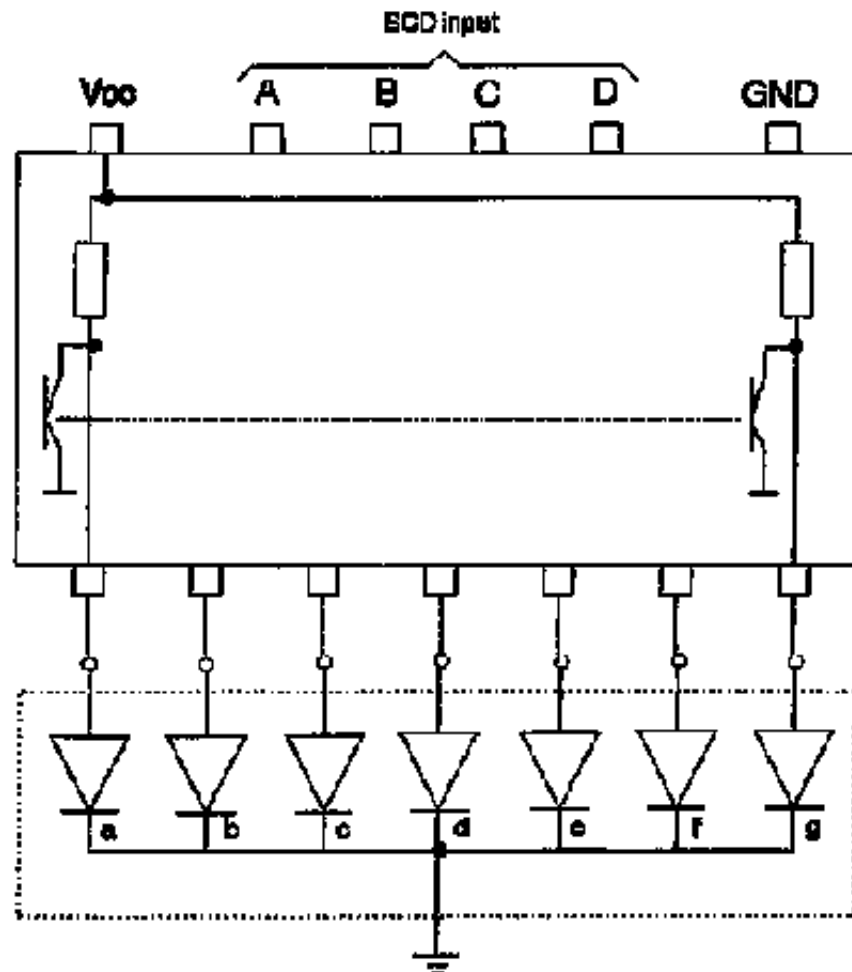
**Fig. 8-7: Seven segment indicator, common cathode type**

## Seven segment decoder

Seven segment decoder are devices to drive seven segment indicators.

Ex: The 7448

(see Fig. 8-8 on the next page)



**Fig. 8-8: Seven segment indicator and decoder**

**The 7448 is a decoder to drive common cathode indicators.**

**When the BCD input is set to:**

$$\mathbf{A\ B\ C\ D = 0\ 1\ 0\ 0}$$

**The internal logic of the decoder forces the LED's b, c, f, and g to conduct.**

**Worksheet No. 8**

**No. 1 Draw the logic diagram, truth table, and the waveform for a three flip-flop serial counter that uses JK master slave flip-flops sensitive to positive clock transition.**

**No. 2 Determine the number of possible states in a counter composed of the following number of flip-flops:**

- a) 5
- b) 8
- c) 11

**No. 3 Draw the logic diagram, truth table, and waveforms for a two flip-flop serial counter operating in the count down mode.**

**No. 4 Design the internal logic circuit for the 7448 (seven segment decoder for the common cathode indicator).**

**No. 5 Sketch the logic circuit for the following seven segment indicators:**

- a) common cathode type
- b) common anode type

[Home](#) > [ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#)



## Digital Teaching Aid (DED Philippinen, 86 p.)

### Data Processing Circuits - Lesson 9

#### Lesson Plan

 *(introduction...)*

 Introduction

 Multiplexer

 Demultiplexer

 Handout No. 3

 Worksheet No. 9

**Digital Teaching Aid (DED Philippinen, 86 p.)**

**Data Processing Circuits - Lesson 9**

**Lesson Plan**

**Titel: Data Processing Circuits**

**Objectives:**

- **Understand the principle of multiplexer and demultiplexer**
- **Able to use the multiplexer solution as design method**

<b>Time</b>	<b>Method</b>	<b>Topic</b>	<b>Way</b>	<b>Remark</b>
		* Review Lesson 8		
		* Introduction		
		* Multiplexer		
		- Principle and logic circuit		
		-The 74 150		
		- Multiplexer design	HO	Handout No. 3
		* Demultiplexer		
		- Principle and logic circuit		
		-The 74 154		
		* Review exercise	WS	Worksheet No. 9
	S: Speech D: Discussion Q/A: Question/Answer E: Exercise		B: Boardscript P: Picture Ex: Example HO: Hands-On WS: Worksheet HT: Hand-Out	

## **Introduction**

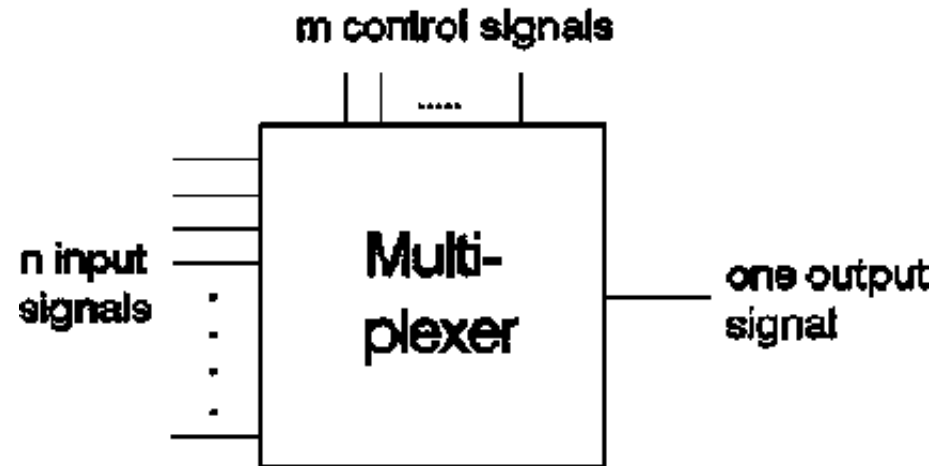
## **Data Processing Circuits**



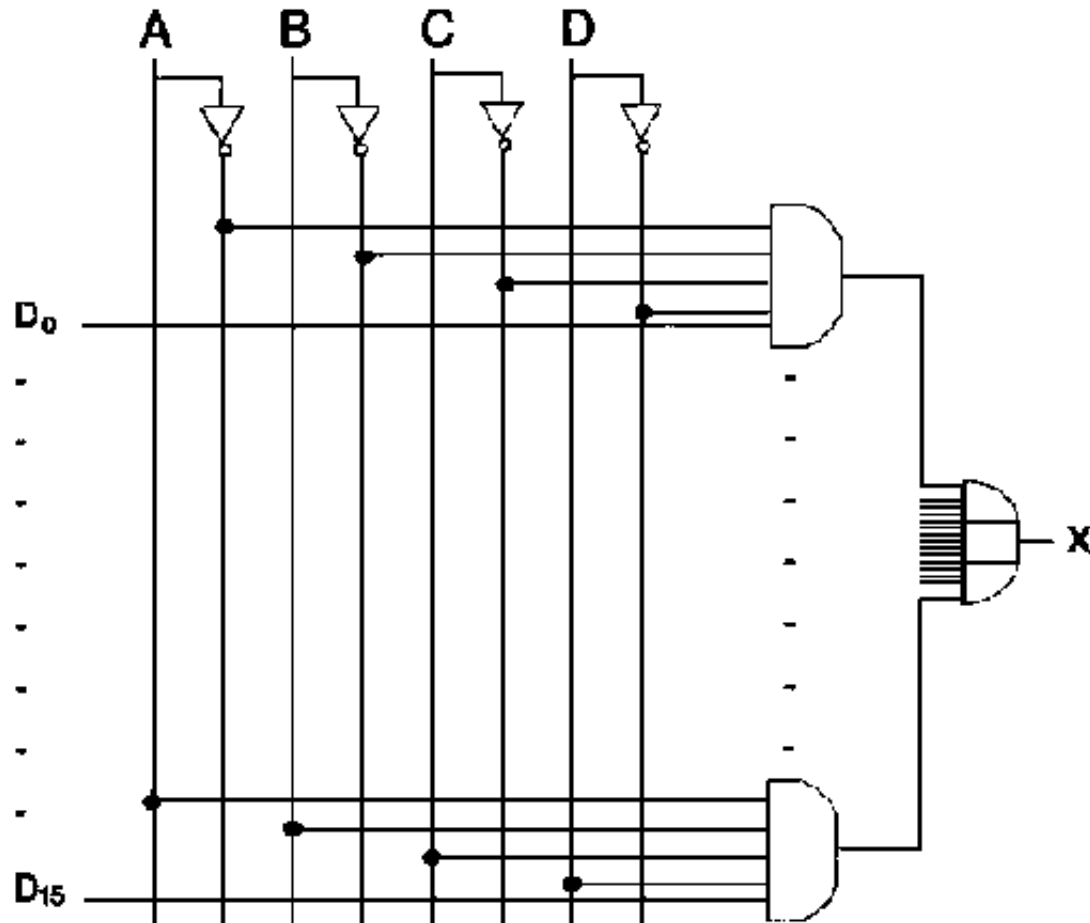
## Data processing circuits: Logic circuits that process binary data.

### Multiplexer

A multiplexer is a circuit with many inputs but only one output.



**Fig. 9-1: Multiplexer**



**Fig. 9-2: Logic circuit, 16 to 1 multiplexer**

**A multiplexer is also called a data selector because the output bit depends on the input data that is selected. The input bits are labeled  $D_0$  to  $D_{15}$ . Only one of them is transmitted to the output. Which one depends on the value of A B C D, the control input.**

Ex: If A B C D = 0 0 0 0

the output will be:

$$\rightarrow Y = D_0$$

So the input bit  $D_0$  is selected.

Or if  $A B C D = 1 1 1 1$

$$\rightarrow Y = D_{15}$$

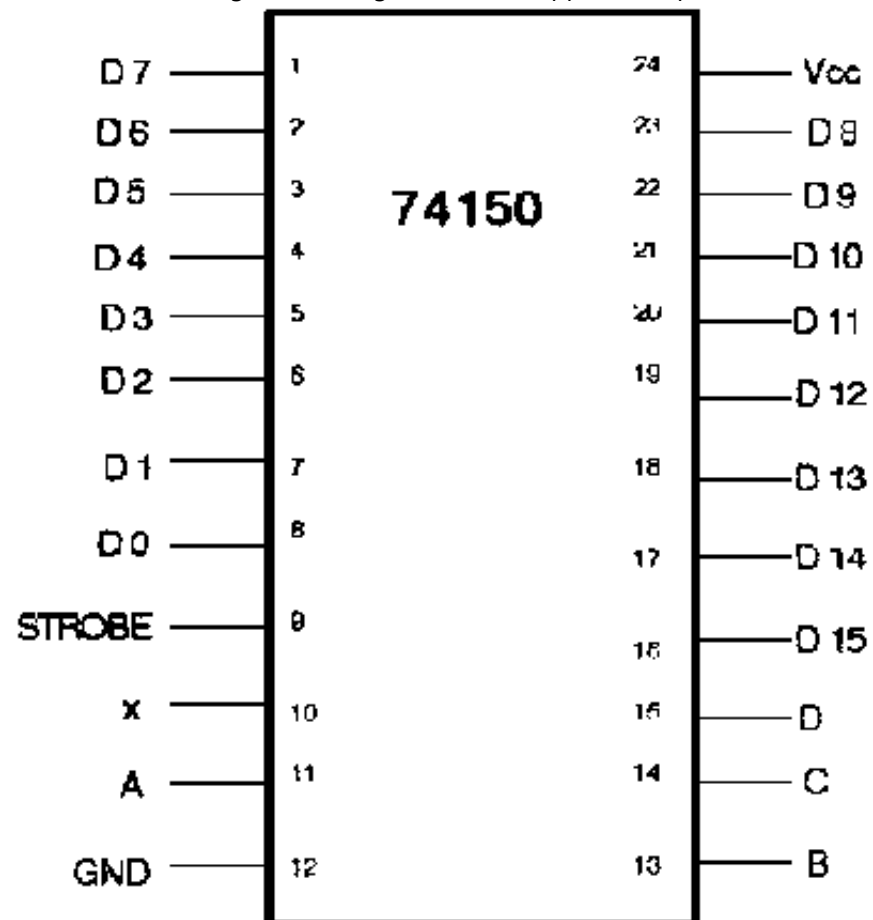
**The control nibble (nibble = 4 bit)  $A B C D$  determines which of the input data bits is transmitted to the output.**

### **The 74 150**

**The TTL device 74 150 is a 16 to 1 multiplexer with inverted output. (see Fig. 9-2, instead of a OR gate, a NOR gate is used to invert the output)**

**Ex: When  $A B C D = 1 0 0 1$**

$$X = \overline{D_9}$$



**Fig. 9-3: Pinout diagram, 74150 16 to 1 multiplexer**

**Pin 9 (STROBE) is an input signal that disables or enables the multiplexer.**

**Fig. 9-4: Truth table, 74 150**

STROBE	A	B	C	D	X
L	0	0	0	0	$\bar{D}_0$
L	0	0	0	1	$\bar{D}_1$

L	0	0	1	0	$\overline{D}_2$
L	0	0	1	1	$\overline{D}_3$
L	0	1	0	0	$\overline{D}_4$
L	0	1	0	1	$\overline{D}_5$
L	0	1	1	0	$\overline{D}_6$
L	0	1	1	1	$\overline{D}_7$
L	1	0	0	0	$\overline{D}_8$
L	1	0	0	1	$\overline{D}_9$
L	1	0	1	0	$\overline{D}_{10}$
L	1	0	1	1	$\overline{D}_{11}$
L	1	1	0	0	$\overline{D}_{12}$
L	1	1	0	1	$\overline{D}_{13}$
L	1	1	1	0	$\overline{D}_{14}$
L	1	1	1	1	$\overline{D}_{15}$
H	X	X	X	X	H

**With high STROBE the value of A B C D doesn't matter, the output will allways be high.**

### **Multiplexer Logic (Multiplexer Design)**

**The starting point for digital design is usually the truth table. We already discussed two standard methods for implementing a truth table:**

- **sum of products method**
- **product of sums method**

**Now we are ready for the third method:**

- **the multiplexer solution**

**The following example explains the multiplexer solution. (Please refer to Handout No. 3)**

**Ex: First we have to complement each output in the truth table (Y), that will be the corresponding data input for the multiplexer:**

$$Y = 1 \rightarrow 0 \rightarrow D_0$$

$$Y = 0 \rightarrow 1 \rightarrow D_1$$

$$Y = 1 \rightarrow 0 \rightarrow D_2$$

$$Y = 1 \rightarrow 0 \rightarrow D_3$$

.

.

.

and so on for every value of Y

**Next, wire the data inputs of the 74 150, so that they equal the foregoing values:**

$D_0 \rightarrow$  grounded

$D_1 \rightarrow$  connected to 5V

$D_2 \rightarrow$  grounded

$D_3 \rightarrow$  grounded

.

.

.

