

Digital Electronics Practice
Using
Integrated Circuits

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Steel Authority of India Limited
Ranchi



Tata McGraw-Hill Publishing Company Limited
NEW DELHI

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Tata McGraw-Hill Publishing Company Limited

This book has been subsidized by the Government of India through
National Book Trust, India, for the benefit of students

Asst Sponsoring Editor: KALPANA SHUKLA

Asst Production Editor: RANJAN KAUL

Production Assistant : B L DOGRA

Rs. 38.00

Published by Tata McGraw-Hill Publishing Company Limited,
12/4 Asaf Ali Road, New Delhi 110 002 and printed by S.P. Jain at
J. Samanta Machinery Company (P) Ltd., 14-A, Kamla Nagar, Delhi 110 007

PREFACE

There has been unprecedented growth in the field of digital techniques since Claude Shannon systematized and adapted George Boole's theoretical work in 1938. Now it has become one of the most fascinating and challenging fields of study.

The importance of digital electronics can be seen from a wide variety of industrial and consumer products, such as automated industrial machinery, computers, microprocessors, pocket calculators, digital watches and clocks, TV games, etc. The importance of digital electronics has increased owing to the advent of integrated circuit (IC) technology. The size, cost and power dissipation of electronic devices have been reduced by 2000:1 from the days of vacuum tubes, and their performance, reliability and efficiency have greatly improved with the improvements in IC technology.

It can be confidently said that almost all graduates in electronics engineering will take up jobs calling for a knowledge of digital electronic principles and practice. Therefore, a sound education in digital electronics is vital for a successful career in electronics. With this in view, we have attempted to write this book to fill the long-felt need of electronics engineering students, practising engineers and scientists. The book will prove extremely useful for a digital electronics course with an associated laboratory.

Students of physics and others with a knowledge of basic electronics but without any prior knowledge of digital systems and ICs will find this book very useful. A thorough understanding of the topics given here will enable them to study and understand the most fascinating fields of microprocessors, microcomputers, etc.

The book has been divided into six parts. The first two experiments of Part I introduce to the reader the basic digital building blocks—the gates, and the other three experiments deal with the characteristics of the gates with totem-pole, open-collector and tri-state outputs. It is very essential to know about these characteristics of ICs to effectively use them in any complex digital system.

Part II deals with the combinational logic circuits starting from simple functions such as half-adder and half-subtractor to more complex systems, such as arithmetic/logic units (ALU), multiplexers, demultiplexers, code converters, etc. All these functions are discussed in detail.

Part III starts with FLIP-FLOPS which are the basic building blocks for sequential circuits. Shift-registers and asynchronous and synchronous counters are thoroughly covered. Semiconductor memories have also been explained in a very simple and concise manner.

Part IV deals with the pulse-generating circuits required in digital systems. In this part very useful and popular analog ICs, such as OP-AMP and timers have also been used, in addition to the available digital ICs.

Part V deals with analog-to-digital (A/D) and digital-to-analog (D/A) converters. These are used as input and output circuits for interfacing digital systems with the real world which is mostly analog.

Each experiment is followed by review questions which will give an opportunity to the students to test their understanding of the topic. At the end of most of the experiments, exercises have been included which will be of additional help in learning more about digital systems.

Based on the topics covered in Parts I through V, the general digital system design methodology have been evolved in Part VI. Trouble-shooting techniques and equipment required for this purpose have been included as a project. The other projects discussed are: the binary multiplier, digital clock, digital voltmeter (DVM), and digital frequency meter.

Useful information about digital ICs, such as the numbering of IC pins, details of IC sockets, interpretation of the information printed on ICs, etc. are given in Appendix A.

TTL is the most popular and widely used IC technology today as far as small-scale (SSI) and medium-scale (MSI) ICs are concerned. The standard TTL family known as the 54/74-series has been used for experiments. Specifications of ICs of this series are given in Appendix B. It is recommended that the student reads Appendices A and B before starting the experimental work.

Appendix C deals with another important logic family, namely CMOS. Information regarding the 54C/74C-series of CMOS ICs and their interfacing with TTL ICs are given here. Appendix D deals with emitter-coupled logic (ECL).

Appendix E gives the pinout connections of about 200 different digital ICs of the 54/74-series which will prove to be very useful for any person working with the 54/77-series of the most popular TTL ICs or with the 54C/74C-series of CMOS ICs.

The specifications and pinouts of timers, OP-AMP, 7-segment LED, NIXIE tube and diodes used in the text are given in Appendix F.

The experiments have been designed generally for a three-hour laboratory session for an adequately prepared student. Therefore, either two laboratory sessions per week for one semester or one laboratory session per week for two semesters will be required for performing all the experiments and completing all the projects. Selected experiments can be done in other situations.

We are grateful to Dr C.R. Mitra, Director, BITS for providing all the necessary facilities. Our special thanks are due to Prof. I.J. Nagrath and Prof. K.V. Ramanan for encouragement and appreciation, and Prof. S.C. Rastogi for making available the necessary laboratory facilities. Many colleagues and students have contributed in bringing out this work, and we are thankful to all of them.