$D_{15} \rightarrow$  grounded

### **Check the circuit:**

**When  $A B C D = 0 0 0 0$**

**$\rightarrow D_0$  is the selected input since  $D_0$  is low.  $Y$  is high**

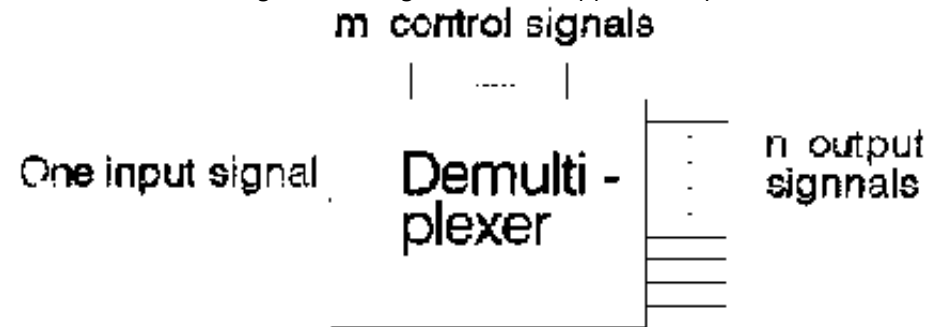
**Please check also the remaining input possibilities!**

### **Universal logic circuit**

**The 74 150 can be used as a design solution for any 4 variable truth table.**

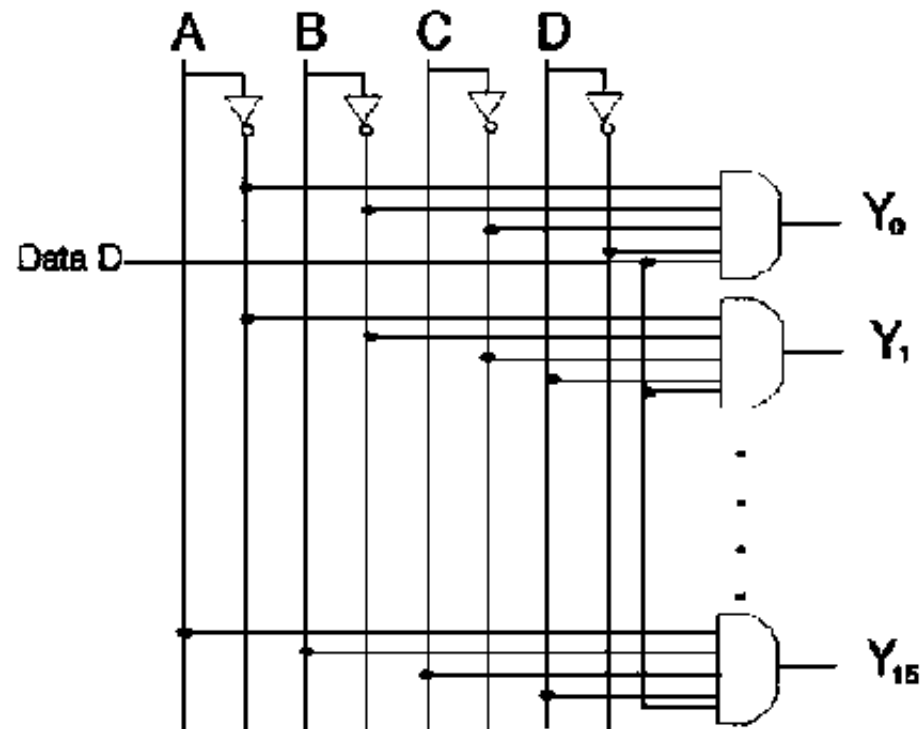
### **Demultiplexer**

**A demultiplexer is a circuit with only one input but many outputs.**



**Fig. 9-5: Demultiplexer**

**By applying control signals, we can steer the input signal to one of the output lines.**



**Fig. 9-6: Logic circuit, 1 to 16 demultiplexer**



## The 74 154

**The 74 154 is a 1 to 16 demultiplexer, with active low STROBE and DATA input.**

***Fig. 9-7: Truth table, 74 154 1 to 16 demultiplexer***

STROBE	DATA	A	B	C	D	Y
L	L	0	0	0	0	Y0
L	L	0	0	0	1	Y1
L	L	0	0	1	0	Y2
L	L	0	0	1	1	Y3
L	L	0	1	0	0	Y4
L	L	0	1	0	1	Y5
L	L	0	1	1	0	Y6
L	L	0	1	1	1	Y7
L	L	1	0	0	0	Y8
L	L	1	0	0	1	Y9
L	L	1	0	1	0	Y10
L	L	1	0	1	1	Y11
L	L	1	1	0	0	Y12
L	L	1	1	0	1	Y13
L	L	1	1	1	0	Y14
L	L	1	1	1	1	Y15

L	H	X	X	X	X	H
H	L	X	X	X	X	H
H	H	X	X	X	X	H

## Handout No. 3

### Example for Multiplexer Solution

**Problem:** Design a logic circuit for the problem which is given through the truth table below. Use a 74150 to implement this table:

A	B	C	D	Y
0	0	0	0	1
0	0	0	1	0
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	0
0	1	1	1	0
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1

1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	0
1	1	1	1	1

**Solution: Complement each Y output to get the corresponding data input:**

$$D0 = 1 = 0$$

$$D1 = 0 =$$

$$D2 =$$

$$D3 =$$

**D**

**D**

**D**

**D**

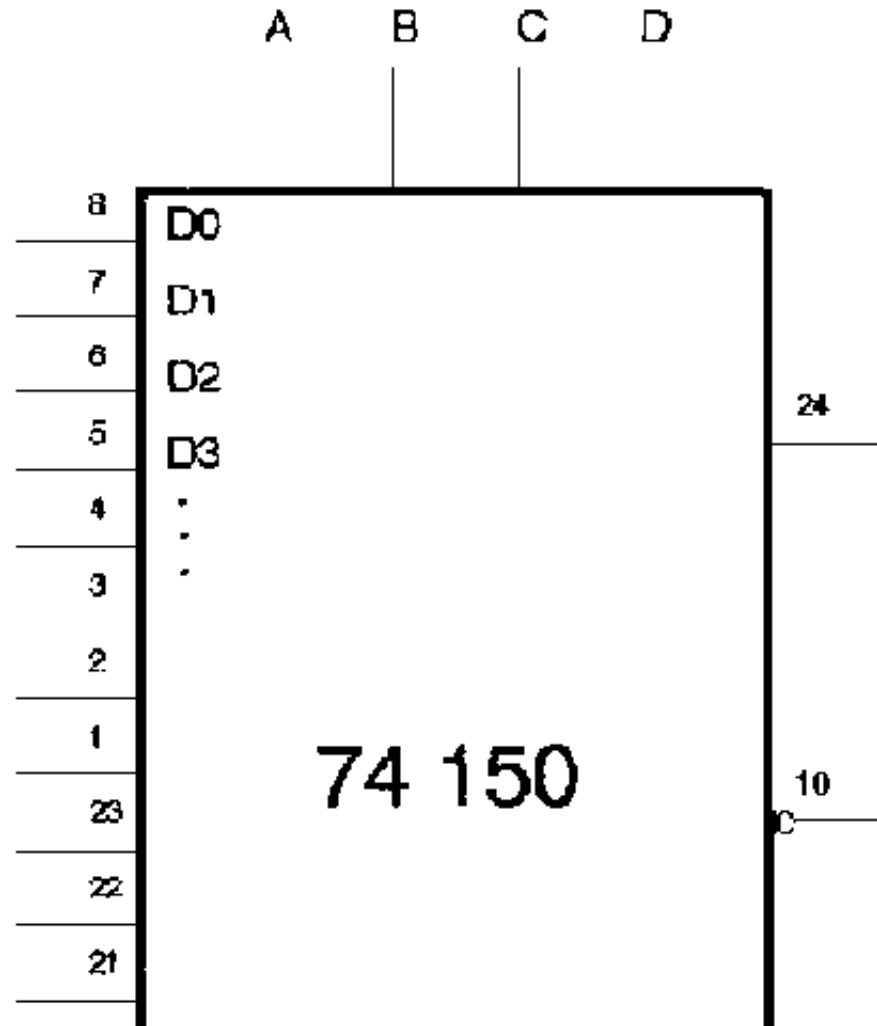
**D**

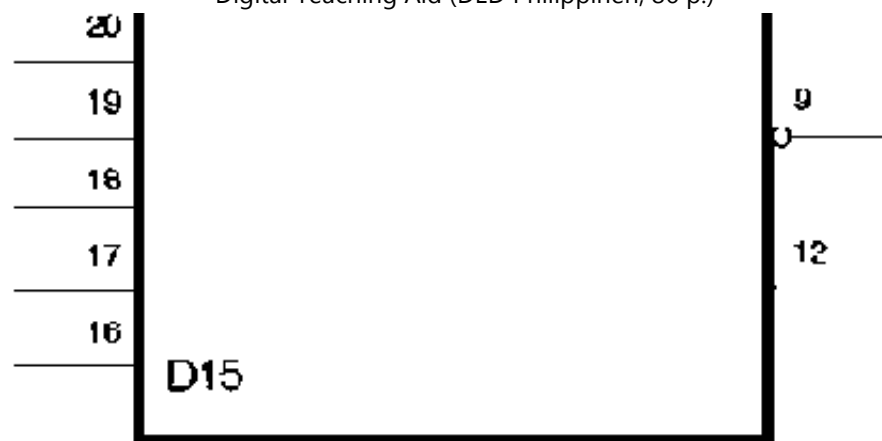
**D**

**D**

**D**  
**D**  
**D**  
**D**  
**D15=**

**Connect: the chip in response to the list of corresponding data inputs:**





Figure

## Universal Logic Circuit

This circuit is an example of multiplexer logic. You ..... an input data pin when the corresponding output is ..... in the truth table.

You connect an input data pin to ..... if the corresponding output is..... in the truth table.

## Worksheet No. 9

No. 1 In Fig. 9-1, if

- a) A B C D = 0 1 1 0
- b) A B C D = 1 0 0 1
- c) A B C D = 1 1 0 1

what does Y equal?

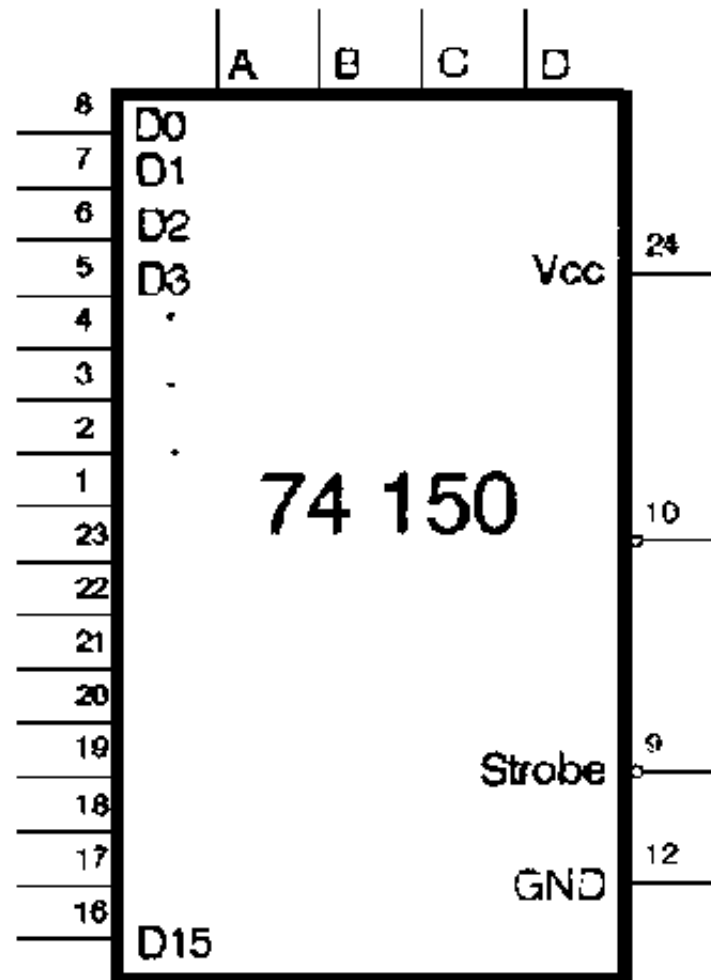


Fig. 9-1: 74 150, 16 to 1 multiplexer

**No. 2** Show how to connect a 74150 (use Fig. 9-1) to implement the following Boolean equation:

$$Y = \bar{A}\bar{B}\bar{C}D + \bar{A}BCD + \bar{A}BC\bar{D}$$

**No. 3** Draw a circuit with two 74150's that has the truth table like the following

**one:**

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>Y<sub>1</sub></b>	<b>Y<sub>2</sub></b>
0	0	0	0	0	0
0	0	0	1	1	0
0	0	1	0	0	0
0	0	1	1	0	1
0	1	0	0	0	0
0	1	0	1	1	1
0	1	1	0	1	1
0	1	1	1	1	1
1	0	0	0	0	1
1	0	0	1	1	0
1	0	1	0	1	0
1	0	1	1	1	0
1	1	0	0	0	0
1	1	0	1	1	0
1	1	1	0	1	1
1	1	1	1	0	0



[Home](#) [ar](#) [cn](#) [de](#) [en](#) [es](#) [fr](#) [id](#) [it](#) [ph](#) [po](#) [ru](#) [sw](#)



## Digital Teaching Aid (DED Philippinen, 86 p.)

 **(introduction...)**

 **Preface**

 **Introduction**

 **Fundamental Logic Operations - Lesson 1**


 **Introduction Boolean Algebra - Lesson 2**

 **Circuit Analysis and Design - Lesson 3**

 **First Evaluation**

 **Karnaugh Mapping - Lesson 4**

 **Karnaugh Mapping II - Lesson 5**

 **Coding - Lesson 6**

 **Flip-Flops - Lesson 7**

 **Second Evaluation**

 **Counter - Lesson 8**

 **Data Processing Circuits - Lesson 9**

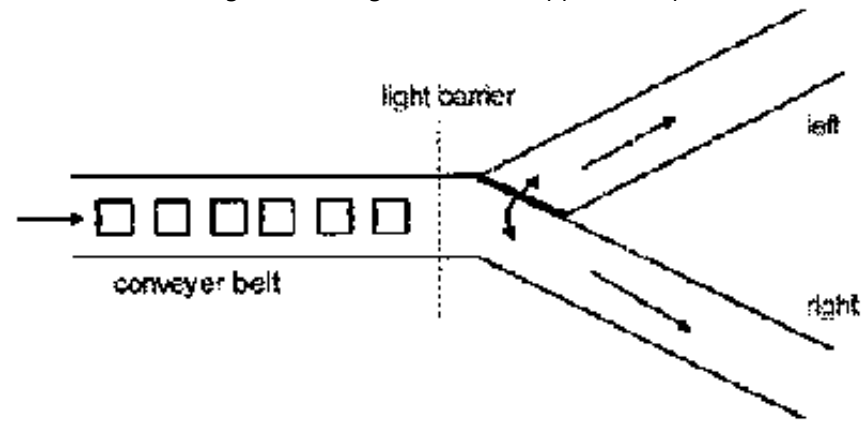
  **Third Evaluation**

 **Answers to Evaluation Problems**

### Third Evaluation

**No. 1 At a distribution point of a conveyer belt a flap which is controlled by a counter circuit is to divert arriving piece-goods always six to the left and four to the right.**





**Fig. 1**

**The counting pulses T are supplied by a light barrier immediately before the diverting flap. The flap opens the way to the left if the control instructions are  $x = 1, y = 0$  and to the right when  $x = 0, y = 1$**

**Develop the truth table. Use the sum of product method. For the simplification use a Karnaugh map. Design the logic circuit.**