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PART I

BASIC GATES—FUNCTIONS AND CHARACTERISTICS

Experiment 1

BASIC LOGIC GATES

1.1 AIM

To study the functions of basic logic gates: AND, OR, NOT, NAND, NOR and EX-OR.

1.2 INTRODUCTION

In digital electronic circuits, two discrete voltage levels are recognized as two logic levels, viz. logic '1' and logic '0'. These are also known as 'HIGH' and 'LOW' logic levels. Depending upon the actual voltages, there are two types of logic circuits: (i) positive logic—in which the higher voltage level corresponds to '1' (HIGH) and the lower level corresponds to '0' (LOW), and (ii) negative logic—in which the lower level corresponds to '1' (HIGH) and the higher level corresponds to '0' (LOW). Figure 1.1(a) and (b) shows the positive and negative logic voltage levels. It may be noted that a specified range of voltages (as shown by the shaded regions in Fig. 1.1) represents the '1' or '0' logic level.

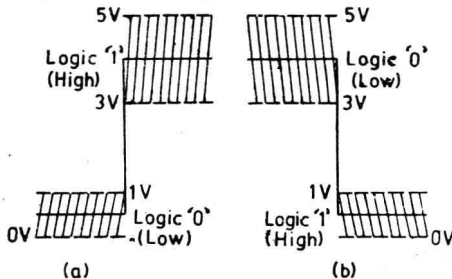


Fig. 1.1 Voltage levels for: (a) positive logic; (b) negative logic

In digital circuits, there are only four basic operations which are required to be performed. These are AND, OR, NOT and FLIP-FLOP. There are two types of digital circuits: (i) combinational circuits and (ii) sequential circuits.

4 Basic Gates—Functions and Characteristics

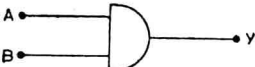

In combinational circuits, the outputs at any instant of time depend completely on the inputs present at that instant of time. In such circuits only AND, OR and NOT operations are required. These circuits are discussed here.

In sequential circuits the outputs at any instant of time depend upon the past outputs as well as the inputs present at that instant of time. Here in addition to AND, OR and NOT operations, FLIP-FLOPS (FF) are also required. These will be studied later.

NAND and NOR operations are also defined which can be used to realize AND, OR and NOT operations.

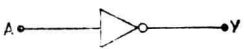
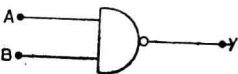
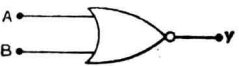

The function, logic diagram and truth table for each of the gates are given in Table 1.1. This table illustrates the AND, OR, NAND and NOR gates with two inputs only, but the number of inputs can be more than two also.

Table 1.1 Logic diagrams, functions and truth tables of basic gates

Gate	Logic diagram	Function	Truth table																		
AND		$Y = A \text{ AND } B$ $= A \cdot B$ $= A \wedge B$ $= AB$	<table border="1"> <thead> <tr> <th colspan="2">Inputs</th> <th>Output</th> </tr> <tr> <th>A</th> <th>B</th> <th>Y</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>0</td> <td>1</td> <td>0</td> </tr> <tr> <td>1</td> <td>0</td> <td>0</td> </tr> <tr> <td>1</td> <td>1</td> <td>1</td> </tr> </tbody> </table>	Inputs		Output	A	B	Y	0	0	0	0	1	0	1	0	0	1	1	1
Inputs		Output																			
A	B	Y																			
0	0	0																			
0	1	0																			
1	0	0																			
1	1	1																			
OR		$Y = A \text{ OR } B$ $= A + B$ $= A \vee B$	<table border="1"> <thead> <tr> <th colspan="2">Inputs</th> <th>Output</th> </tr> <tr> <th>A</th> <th>B</th> <th>Y</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>0</td> <td>1</td> <td>1</td> </tr> <tr> <td>1</td> <td>0</td> <td>1</td> </tr> <tr> <td>1</td> <td>1</td> <td>1</td> </tr> </tbody> </table>	Inputs		Output	A	B	Y	0	0	0	0	1	1	1	0	1	1	1	1
Inputs		Output																			
A	B	Y																			
0	0	0																			
0	1	1																			
1	0	1																			
1	1	1																			

(Contd)

Table 1.1 (Contd)

Gate	Logic diagram	Function	Truth table	
NOT (Invertor)		$Y = \text{NOT } A$ $= \bar{A}$	Input	Output
			A	Y
			0	1
				0
NAND		$Y = A \text{ NOT AND } B$ $= A \text{ NAND } B$ $= \overline{A \cdot B}$ $= \overline{A \wedge B}$ $= A \uparrow B$ $= \overline{AB}$	Inputs	Output
			A B	Y
			0 0	1
			0 1	1
			1 0	1
			1 1	0
NOR		$Y = A \text{ NOT OR } B$ $= A \text{ NOR } B$ $= \overline{A + B}$ $= \overline{A \vee B}$ $= A \downarrow B$	Inputs	Output
			A B	Y
			0 0	1
			0 1	0
			1 0	0
			1 1	0
EX-OR		$Y = A \text{ EX-OR } B$ $= A \oplus B$ $= \overline{A}B + A\overline{B}$ $= A \nabla B$	Inputs	Output
			A B	Y
			0 0	0
			0 1	1
			1 0	1
			1 1	0