**Take a decimal counter with four output lines ( $2^0, 2^1, 2^2, 2^3$ ).**

**No. 2 Sketch an asynchronous mod 16 counter. Use JK-MS flip flops.**

**No. 3 Show how to connect a 74150 multiplexer (Fig. 2) to implement the following boolean equation:**

$$y = \bar{A}B\bar{C}D + A\bar{B}C\bar{D} + ABC\bar{D}$$

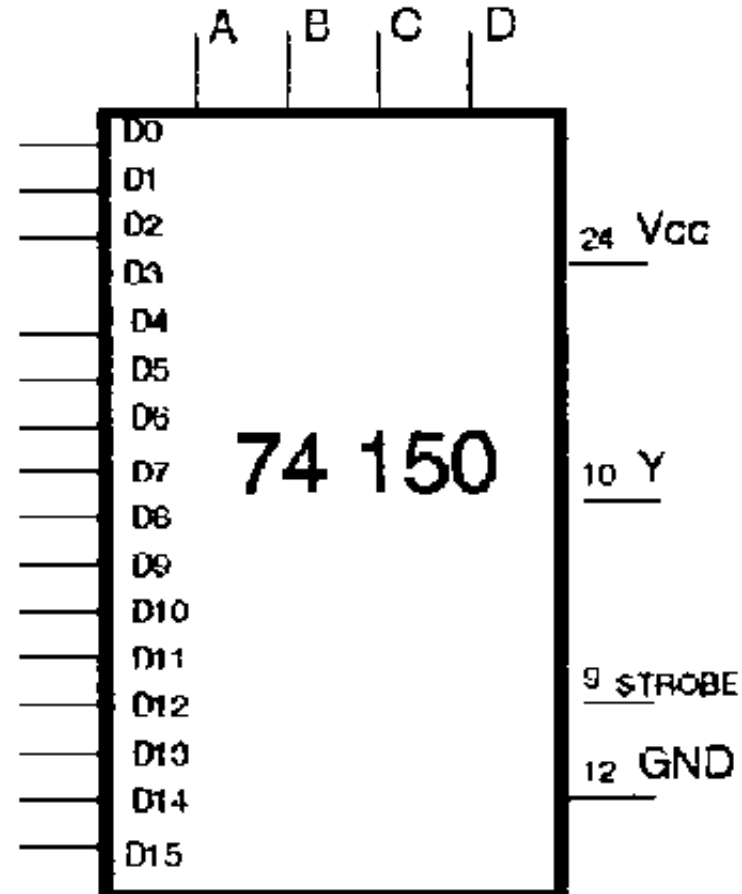


Fig. 2

**No. 4** Input signals R and T are low in Fig. 3. Which is the active output line when A B C D = 0011?

**No. 5** To get the y<sub>9</sub> output line active in Fig. 3, what are the input signals you need?

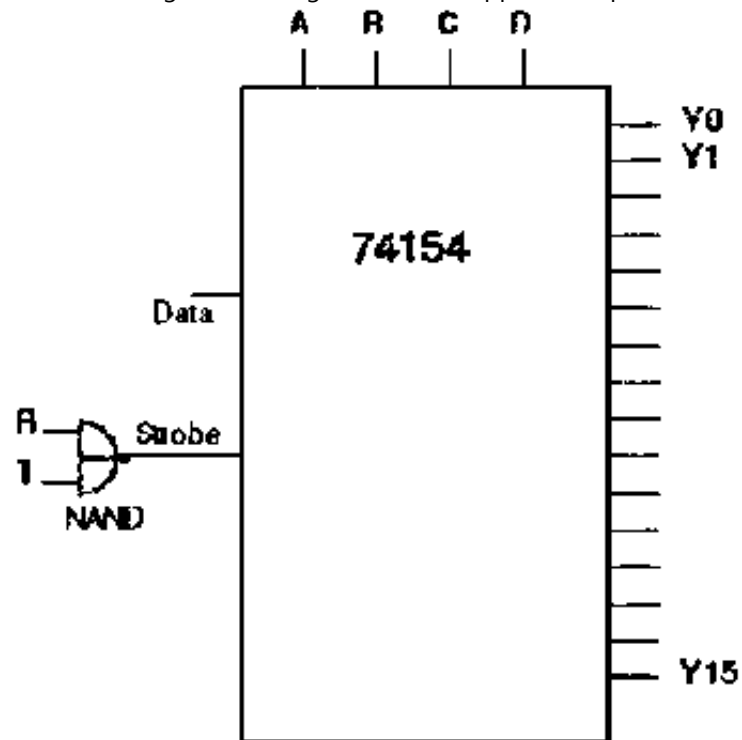


Fig. 3

[Home](#) > [ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#)

 **Digital Teaching Aid (DED Philippines, 86 p.)**

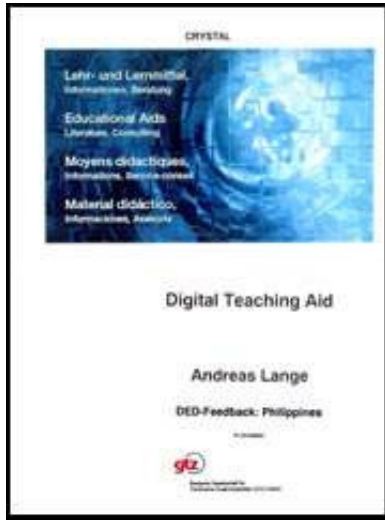
 **(introduction...)**

 **Preface**

 **Introduction**

 **Fundamental Logic Operations - Lesson 1**

 **Introduction Boolean Algebra - Lesson 2**



- 📁 **Circuit Analysis and Design - Lesson 3**
- 📄 **First Evaluation**
- 📁 **Karnaugh Mapping - Lesson 4**
- 📁 **Karnaugh Mapping II - Lesson 5**
- 📁 **Coding - Lesson 6**
- 📁 **Flip-Flops - Lesson 7**
- 📄 **Second Evaluation**
- 📁 **Counter - Lesson 8**
- 📁 **Data Processing Circuits - Lesson 9**
- 📄 **Third Evaluation**
- ➔📄 **Answers to Evaluation Problems**

## Answers to Evaluation Problems

### First evaluation:

#### No. 1

A	B	C	X	
0	0	0	0	
0	0	1	1	
0	1	0	0	
0	1	1	1	$X = A B + C$
1	0	0	0	

1	0	1	1	
1	1	0	1	
1	1	1	1	

**No. 3**

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

**No. 4**

A	B	C	D	X
0	0	0	0	.
.	.	.	.	.
.	.	.	.	.
1	1	0	1	1
1	1	1	0	1
1	1	1	1	1

$$X = A\overline{B}\overline{C}D + A\overline{B}C\overline{D} + ABCD$$

**No. 5**

$$X = A\bar{B} + \bar{B}D + \bar{B}C + A\bar{C}D + \bar{A}CD$$

## Second evaluation:

### No. 1

A	B	C	X	
0	0	0	0	
0	0	1	0	
0	1	0	0	
0	1	1	1	$Q = AB + AC$
1	0	0	0	
1	0	1	1	
1	1	0	0	
1	1	1	1	

### No. 2

	A	B	C	T	U	V	W	X	Y	Z
0	0	0	0	X	X	X	X	X	X	X
1	0	0	1	0	0	0	1	0	0	0
2	0	1	0	1	0	0	0	0	0	1
3	0	1	1	1	0	0	1	0	0	1
4	1	0	0	1	0	1	0	1	0	1

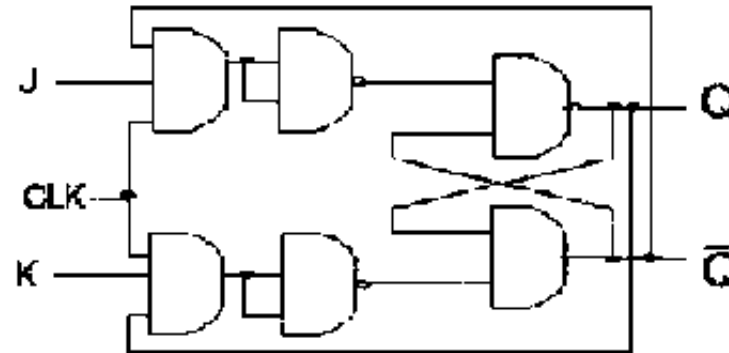
5	1	0	1	1	0	1	1	1	0	1
6	1	1	0	1	1	1	0	1	1	1
7	1	1	1	x	x	x	x	x	x	x

$$T = Z \quad T = B + A \quad V = A$$

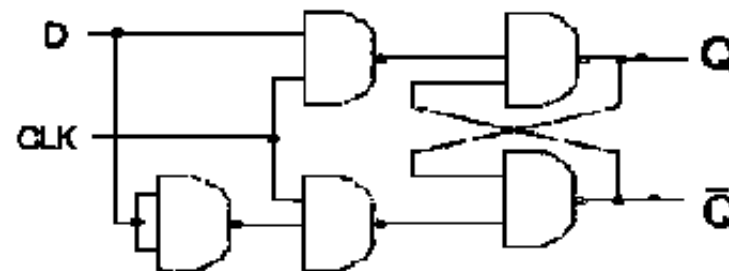
$$U = Y$$

$$V = X \quad U = AB \quad W = C$$

## Second evaluation:



**No. 3**



**No. 4**

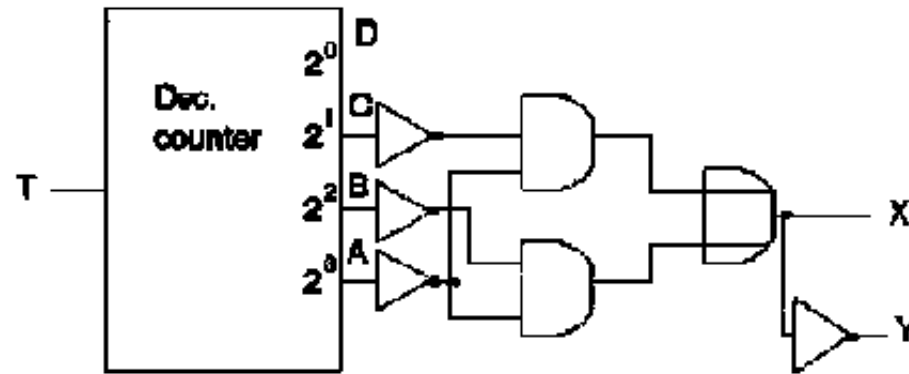
**Third evaluation:****No. 1**

clock	A	B	C	D	X	Y	
0	0	0	0	0	1	0	
1	0	0	0	1	1	0	
2	0	0	1	0	1	0	
3	0	0	1	1	1	0	
4	0	1	0	0	1	0	
5	0	1	0	1	1	0	
6	0	1	1	0	0	1	
7	0	1	1	1	0	1	
8	1	0	0	0	0	1	
9	1	0	0	1	0	1	
	Don't care conditions						

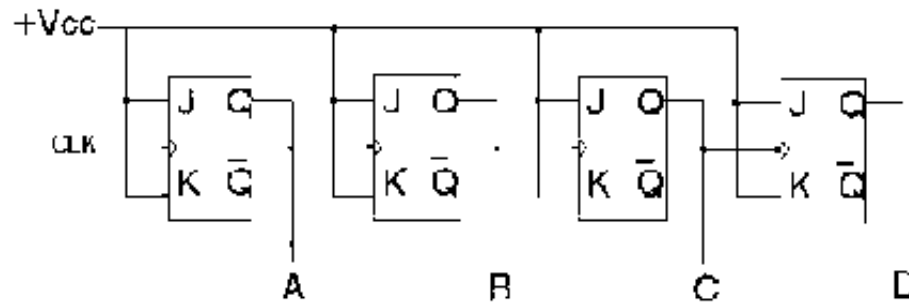
$$X = \overline{A}\overline{B} + \overline{A}\overline{C}$$

$$Y = \overline{X}$$





Figure

No. 2No. 3

- Connect Vcc to 5V
- Connect GND and Strobe to ground
- Connect D5, D10, and D14 to ground
- Connect all other D inputs to 5V

No. 4

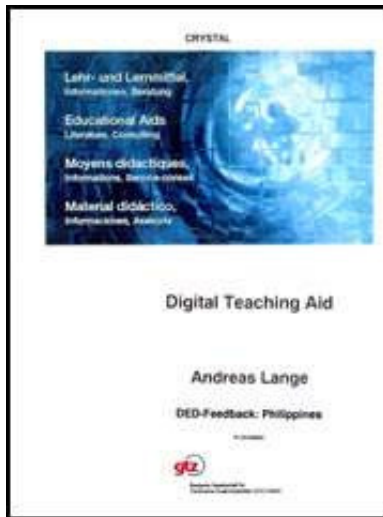

**No output line is active, chip is disabled → Strobe is high!**





**No. 5**

**-R and T → high**  
**-ABCD = 1001**



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 **Digital Teaching Aid (DED Philippinen, 86 p.)** **(introduction...)**  **Preface** **Introduction** **Fundamental Logic Operations - Lesson 1** **Introduction Boolean Algebra - Lesson 2** **Circuit Analysis and Design - Lesson 3** **First Evaluation** **Karnaugh Mapping - Lesson 4** **Karnaugh Mapping II - Lesson 5** **Coding - Lesson 6** **Flip-Flops - Lesson 7** **Second Evaluation**

-  **Counter - Lesson 8**
-  **Data Processing Circuits - Lesson 9**
-  **Third Evaluation**
-  **Answers to Evaluation Problems**

## **Preface**

**Nearly two years ago the German Development Service (DED) offered me the possibility to assist a technical college in the Philippines.**

**I had finished my studies in electronic engineering in Germany and had gained several years of working experience in the development of medical electronic equipment and the organization of telecommunication units.**

**Since I have been assigned with the Don Bosco Technical College, I have been teaching in electronics, computer science, and have been working in the training for instructors.**

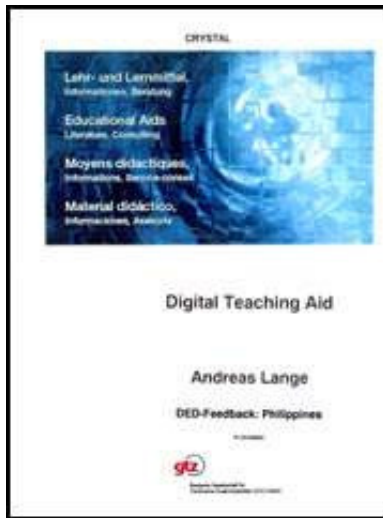
**One of the mayor problems I encountered was the lack of preparation time for the lessons. Many teachers are under steady time pressure because they have to serve two or more jobs in order to earn the adequate income. That gave me the idea to develop a ready-made lesson preparation for teachers.**

**Based on my experience and also due to the visit of many other schools I edited and compiled this Teaching Aid. I tried to integrate practice and theory which is the best way to provide a solid foundation. I hope this will support the teachers as well as it can improve the quality of classes.**

# Canlubang, Philippines February 1994

Andreas Lange

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## Digital Teaching Aid (DED Philippinen, 86 p.)

 *(introduction...)*

 Preface

  Introduction

 Fundamental Logic Operations - Lesson 1


 Introduction Boolean Algebra - Lesson 2

 Circuit Analysis and Design - Lesson 3

 First Evaluation

 Karnaugh Mapping - Lesson 4

 Karnaugh Mapping II - Lesson 5

 Coding - Lesson 6

 Flip-Flops - Lesson 7

 Second Evaluation

 Counter - Lesson 8

 Data Processing Circuits - Lesson 9



## **Third Evaluation Answers to Evaluation Problems**

### **Introduction**

**This Teaching Aid is addressed to teachers and schools which offer any kind of electronic courses (i.e. computer maintenance, machine control, radio and tv repair, etc). It provides the basic knowledge for technicians as well as it can be used to run basic courses at technical colleges.**

**Digital Teaching Aid is a teaching module made for teachers. It is a ready - made lesson preparation and not a textbook. Therefore, you (the teacher) should already have some background knowledge on digital electronics. This module gives you all the material you need to run a course in basic digital electronics.**

**The module is divided into lessons, each lesson is headed by a lesson plan followed by boardscripts, worksheets, and handouts. It also contains three evaluations which you can use as tests/exams or as advanced exercises. The lesson plans are not only containing the contents of the lesson, but also gives you the objectives and suggested methods and ways to carry out the lesson. The following informs you about the purpose of every lesson plan column:**

- Time** - The 'Time' column is still blank, it is up to you to decide how much time you would like to spend on each topic. The average time per lesson is approximately 90 minutes and 45 minutes for the review exercise (Worksheet).
- Method** - The 'Method' column suggests a sample of teaching methods. Lesson plan 1 and 2 are already filled up to give you an example on how to use this column. I

recommend the use of abbreviations, the meaning of every abbreviation is given at the bottom of every method column.

**Topic** - The 'Topic' column gives you a brief description of the contents of every lesson. Feel free to add or drop some topics. Every topic is handled in the following boardscript pages.

**Way** - The 'Way' column suggests a sample of teaching tools. Lesson plan 1 and 2 are already filled up. The explanation for the abbreviation used is given at the bottom of every way column. The boardscript pages of every lesson contain examples (EX) and hands on (HO) exercises. The HO's should be carried out by the students during the lesson.

**Remark** - The 'Remark' column provides you with space for additional information. (i.e.: Where can I find the transparency/picture which I decided to use, or: What is the filename of the demo program which I already prepared)

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 **Digital Teaching Aid (DED Philippinen, 86 p.)**

  **Fundamental Logic Operations - Lesson 1**

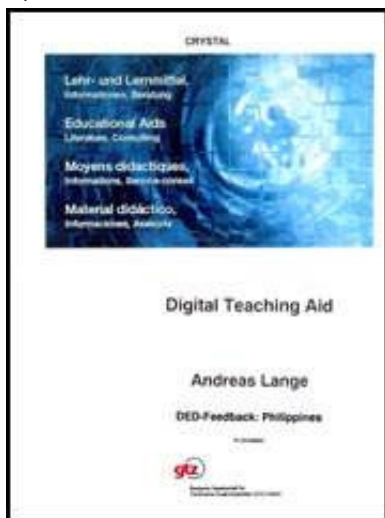
 **Lesson Plan**

 **(introduction...)**

 **Introduction**

 **TTL circuits**

 **Logic operations**



# Handout No. 1

## Worksheet No. 1

### Digital Teaching Aid (DED Philippinen, 86 p.)

### Fundamental Logic Operations - Lesson 1

### Lesson Plan

**Titel: Fundamental Logic Operations**

### Objectives:

- Understand the principle of NOT, AND, OR operations
- Able to convert binary and decimal numbers

Time	Method	Topic	Way	Remark
	S,D	* Introduction	Ex	
		- Analog and digital		

		signals		
	S,Q/A	* Review	B	
		-Transistor in hard saturation		
		- Inverter function		
	S,D	*TTL circuits	B	
		-History		
		- Standards		
	S	* Logic operations	B	
	S,E	-NOT	HO	Handout No. 1 (Family of TTL devices)
	S,E	-AND	EX	
	S,E	-OR	EX	
	E	* Binary number system	WS	Worksheet No. 1
	S: Speech D: Discussion Q/A: Question/Answer E: Exercise		B: Boardscript P: Picture Ex: Example HO: Hands-On WS: Worksheet	



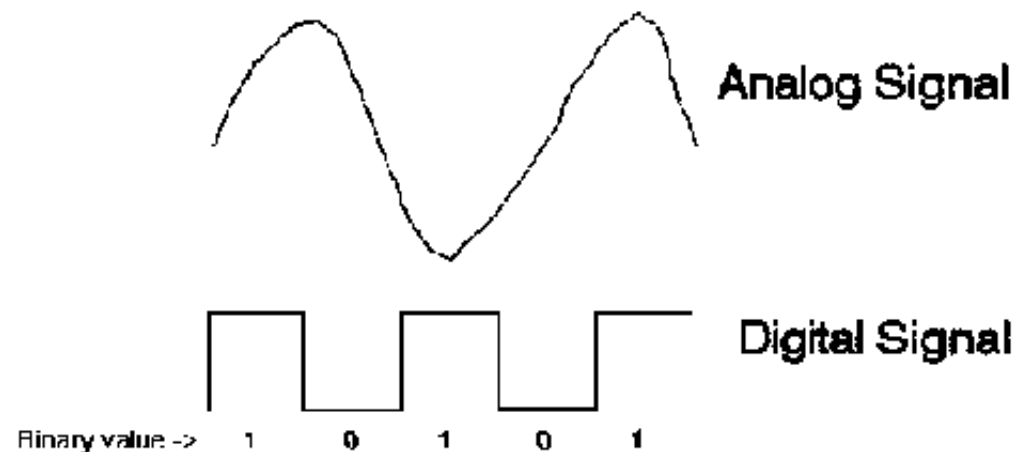
## **Introduction**

## **Fundamental Logic Operations**

## **Digital Electronics**

**The world of electronics is divided into two areas: analog and digital. Analog circuits consist mainly of amplifiers for voltage or current variations that are smooth and continuous. Digital circuits provide electronic switching of voltage pulses. A pulse has abrupt changes between two extreme amplitude levels (i.e.: 5 volt = high level and 0 volt = low level).**

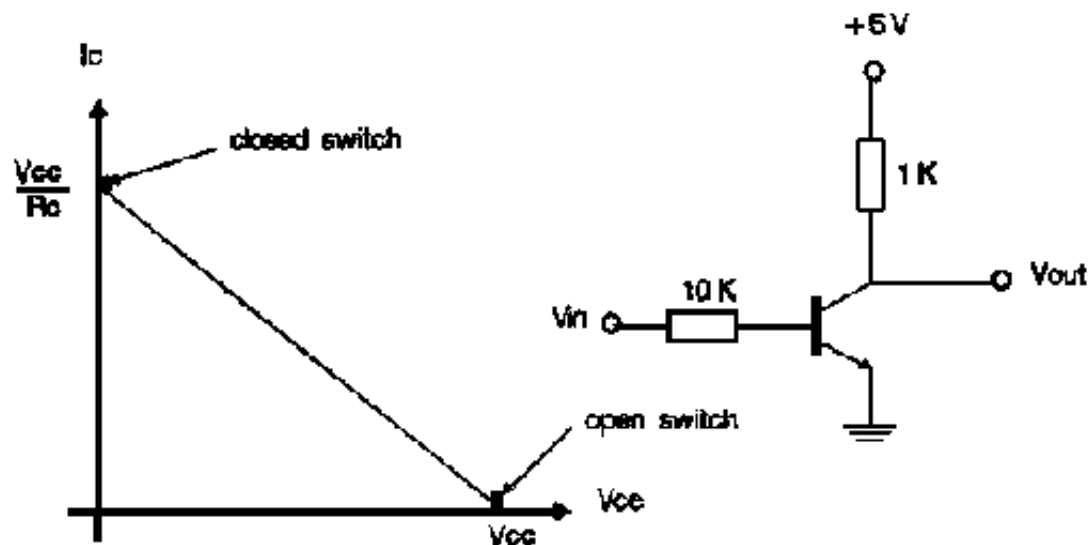
**Since the digital signal has only two significant levels, either high or low, it is useful to represent the pulses in a binary number system with the digits 1 and 0. (see also Worksheet 1, Binary number system)**



**Fig. 1-1: Analog versus digital signals**

## Transistor in digital electronic

**A transistor can be used in analog and digital electronic. In digital electronic the transistor operates usually in hard saturation. (see also Amplifier Teaching Aid, Transistor as switch)**



## ***Fig. 1-2: Load line and circuit for a transistor switch***

### **Hard Saturation**

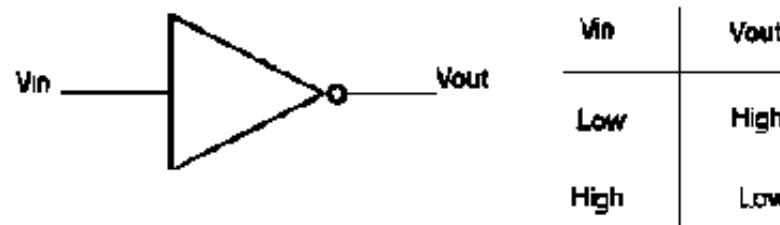
To get hard saturation, a designer makes  $I_C$  approximately 10 times the value of  $I_B$ .

When the max.  $V_{in}$  equals to the supply voltage you can get hard saturation by using a ratio of:

**10:1 for  $R_B/R_C$**

### **Inverter Function**

A transistor switch (circuit as above) can be used to build the first device in digital electronic, the inverter:

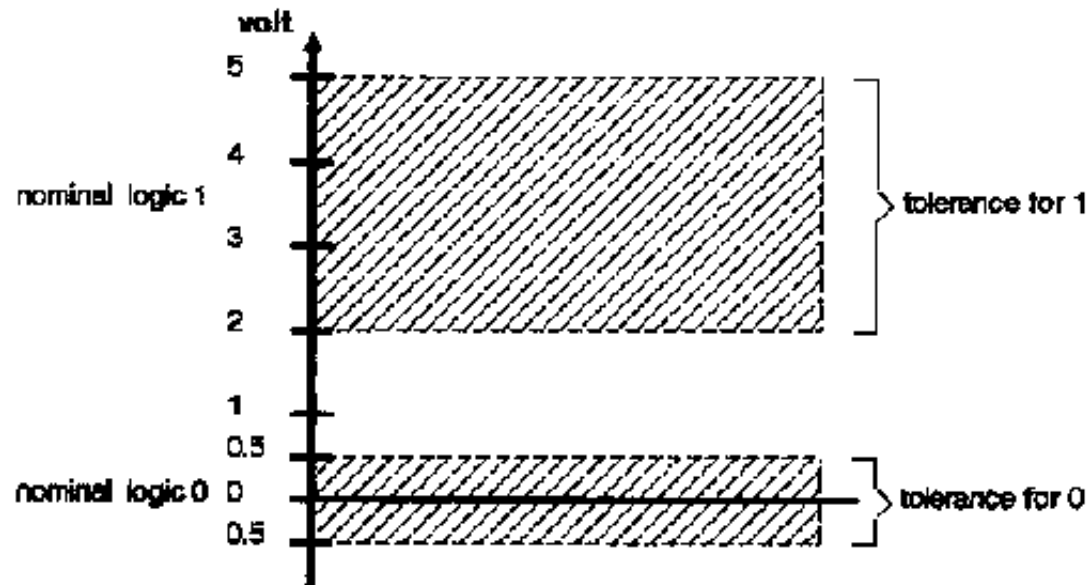


***Fig. 1-3: Inverter symbol and truth table***

Because in digital electronics mainly ready made devices are used (Integrated circuits IC), we don't care any more how the single device is built up. From now on we will use only these ready made devices.

## TTL circuits

**1964 TEXAS Instruments introduced a family of digital devices which became standard elements in digital electronic: The TTL (Transistor Transistor Logic) circuits. The High (1) and Low (0) state is represented by voltage levels.**



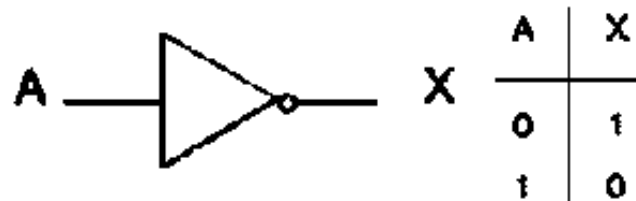
***Fig. 1-4: Voltage levels for high and low state in TTL IC's***

## Logic operations

**All decisions and operations can be realized by means of the three basic operations:**

**NOT, AND, OR**

**NOT (Inverter)**

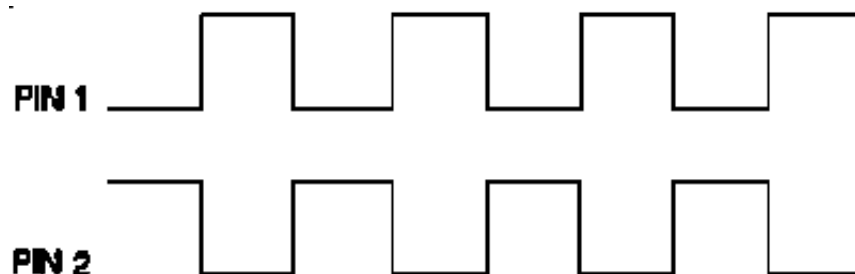


**Fig. 1-5: NOT (Inverter) symbol and truth table**

**Circuit example: 7404 TTL device (see Handout No. 1)**

**HO: A 1KHz square wave drives pin 1 of a 7404. What does the voltage waveform at pin 2 look like?**

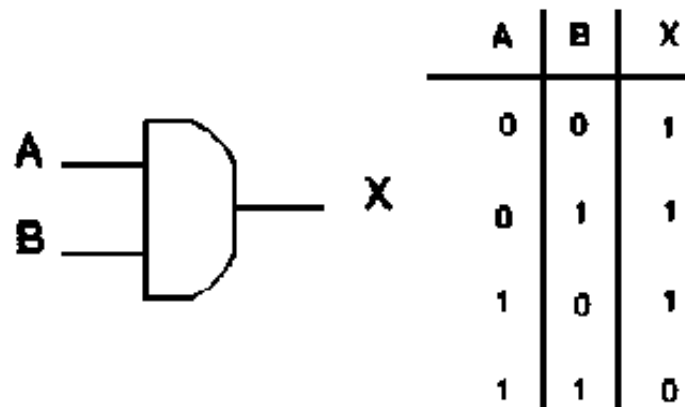
**Solution:**



**Fig. 1-6: Timing diagram, Inverter input (pin 1) and output (pin 2)**

**AND gates**

**AND operation: The output supplies an high (1) signal if to all inputs high (1) signals are applied.**

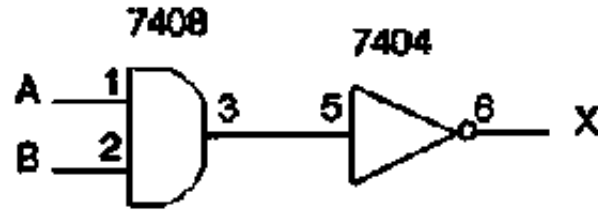


***Fig. 1-6: AND symbol and truth table***

**AND application example: An elevator motor may only start to work if the doors are shut AND an operation occurred.**

**Circuit example: TTL device 7408, two input AND gate**

**Ex: Develop the truth table for the following logic circuit.**



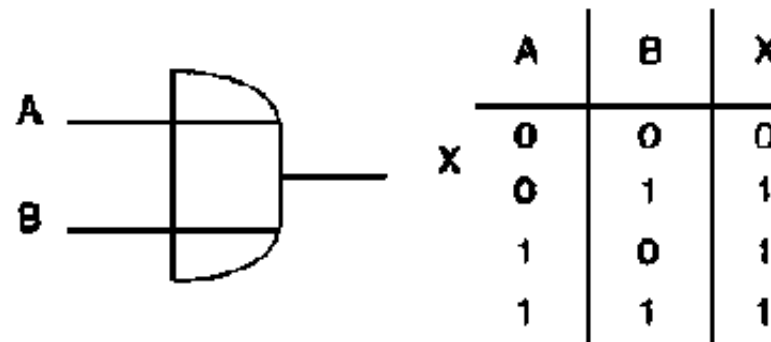
**Solution:**

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

**Fig. 1-8: Logic circuit with truth table**

## OR gates

**OR operation:** An OR operation supplies a high signal at the output if to one or more inputs high signals are applied.

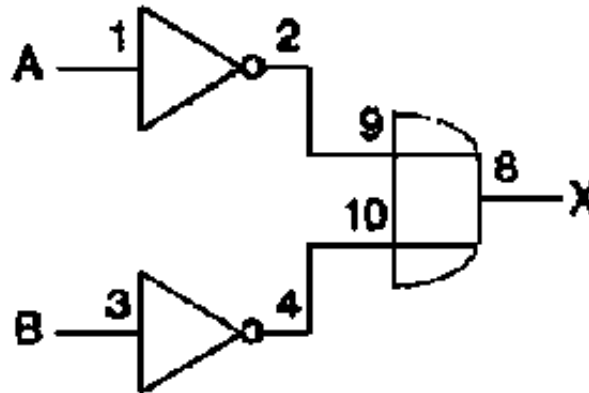


**Fig. 1-9: OR gate, symbol and truth table**

**OR application example:** A pump has to be switched on when the water level has fallen to a certain level **OR** too much water is taken out of the container.

**Circuit example:** TTL device 7432, two input OR gate

**Ex:** Develop the truth table for the following logic circuit.



**Solution:**

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

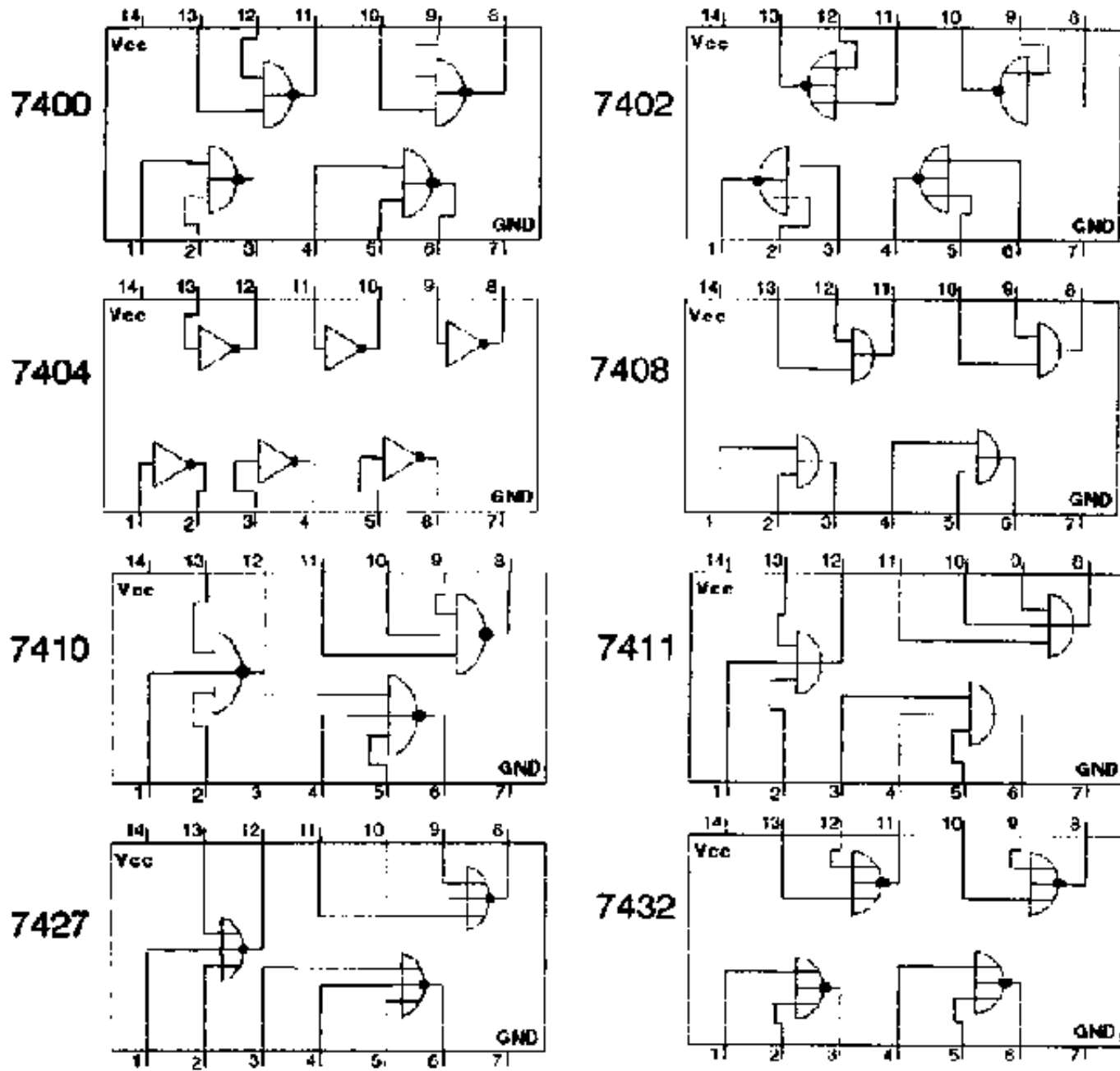
***Fig. 1-10: Logic circuit with truth table***

## Handout No. 1



## **The 7400 Family of TTL Devices (Sample List)**

<b>Device number</b>	<b>Description</b>
7400	Quad 2 input NAND gates
7402	Quad 2 input NOR gates
7404	Hex inverter
7408	Quad 2 input AND gates
7410	Triple 3 input NAND gates
7411	Triple 3 input AND gates
7427	Triple 3 input NOR gates
7432	Quad 2 input OR gates



Figure

## Worksheet No. 1

### Binary number system

All number systems have a base, which specifies how many digits can be used in each place count. For binary numbers the base is 2, with 0 and 1 as the only two digits. In the decimal system, the base is 10.

Decimal digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Binary digits: 0, 1

### Decimal to Binary Conversion

$$\begin{array}{cccc}
 & \text{Binary number} & & \\
 & 1 & 0 & 0 & 1 \\
 & \swarrow & \swarrow & \swarrow & \swarrow \\
 1 \cdot 2^3 & + & 0 \cdot 2^2 & + & 0 \cdot 2^1 & + & 1 \cdot 2^0 \\
 \downarrow & & \downarrow & & \downarrow & & \downarrow \\
 8 & + & 0 & + & 0 & + & 1 & = & 9 & \text{Decimal number}
 \end{array}$$

EX: Convert a 4 bit binary number (100 1) into decimal.

*Each digit position has specified weight, for binary numbers the position represents a power of two.*

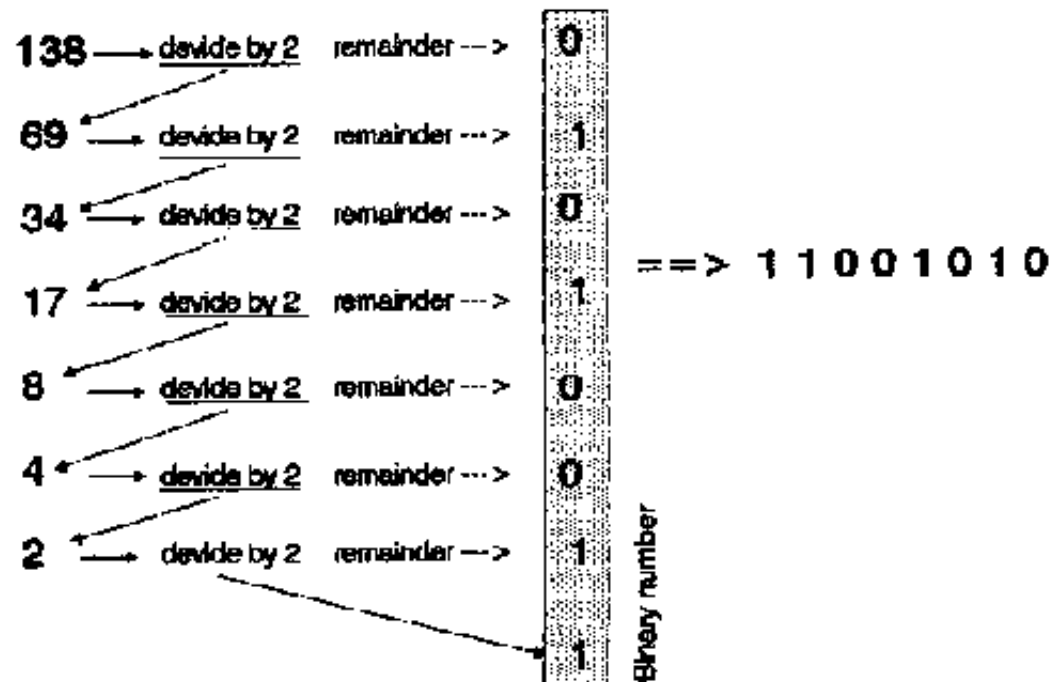
$$\begin{array}{cccccccc}
 & 1 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\
 & \swarrow & \swarrow & \swarrow & \downarrow & \swarrow & \swarrow & \swarrow & \swarrow \\
 1 & 2^7 & + 0 & + 0 & + 1 & 2^4 & + 0 & + 1 & 2^2 & + 0 & + 1 & 2^0 \\
 \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
 128 & + 0 & + 0 & + 16 & + 0 & + 4 & + 0 & + 1 & = 149
 \end{array}$$

**EX: Convert a 8 bit number (10010101) into decimal**

**HO: Convert the following binary numbers into decimal:**

**101, 1100, 1110, 1000, 0110, 11001010, 01101111, 10001100**

### Binary to decimal conversion

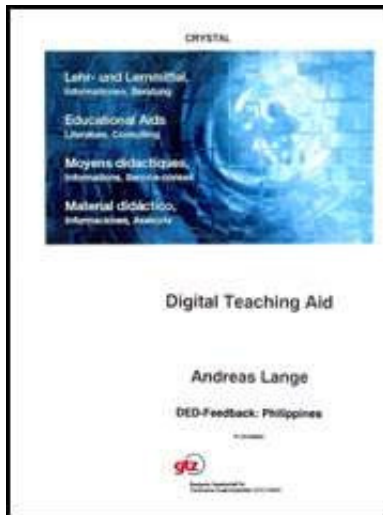


**EX: Convert the decimal number 138 into a binary number**

# HO: Convert the following decimal numbers into binary numbers:

**12, 8, 127, 247, 139, 255**

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## Digital Teaching Aid (DED Philippinen, 86 p.)

### Introduction Boolean Algebra - Lesson 2

#### Lesson Plan

##### Introduction

##### Boolean algebra

##### Boolean equations of logic circuits

##### NOR and NAN gates

##### De Morgan's theorems

##### Worksheet No. 2

## Digital Teaching Aid (DED Philippinen, 86 p.)

### Introduction Boolean Algebra - Lesson 2

#### Lesson Plan

#### Introduction

## Titel: Introduction Boolean Algebra

### Objectives:

- Able to express the basic operations in Boolean algebra
- Know how to describe a logic circuit in a Boolean equation
- Understand the basic Boolean theorems.

Time	Method	Topic	Way	Remark
	Q/A	* Review Lesson 1	B	
	S	* Introduction - George Boole	B	
	S	* Boolean algebra	B,Ex	
	S,E	- NOT operation		
		- OR operation		
		- AND operation		
	S,E	- Boolean equations of logic circuits	B,Ex	
		- NOR gates Truth table	B	
	S,D	- De Morgan's 1. theorem	B	
		- NAND gates Truth table	B	
	E	- De Morgan's 2. theorem	B,HO	
	E	* Review Exercise	WS	Worksheet No. 2
	S: Speech		B: Boardscript	

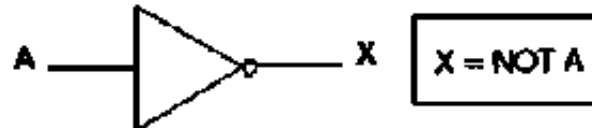
S. Speech  
 D: Discussion  
 Q/A:  
 Question/Answer  
 E: Exercise

D. Description  
 P: Picture  
 Ex: Example  
 HO: Hands-  
 On  
 WS:  
 Worksheet  
 HT: Hand-Out

## Boolean algebra

**George Boole (1854) invented a new kind of algebra that could be used to analyse and design digital and computer circuits.**

### NOT operation



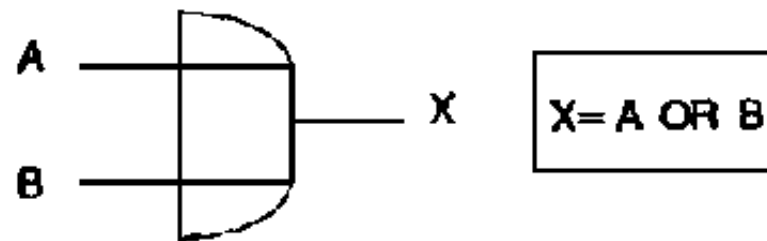
***Fig. 2-1: Inverter symbol and Boolean notation***

**Ex: If A is 0 (low)  $\rightarrow X = \text{NOT } 0 = 1$**

**In Boolean algebra the overbar stands for NOT operation.**

$$X = \bar{A}$$

### OR operation



**Fig. 2-2: OR symbol and Boolean notation**

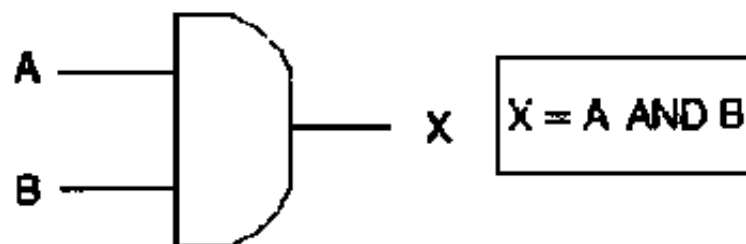
**Ex:** If  $A = 0$ ,  $B = 1 \rightarrow X = A \text{ or } B = 0 \text{ or } 1 = 1$

**In Boolean algebra the + sign stands for the OR operation:**

$$X = A + B$$

**Ex:** If  $A = 1$ ,  $B = 0 \rightarrow X = A + B = 1 + 0 = 1$

**AND operation**



**Fig. 2-3: AND symbol and Boolean notation**

**In Boolean algebra the multiplication sign stands for the AND operation:**

$$X = A \cdot B$$

**or simply:**



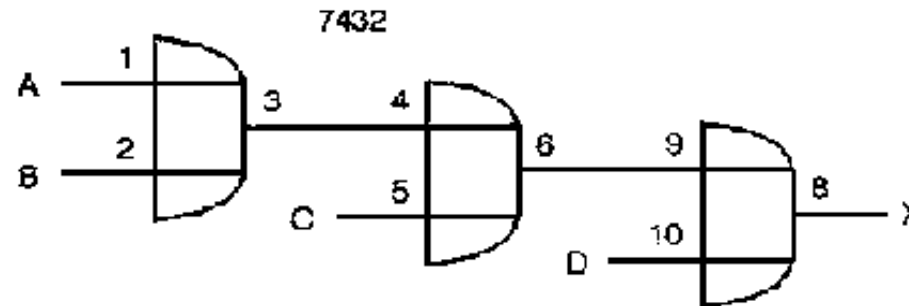
$$X = A B$$

**Ex:** If  $A = 1$ ,  $B = 0 \rightarrow X = A B = 1 \cdot 0 = 0$

### Boolean equations of logic circuits

You can use Boolean algebra as a shorthand notation for digital circuits.

**Ex:**



**Fig. 2-4: Digital circuit**

**Output of the first gate:**

$$X_3 = A + B$$

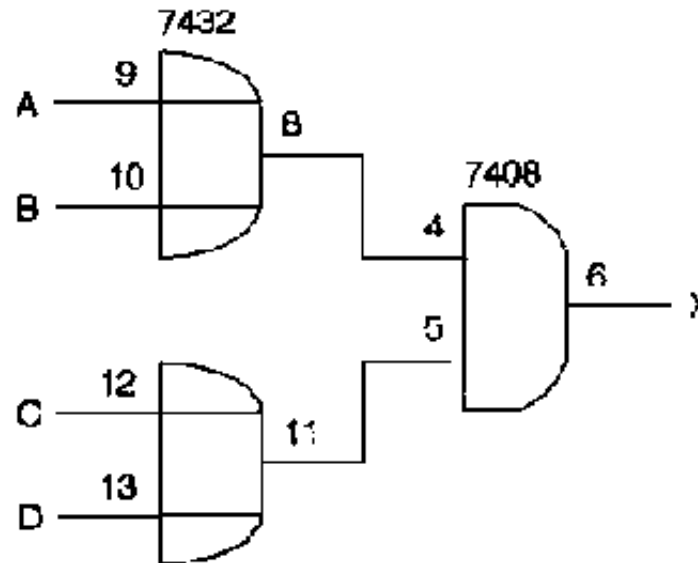
**Output of the second gate:**

$$X_6 = X_3 + C = A + B + C$$

**The final output is:**

$$X_8 = X_6 + D = A + B + C + D = X$$

**HO: Find the Boolean equation for the following circuit.**



***Fig. 2-5: Logic circuit***

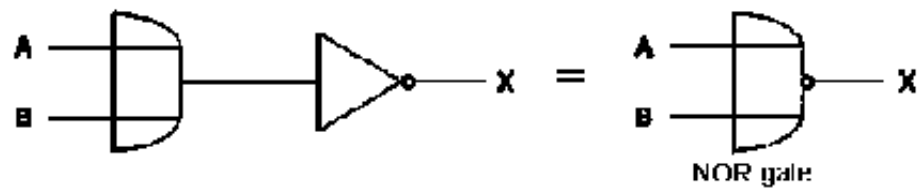
**Solution:**

$$X = (A + B) (C + D)$$

**NOR and NAN gates**

**NOR gate**

**Based on the three fundamental logic operations it is possible to design additional logic devices.**

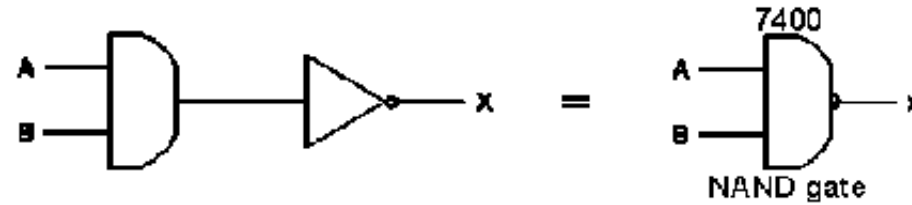


A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

**Fig. 2-6: NOR gate, symbol and truth table**

**Formula:**  $X = \overline{A+B}$

**NAND gate**



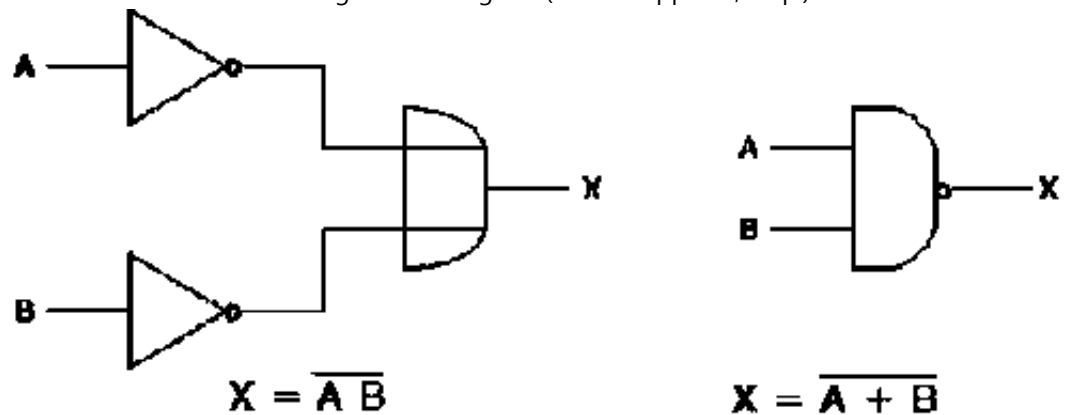
A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

**Fig. 2-7: NAND gate, symbol and truth table**

**Formula:**  $X = \overline{A B}$

**De Morgan's theorems**

**Augustus De Morgan was the first who found the link between logic and mathematics.**



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

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

**Fig. 2-8: Logic circuits with the same output**

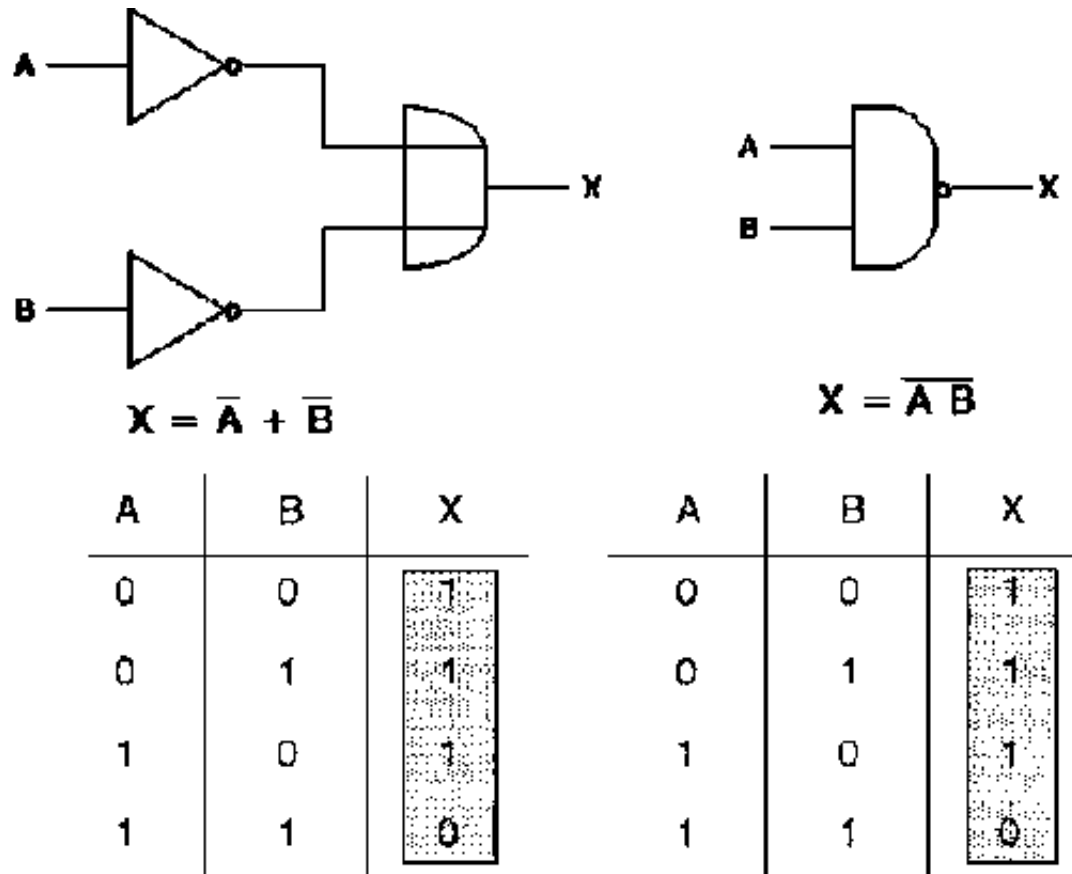
**Although the circuits are different but the output, as we can see in the truth table, is equal. Therefore we can write:**

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

### ***De Morgan's First Theorem***

**Also if we compare the two circuits on the next page we can easily see that the output is the same, although the circuits are different.**

(see Fig. 2-9)



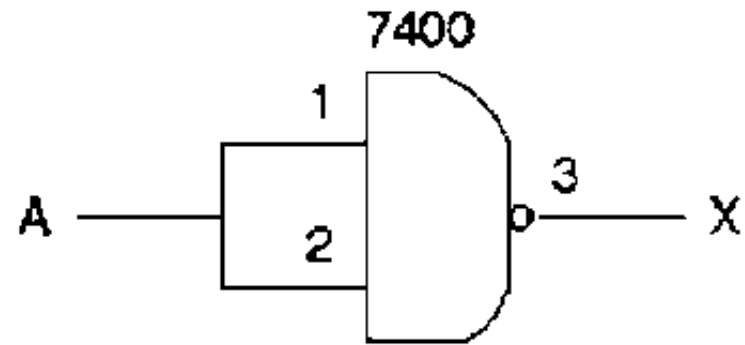
**Fig. 2-9: Logic circuits with the same output**

So we can write:

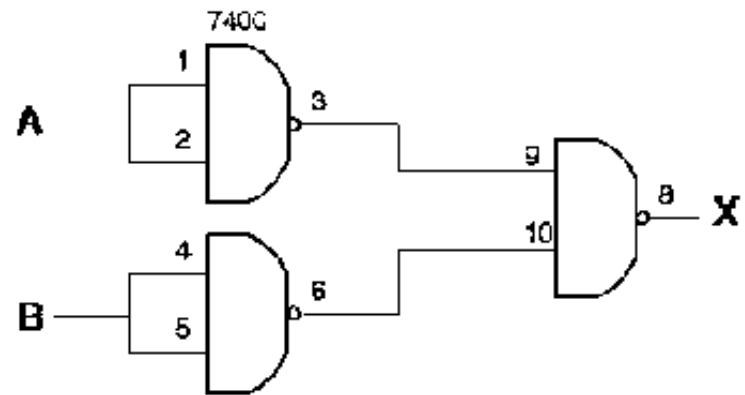
$$\overline{AB} = \bar{A} + \bar{B}$$

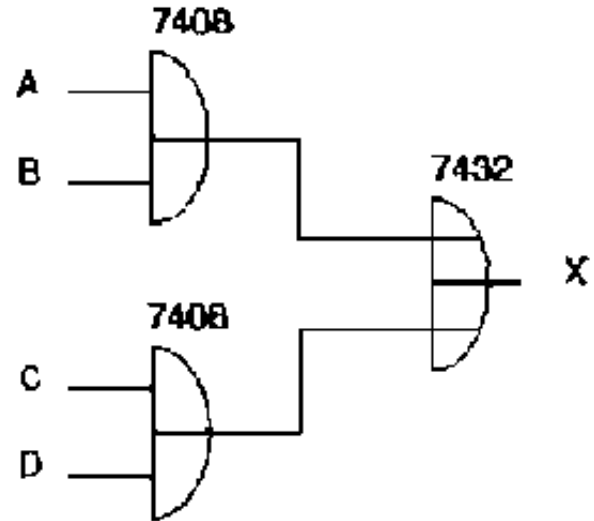
**De Morgan's Second Theorem**

**HO: How can you connect a NAND gate to get an inverter**

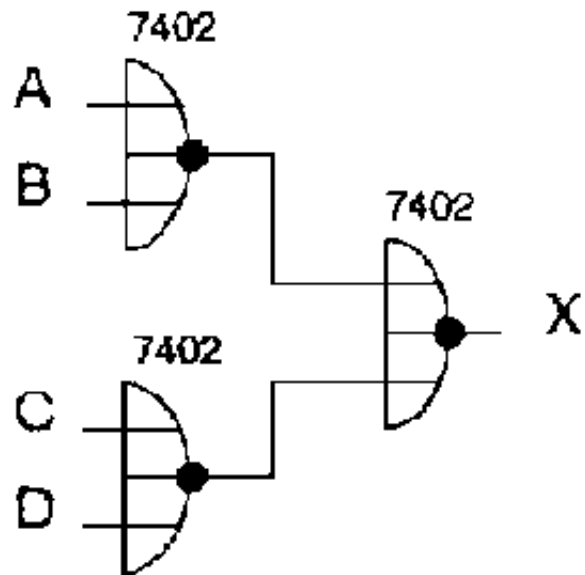
**Solution:****Figure**

**HO:** How can you connect NAND gates to get an OR gate?

**Solution:****Figure****Worksheet No. 2**

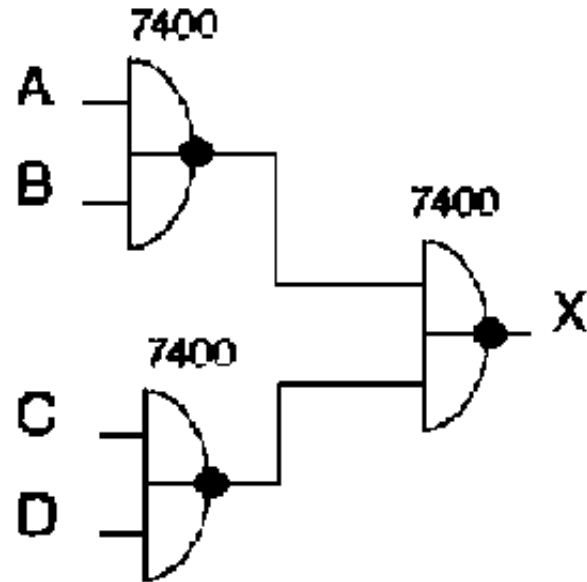


**No. 1 What is the Boolean equation? What is the truth table?**

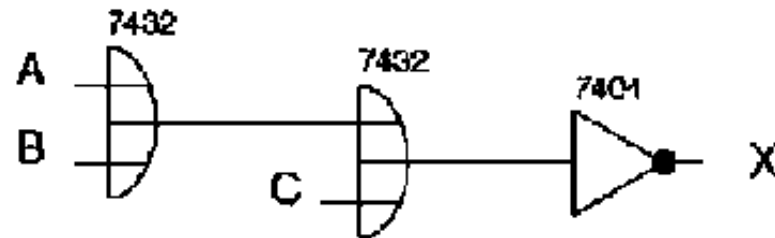


**No. 2 What is the Boolean equation? What is the truth table?**





**No. 3 What is the Boolean equation? What is the truth table?**



**No. 4 Construct the truth table.**

**No. 5 Draw the logic circuit whose Boolean equation is**

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

**Use the 7404 and the 7432 with pin numbers**

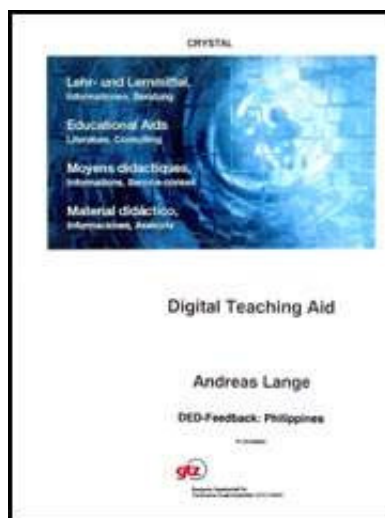
**No. 6 Draw the logic circuit whose Boolean equation is**

$$X = \overline{ABC} - ABC$$

**Use the 7404, 7432 and the 7411 with pin numbers.**



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## Digital Teaching Aid (DED Philippinen, 86 p.)

### Circuit Analysis and Design - Lesson 3

#### Lesson Plan

 *(introduction...)*

 Introduction

 Boolean laws and theorems

 Sum of product method

 Design example

 Handout No. 2

 Worksheet No. 3

**Digital Teaching Aid (DED Philippinen, 86 p.)**

**Circuit Analysis and Design - Lesson 3**

**Lesson Plan**

**Titel: Circuit Analysis and Design**

**Objectives:**

- Know how to apply the basic Boolean laws
- Able to create digital circuits with the help of the sum of products method

Time	Method	Topic	Way	Remark
		* Review Lesson 2		
		* Introduction		
		* Boolean laws and theorems	HO	Handout No. 2 (Boolean Algebra Theorems)
		- Basic laws		
		- Boolean relation about OR operations		
		- Boolean relations about AND operations		
		* Sum of products method		
		- Fundamental products		
		- Sum of products equations		
		* Review Exercise	WS	Worksheet No. 3
	S: Speech D: Discussion QA:		B: Boardscript P: Picture	

Question/Answer  
E: Exercise

Ex:  
Example  
HO:  
Hands-On  
WS:  
Worksheet  
HT: Hand-  
Out

## Introduction

## Circuit Analysis and Design

### Boolean laws and theorems

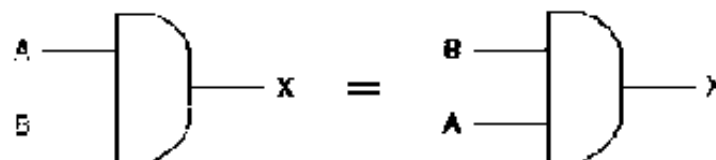
### Basic laws

(see also Handout No. 2)

### Commutative law:

$$A + B = B + A$$

$$A B = B A$$

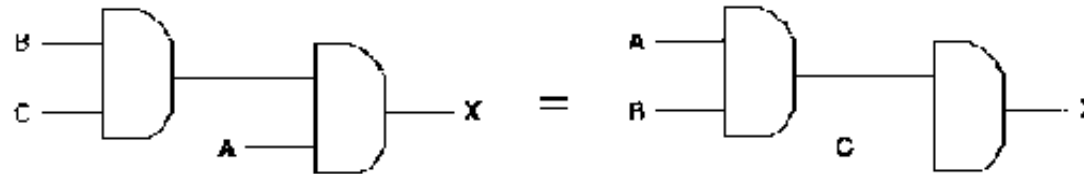


**Fig. 3-1: Commutative law**

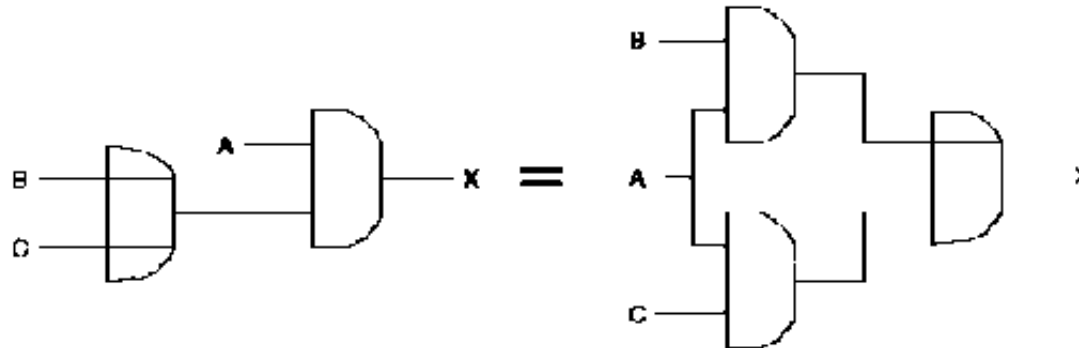
**Associative law:**

$$A + (B + C) = (A + B) + C$$

$$A (B + C) = (A B) C$$

**Fig. 3-2: Associative law****Distributive law:**

$$A (B + C) = AB + AC$$

**Fig. 3-3: Distributive law****Boolean relations about OR operations**

$$A + 0 = A$$

**Proof:**

**when A is 0**

$$0 + 0 = 0$$

**when A is 1**

$$1 + 0 = 1$$

$$A + A = A$$

**Proof:**

**when A is 0**

$$0 + 0 = 0$$

**when A is 1**

$$1 + 1 = 1$$

$$A + 1 = 1$$

**Proof:**

**when A is 0**

$$0 + 1 = 1$$

**when A is 1**

$$1 + 1 = 1$$

$$A + A = 1$$

**If one input is high, the output is high no matter what the other input is.**

### Boolean relations about AND operations

$$A \bullet 1 = A$$

$$A \bullet A = A$$

$$A \bullet 0 = 0$$

**HO: Check the equations above in the same way as we did it before.**

$$A \bullet A = 0$$

**If one input is low, the output is low no matter what the other input is.**

### **Double inversion**

$$\overline{\overline{A}} = A$$

### **De Morgan's theorems**

$$\overline{A+B} = \overline{A} \overline{B} \text{ see also Lesson 1}$$

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

## Duality theorem

1. Change each OR sign to an AND sign
2. Change each AND sign to an OR sign
3. Complement any 0 or 1 appearing in the expression

Ex:  $A + 0 = A$

$\rightarrow A \cdot 1 = A$

Ex:  $A(B + C) = AB + AC$

$\rightarrow A + B \cdot C = (A + B)(A + C)$

***TIP: Proof it with a truth table***

**Ex: Simplify the following Boolean equation**

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

**Solution: (see also Handout No. 2)**

$$X = A(\bar{B} + B) \text{ Handout 2 No. 3a}$$

$$X = A(1) \quad \text{No. 8a}$$

$$X = A \quad \text{No. 7b}$$

**HO: Simplify the following Boolean equation**



$$X = (\bar{A} + B)(A - B)$$

### Solution:

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

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

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

$$\mathbf{X = B + B}$$

$$\mathbf{X = B}$$

### Sum of product method

**Fig. 3-4: Example truth table with fundamental products**

A	B	X	Fundamental Products
0	0	0	$\bar{A}\bar{B}\bar{C}$
0	0	1	$\bar{A}\bar{B}C$
0	1	0	$\bar{A}B\bar{C}$
0	1	1	$\bar{A}BC$
1	0	0	$A\bar{B}\bar{C}$
1	0	1	$A\bar{B}C$
1	1	0	$ABC\bar{C}$

1	1	1	$\bar{A}\bar{B}C$
---	---	---	-------------------

## Design example

### Sum of products equation

Given is the following truth table:

*Fig. 3-5: Example truth table*

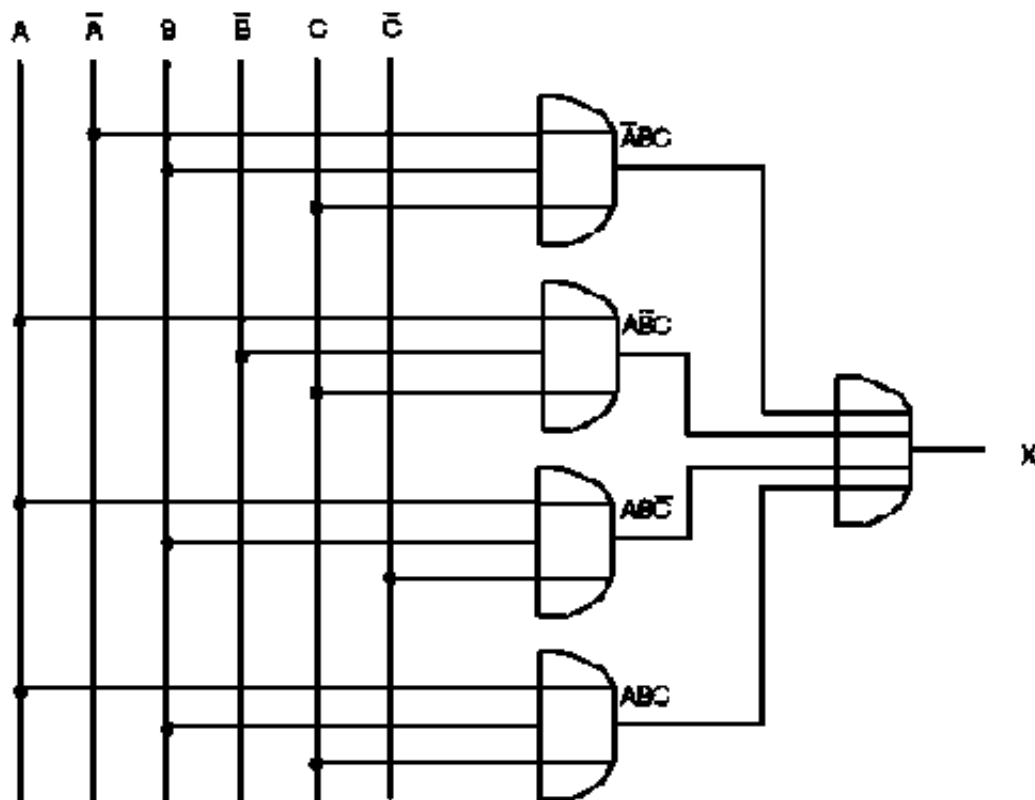
A	B	C	X		
0	0	0	0		
0	0	1	0		
0	1	0	0		
0	1	1	1	→	$\bar{A}BC$
1	0	0	0		
1	0	1	1	→	$A\bar{B}C$
1	1	0	1	→	$AB\bar{C}$
1	1	1	1	→	$ABC$

**We have to locate each output 1 in the truth table and write down the fundamental product.**

**The next step is to OR the fundamental products:**

$$X = \bar{A}BC + A\bar{B}C + ABC\bar{C} + ABC$$

**Now we can derive the corresponding logic circuit:**



**Fig. 3-6: Logic circuit**

**HO: What is the sum of product circuit for the given truth table?**

**Fig. 3-7: Truth table**

A	B	C	X
0	0	0	1

0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	0

## Handout No. 2

### Boolean Algebra Theorems

No	Theorem	Name
<b>1a</b>	$A + B = B + A$	<b>Commutative law</b>
<b>1b</b>	$AB = BA$	
<b>2a</b>	$(A + B) + C = A + (B + C)$	<b>Associative law</b>
<b>2b</b>	$(AB) C = A (B + C)$	
<b>3a</b>	$A (B + C) = AB + AC$	<b>Distributive law</b>
<b>3b</b>	$A + (BC) = (A + B) (A + C)$	
<b>4a</b>	$A + A = A$	<b>Identity law</b>
<b>4b</b>	$AA = A$	
<b>5a</b>	$\overline{\overline{A}} = A$	<b>Negation</b>
<b>5b</b>		

<b>6a</b>	$\bar{A} + AB = A$	<b>Redundancy</b>
<b>6b</b>	$A(A + B) = A$	
<b>7a</b>	$0 + A = A$	
<b>7b</b>	$1 A = A$	
<b>7c</b>	$1 + A = 1$	
<b>7d</b>	$0A = 0$	
<b>8A</b>	$\bar{A} + A = 1$	
<b>8b</b>	$\bar{A} A = 0$	
<b>9a</b>	$A + \bar{A}B = A + B$	
<b>9c</b>	$A(\bar{A} + B) = AB$	
<b>10a</b>	$\overline{A+B} = \bar{A}\bar{B}$	<b>De Morgan's laws</b>
<b>10b</b>	$\overline{AB} = \bar{A} + \bar{B}$	

## Worksheet No. 3

### No. 1 Simplify the Boolean equation and describe the logic circuit:

$$\overline{ABC} + \overline{A}BC + A\overline{B}C - ABC = X$$

### No. 2 Simplify the following Boolean expressions:

$$\bar{A}\bar{B} + AB + \bar{A}B$$

$$(A + B)(A + \bar{B})$$

$$\bar{A}B + A\bar{B} + AB + \bar{A}\bar{B}$$










**No. 3** A digital system has a 4-bit input from 0000 to 1111. Design a logic circuit that produces a high output whenever the equivalent decimal input is greater than 13.

**No. 4** In a heating plant the burner X has to be switched on, when the circulating pump A is actuated and the temperature probe B for the warm water supply or the room temperature probe C respond.

- a) Develop the truth table
- b) Write down the sum of products equation
- c) Draw the logic circuit
- d) Use Boolean algebra to simplify the equation
- e) Draw the corresponding logic circuit.

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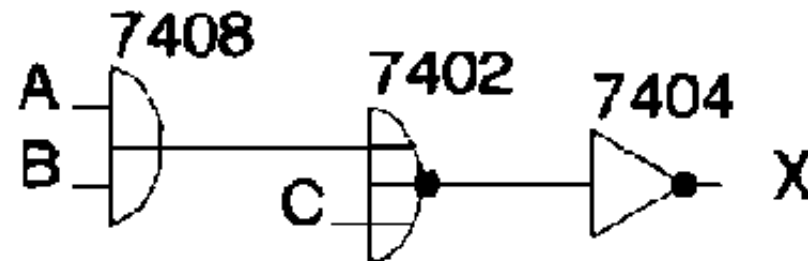
-  **Digital Teaching Aid (DED Philippinen, 86 p.)**
-  **(introduction...)**
-  **Preface**
-  **Introduction**
-  **Fundamental Logic Operations - Lesson 1**
-  **Introduction Boolean Algebra - Lesson 2**
-  **Circuit Analysis and Design - Lesson 3**
-   **First Evaluation**

- Karnaugh Mapping - Lesson 4**
- Karnaugh Mapping II - Lesson 5**
- Coding - Lesson 6**
- Flip-Flops - Lesson 7**
- Second Evaluation**
- Counter - Lesson 8**
- Data Processing Circuits - Lesson 9**
- Third Evaluation**
- Answers to Evaluation Problems**

## First Evaluation

### No. 1 Construct the truth Table

What is the Boolean equation?



Figure

### No. 2 Draw the logic circuit whose Boolean equation is

$$X = \overline{(ABC)D}$$

## Use the 7404, 7408 and the 7411 with pin numbers

### No. 3 Simplify the following Boolean expressions

$$ABC + \bar{A}B + A\bar{B}C$$

$$ABC + AC$$

$$\overline{(A+B)}(\bar{A} + \bar{B})$$

### No. 4 A digital system has a 4 bit input from 0000 to 1111.

Design a logic circuit that produces a high output whenever the equivalent hex input is greater than C.

Truth table

Sum of products equation

Logic circuit

### No. 5

A	B	C	D	Y
0	0	0	0	0
0	0	0	1	1
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0



0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	0
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	0
1	1	0	1	1
1	1	1	0	1
1	1	1	1	0

- Draw the Karnaugh map
- Encircle all octets, quads, and pairs you can find.
- What is the simplified Boolean equation?
- Draw the logic circuit using NAND gates.

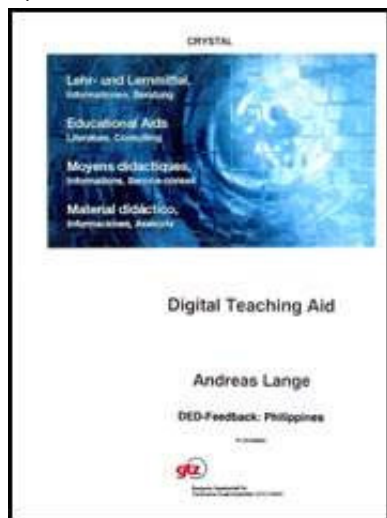









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 **Digital Teaching Aid (DED Philippinen, 86 p.)**

  **Karnaugh Mapping - Lesson 4**

 **Lesson Plan**



-  **(introduction...)**
-  **Introduction**
-  **Karnaugh map**
-  **Truth table to Karnaugh map**
-  **Pairs, Quads, and Octets**
-  **Overlapping and Rolling**
-  **Worksheet No. 4**

## Digital Teaching Aid (DED Philippinen, 86 p.)

### Karnaugh Mapping - Lesson 4

#### Lesson Plan

**Titel: Karnaugh Mapping**

#### Objectives:

- **Able to derive Karnaugh maps from a given truth table**
- **Know how to simplify Karnaugh maps**

Time	Method	Topic	Way	Remark
		* Review Lesson 3		
		* Introduction		
		- Karnaugh map		

		* Karnaugh map		
		* Karnaugh mapping		
		- Truth table to Karnaugh map		
		- Two variable map		
		- Three variable map		
		- Four variable map		
		- Pairs, Quads, and Octets		
		- Overlapping groups		
		- Rolling the map		
		* Review exercise	WS	Worksheet No. 4
	S: Speech D Discussion Q/A: Question/Answer E: Exercise		B: Boardscript P: Picture Ex: Example HO: Hands-On WS: Worksheet HT: Hand-Out	

## Introduction

## Karnaugh Mapping

## Simplify a Boolean equation

$$\text{Ex: } X = \bar{A}\bar{B}\bar{C} + \bar{A}B\bar{C} + A\bar{B}\bar{C} + ABC$$

$$X = \bar{C}(\bar{A}\bar{B} + \bar{A}B + A\bar{B} + AB) \quad \bar{C} \text{ is common in each term}$$

$$X = \bar{C}[(\bar{A}(\bar{B} + B) + A(\bar{B} + B))] \quad \text{Again factor to get}$$

$$X = \bar{C}[\bar{A}(1) + A(1)] \quad \text{Simplify}$$

$$X = \bar{C}(\bar{A} + A) \quad \text{Simplify}$$

$$X = \bar{C}$$

## Karnaugh map

**As you see, Boolean algebra can be used to create simpler circuits. But if you not quite familiar with Boolean theorems it is difficult to find the best simplification. Therefore Karnaugh mapping is the better alternative for simplification.**

## Truth table to Karnaugh map

**The starting point for digital circuit design is usually the truth table which gives us the following information:**

**Under which input condition occurs a certain output condition.**

## Two variable map

**Ex:**


A	B	X		$\bar{B}$	B
0	0	0	$\bar{A}$	0	0
0	1	0	A	1	1
1	0	1			
1	1	1			

**Fig. 4-1: Two variable Karnaugh map**

**The truth table outputs are translated into the Karnaugh map. Each position in the map represents a certain fundamental product.**

### **Three variable map**

**Ex:**

A	B	C	X		C	C	
0	0	0	0		$\bar{A}\bar{B}$	0	0
0	0	1	0		$\bar{A}B$	1	0
0	1	0	1		$AB$	1	1
0	1	1	0		$A\bar{B}$	0	0
1	0	0	0				
1	0	1	0				
1	1	0	1				
1	1	1	1				

**Fig. 4-2: Three variable Karnaugh map**

## Four variable map

**Many digital systems process 4 bit numbers. For this reason, logic circuits are often designed to handle 4 input variables.**

**Ex:**

**(see Fig. 4-3)**

A	B	C	D	X		$c\bar{d}$	$\bar{c}d$	$cd$	$c\bar{d}$
0	0	0	0	0					
0	0	0	1	1	$\bar{A}\bar{B}$	0	1	0	0
0	0	1	0	0					
0	0	1	1	0	$\bar{A}B$	0	0	0	1
0	1	0	0	0	$AB$	0	0	0	1
0	1	0	1	0	$A\bar{B}$	0	0	0	0
0	1	1	0	1					
0	1	1	1	1					
1	0	0	0	0					
1	0	0	1	0					
1	0	1	0	0					
1	0	1	1	0					
1	1	0	0	0					
1	1	0	1	0					
1	1	1	0	1					
1	1	1	1	0					
1	1	1	1	0					

**Fig. 4-3: Four variable Karnaugh map**

## Pairs, Quads, and Octets

### Pairs

	$\bar{c}\bar{d}$	$\bar{c}d$	$cd$	$c\bar{d}$	
$A\bar{B}$	0	0	0	0	
$\bar{A}B$	0	0	0	0	
$AB$	0	0	1	1	represents ABCD product
$A\bar{B}$	0	0	0	0	represents ABCD product

**Fig. 4-4: Four variable simplification**

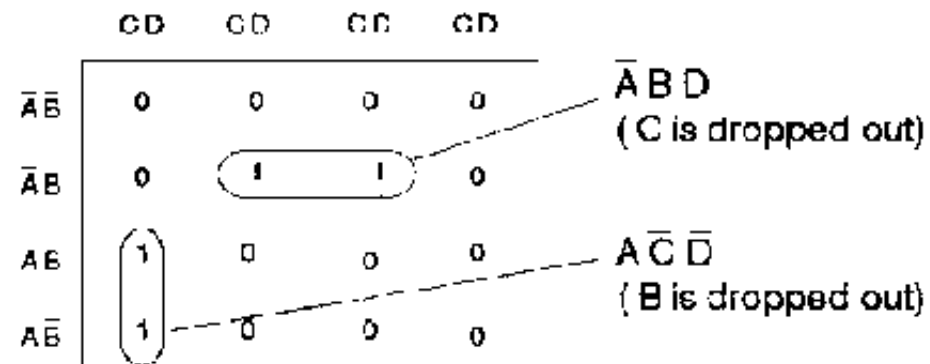
**As you see in Fig. 4-4, only one variable goes from uncomplement to complement. Whenever this happens, you can eliminate the variable that changes form.**

$$\text{Proof: } X = ABCD + ABC\bar{D}$$

$$X = ABC(D + \bar{D})$$

$$\mathbf{X = A B C}$$

**Ex:**



**Fig. 4-5: Pairs**

**Whenever you see a pair first encircle it and then simplify to get the simplified Boolean expression:**

$$X = A\bar{C}\bar{D} + \bar{A}BD$$

**Quad**



	$\bar{C}\bar{D}$	$CD$	$CD$	$CD$
$\bar{A}\bar{B}$	0	0	0	0
$\bar{A}B$	0	0	0	0
$AB$	1	1	1	1
$A\bar{B}$	0	0	0	0

**Fig. 4-6: Quad**

**Quad: A group of 4 one's that are horizontally or vertically adjacent. End to end or in form of a square.**

**A quad eliminates two variables and their complements.**

Proof:  $X = A\bar{B}\bar{C} + ABC$  (two pairs)

$$X = A B (C + \bar{C})$$

$$X = A B$$

**Encircle the quad and step through the different one's in the quad and determine which two variables go from complement to uncomplement (or vs), these are the variables that drop out.**

**Ex:**

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	0	0	0
$\bar{A}B$	0	0	0	0
$AB$	0	0	1	1
$A\bar{B}$	0	0	1	1

**Fig. 4-7: Quad**

The variables **B** and **D** can be eliminated. So we get the following equation:

$$X = A C$$

**Octet**

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	0	0	0
$\bar{A}B$	0	0	0	0
$AB$	1	1	1	1
$A\bar{B}$	1	1	1	1

**Fig. 4-8: Octet**

## **An octet eliminates three variables and their complements.**

Proof:  $X = A\bar{C} + AC$  (two quads)

$$X = A(C + \bar{C})$$

$$X = A$$

## **Karnaugh Simplifications**

### **Process:**

- 1. Draw the Karnaugh map**
- 2. Look for octets and encircle them.**
- 3. Look for quads and encircle them.**
- 4. Look for pairs and encircle them.**
- 5. Simplify and write down the equation.**

### **Ex:**

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	1	1	1
$\bar{A}B$	0	0	0	1
$AB$	1	1	0	1
$A\bar{B}$	1	1	0	1

**Fig. 4-9: Karnaugh map**

$$X = A\bar{C} - C\bar{D} + \bar{A}BD$$

## Overlapping and Rolling

## Overlapping groups

**Ex:**

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	0	0	0
$\bar{A}B$	0	1	0	0
$AB$	1	1	1	1
$A\bar{B}$	1	1	1	1

**Fig. 4-10: Karnaugh map**

**Groups can overlap to get a simpler equation:**

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

**Rolling the map**

**Ex:**

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	0	0	0
$\bar{A}B$	1	0	0	1
$AB$	1	0	0	1
$A\bar{B}$	0	0	0	0

**Fig. 4-11: Karnaugh map**

**Instead of encircling two pairs:**

$$X = \bar{B}\bar{C}D + B\bar{C}\bar{D}$$

**We can roll the map and encircle a quad:**

$$X = \bar{B}\bar{D}$$

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	1	1	0	1
$\bar{A}B$	1	1	0	1
$AB$	1	1	0	0
$A\bar{B}$	1	1	0	1

**HO: Simplify the following map.**

**Solution:**

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

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	0	0	0
$\bar{A}B$	0	0	1	0
$AB$	1	1	1	1
$A\bar{B}$	0	1	1	1

**HO: Simplify the following map.**

**Solution:**

$$X = AB + AD + AC + BCD$$

## Worksheet No. 4

**No. 1 Simplify the following Karnaugh maps and write down the Boolean equation for every map.**

	$\bar{C}$	$C$
$\bar{A}\bar{B}$	0	0

$\bar{A}\bar{B}$	1	0
$\bar{A}B$	1	1
$A\bar{B}$	0	0

	$\bar{C}$	C
$\bar{A}\bar{B}$	1	1
$\bar{A}B$	0	0
$AB$	1	0
$A\bar{B}$	1	1

	$\bar{C}$	C
$\bar{A}\bar{B}$	1	0
$\bar{A}B$	0	0
$AB$	0	0
$A\bar{B}$	1	0

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	1	0	0
$\bar{A}B$	1	0	1	1
$AB$	1	0	0	1
$A\bar{B}$	0	1	1	0



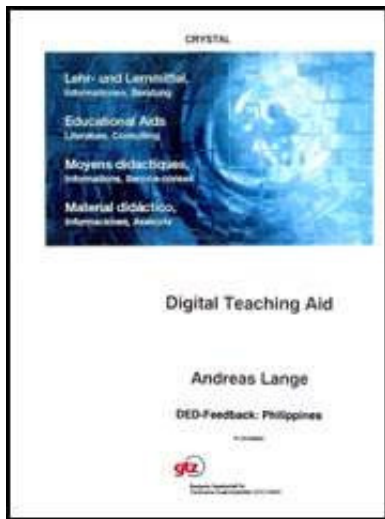
	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	1	1	0	1
$\bar{A}B$	0	0	1	1
$AB$	0	0	0	1
$A\bar{B}$	1	1	0	1

**No. 2** Translate each output ( $v, w, x, y, z$ ) into a Karnaugh map, do the simplification and write down the Boolean equation.

A	B	C	D	v	w	x	y	z
0	0	0	0	1	1	0	1	0
0	0	0	1	0	1	0	1	1
0	0	1	0	0	1	0	0	0
0	0	1	1	0	0	0	0	1
0	1	0	0	0	0	1	0	1
0	1	0	1	1	0	1	1	0
0	1	1	0	1	1	1	1	0
0	1	1	1	1	0	1	1	0
1	0	0	0	0	1	0	0	1
1	0	0	1	1	1	1	1	0
1	0	1	0	0	1	0	1	0
1	0	1	1	1	1	1	1	1
1	1	0	0	0	0	0	0	1

1	1	0	1	1	0	0	0	1
1	1	1	0	0	0	0	1	1
1	1	1	1	0	1	0	0	0

[Home](#) > [ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#)



## Digital Teaching Aid (DED Philippinen, 86 p.)

### Karnaugh Mapping II - Lesson 5

#### Lesson Plan

 *(introduction...)*

 Introduction

 Product of sums method

 Don't care conditions

 Worksheet No. 5

**Digital Teaching Aid (DED Philippinen, 86 p.)**

**Karnaugh Mapping II - Lesson 5**

**Lesson Plan**

**Titel: Karnaugh Mapping II**

**Objectives:**

- Understand the product of sums method
- Able to use "Don't care conditions" for more effective simplifications

Time	Method	Topic	Way	Remark
		* Review Lesson 4		
		* Introduction		
		* Product of sums method		
		- Fundamental sums		
		- Product off sums simplifications		
		* Don't care conditions		
		-Truth table		
		- Karnaugh map		
		* Review exercise		Worksheet No. 5
	S: Speech D: Discussion Q/A: Question/Answer E: Exercise		B: Boardscript P: Picture Ex: Example HO: Hands-On WS: Worksheet HT: Hand-Out	

## Introduction

### Karnaugh Mapping II

#### Product of sums method

Instead of using the sum of products method we can also take the product of sums method which is based on the fundamental sums:

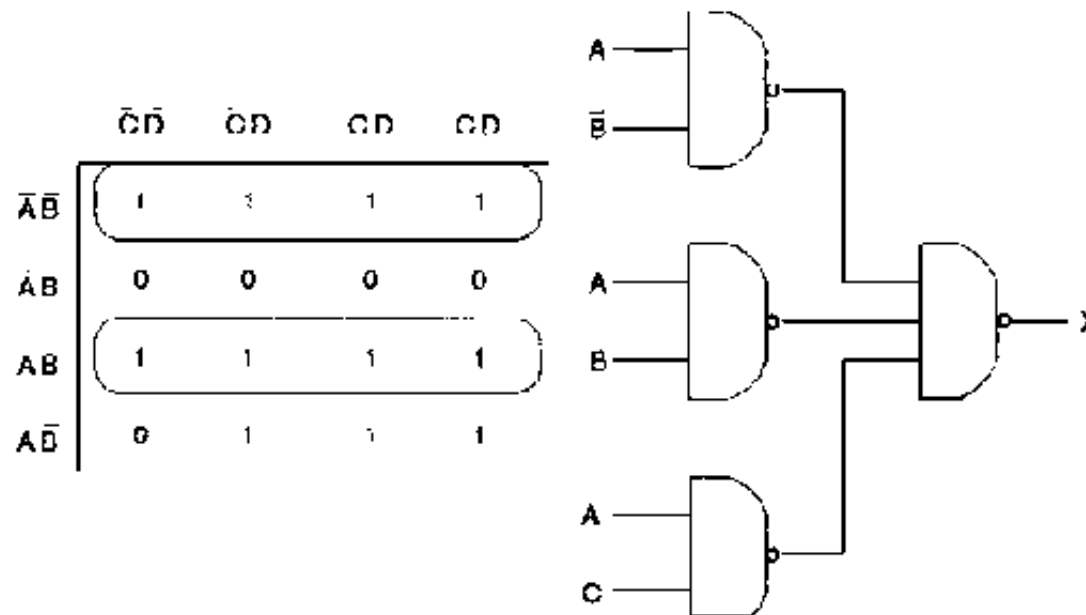
**Fig. 5-1: Truth table with fundamental sums**

A	B	C	X		Fundamental sums
0	0	0	0	→	$A+B+C$
0	0	1	1		
0	1	0	1		
0	1	1	0	→	$A+\bar{B}+\bar{C}$
1	0	0	1		
1	0	1	1		
1	1	0	0	→	$\bar{A}+\bar{B}+C$
1	1	1	1		

#### Product of sums simplification

**A equation gained through the sum of product method can be realized into a**

## NAND-NAND logic circuit.



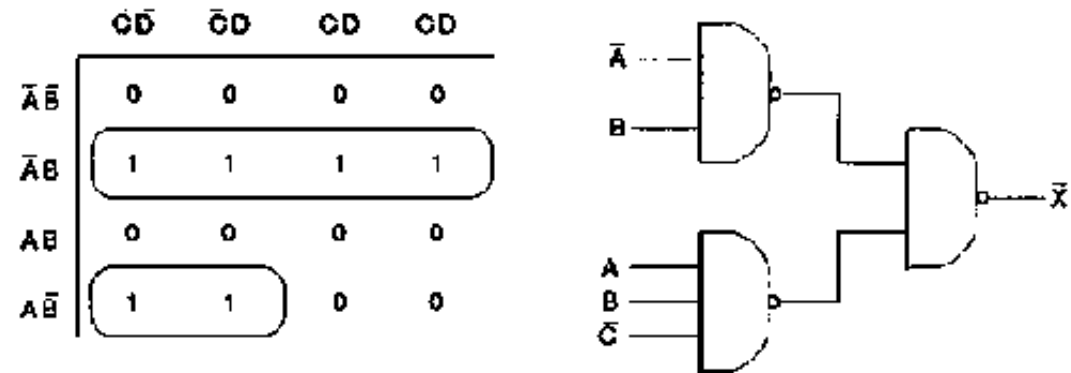
**Fig. 5-2: NAND-NAND logic circuit**

If we simplify the Karnaugh map in Fig. 5-2 we get the following equation:

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

Based on this equation we can draw the logic circuit like in Fig. 5-2. This solution is made with the help of the sum of product method. If we want to try the product of sums method we have to go through the following steps:

**1. Complement the Karnaugh map and draw the complementary NAND-NAND circuit:**

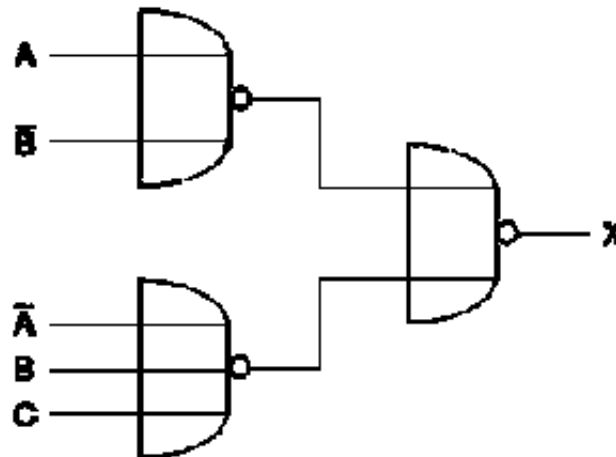


**Fig. 5-3: Complementary NAND-NAND circuit**

**The simplified equation is:**

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

**2. Convert the complementary NAND-NAND circuit to a NOR-NOR circuit:**



**Fig. 5-4: NOR-NOR circuit**

**we have changed all NAND to NOR and complemented all signals.**

**3. Now we got a product of sums solution for X. The last step is to compare both circuits (NAND-NAND, NOR-NOR) to find out which circuit is the simpler one, meaning the cheaper one. Because we need less gates. In our case the sum of product solution (NOR-NOR circuit) is the better solution.**

### **Summary of process**

#### **1. Convert the truth table into a Karnaugh map**

- Write the sum of products equation**
- Draw the NAND-NAND circuit**

#### **2. Complement the Karnaugh map**

- Draw the complementary NAND-NAND circuit ( $\bar{X}$ )**

#### **3. Convert the complementary NAND-NAND circuit to a NOR-NOR circuit.**

- Change all NAND to NOR**
- Complement all signals**

#### **4. Compare NAND-NAND circuit with NOR-NOR circuit.**

### **Don't care conditions**

**In some digital systems, certain input conditions never occur during normal operations; therefore, the corresponding output never appears.**

⇒ **It is indicated in the truth table by an X.**

**Fig. 5-5: Don't care conditions**

A	B	C	D	Z	
0	0	0	0	0	
0	0	0	1	0	
0	0	1	0	0	
0	0	1	1	0	
0	1	0	0	0	
0	1	0	1	0	
0	1	1	0	0	
0	1	1	1	0	
1	0	0	0	0	
1	0	0	1	1	
1	0	1	0	X	
1	0	1	1	X	
1	1	0	0	X	Don't care conditions
1	1	0	1	X	
1	1	1	0	X	
1	1	1	1	X	

**Don't care conditions are like wild cards, you can let them stand for what ever you**



**like:**

	$\bar{C}\bar{D}$	$\bar{C}D$	$CD$	$C\bar{D}$
$\bar{A}\bar{B}$	0	0	0	0
$\bar{A}B$	0	0	0	0
$AB$	X	X	X	X
$A\bar{B}$	X	1	X	X

$Z = AD$

**Fig. 5-6: Karnaugh map and simplified equation****HO: Simplify the following Boolean function:**

$$F(w,x,y,z) = \Sigma(1,3,7,11,15)$$

**That has the don't care conditions:**

$$d(w,x,y,z) = \Sigma(0,2,5)$$

**Solution:****First we have to translate the function into a truth table:**

W	X	Y	Z	F
0	0	0	0	X
0	0	0	1	1
0	0	1	0	X
0	0	1	1	1
0	1	0	0	0
0	1	0	1	X
0	1	1	0	0
0	1	1	1	1
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	1
1	1	0	0	0
1	1	0	1	0
1	1	1	0	0
1	1	1	1	1

**Now we have to convert it into a Karnaugh map and simplify it:**

	$\bar{Y}\bar{Z}$	$\bar{Y}Z$	$YZ$	$Y\bar{Z}$
$\bar{W}\bar{X}$	X	1	1	X
$\bar{W}X$	0	X	1	0
$W\bar{X}$	0	0	1	0
$WX$	0	0	1	0

Figure

## Worksheet No. 5

### No. 1

A	B	C	D	Y
0	0	0	0	0
0	0	0	1	1
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	1
0	1	1	0	0
0	1	1	1	0

1	0	0	0	0
1	0	0	1	0
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1
1	1	1	1	1

- a) Draw the Karnaugh map.
- b) Encircle all octets, quads and pairs you can find.
- c) What is the simplified Boolean equation for the Karnaugh map?
- d) Draw the logic circuit.
- e) Suppose the last six entries of the truth table are changed to don't cares. Using the Karnaugh map, show the simplified circuit.
- f) What is the simplified NOR-NOR circuit?