These functions can be realized by using discrete devices, such as diodes, bipolar junction transistors (BJTs), and field effect transistors (FETs). However, since these gates are now directly available in the integrated circuit (IC) form, we will be dealing with only ICs. Table 1.2 gives a list of available basic gates in the IC form.

Table 1.2 Available basic gate ICs

IC number	Description
7400	Quad 2-input NAND gates
7402	Quad 2-input NOR gates
7404	Hex inverters
7408	Quad 2-input AND gates
7410	Triple 3-input NAND gates
7411	Triple 3-input AND gates
7420	Dual 4-input NAND gates
7421	Dual 4-input AND gates
7427	Triple 3-input NOR gates
7430	8-input NAND gate
7432	Quad 2-input OR gates
7486, 74386	Quad EXCLUSIVE-OR gates
74133	13-input NAND gate
74135	Quad EX-OR/NOR gates
74260	Dual 5-input NOR gates

1.3 EXPERIMENTS

1.3.1 Basic Operations

(i) AND gate

Identify the terminals of the 7408 quad, 2-input IC AND gate (refer Appendix E). Connect +5.0 V dc between V_{cc} and GND terminals (Positive terminal of the supply must be connected to the V_{cc} terminal). Use +5 V for logic '1' and 0 V for logic '0'. A section of the IC is shown in Fig. 1.2(a). Measure the output voltages for the various combinations of the input voltages given in Table 1.3 and verify the results with the truth table of the AND gate given in Table 1.1.

Table 1.3 Various input combinations

A	B
0 V	0 V
0 V	5 V
5 V	0 V
5 V	5 V

Check if the output voltages for the logic levels '1' and '0' correspond to the values given in Fig. 1.1(a).

(ii) OR gate

Repeat (i) for a 7432 quad, 2-input IC OR gate, a section of which is shown in Fig. 1.2(b).

(iii) NOT gate

Repeat (i) for a 7404 hex IC inverter, a section of which is shown in Fig. 1.2(c).

(iv) NAND gate

Repeat (i) for a 7400 quad, 2-input IC NAND gate, a section of which is shown in Fig. 1.2(d).

(v) NOR gate

Repeat (i) for a 7402 quad, 2-input IC NOR gate, a section of which is shown in Fig. 1.2(e).

(vi) EX-OR gate

Repeat (i) for a 7486 quad, IC EX-OR gate, a section of which is shown in Fig. 1.2(f).

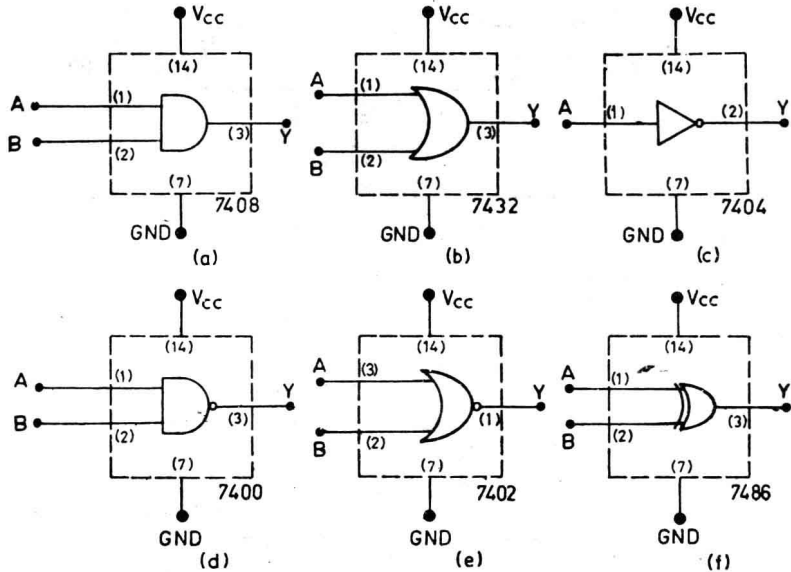


Fig. 1.2 Single sections of ICs: (a) 7408; (b) 7432; (c) 7404; (d) 7400; (e) 7402; (f) 7486

1.3.2 Combinations of Gates

(i) Set up the circuits shown in Fig. 1.3. Find experimentally the truth table for each circuit and verify theoretically. Match the truth table of each part with the truth tables given in Table 1.1 and name the operation performed by each part.

8 Basic Gates—Functions and Characteristics

(ii) Replace each NAND gate in Fig. 1.3(c) and (d) by a NOR gate and repeat (i).

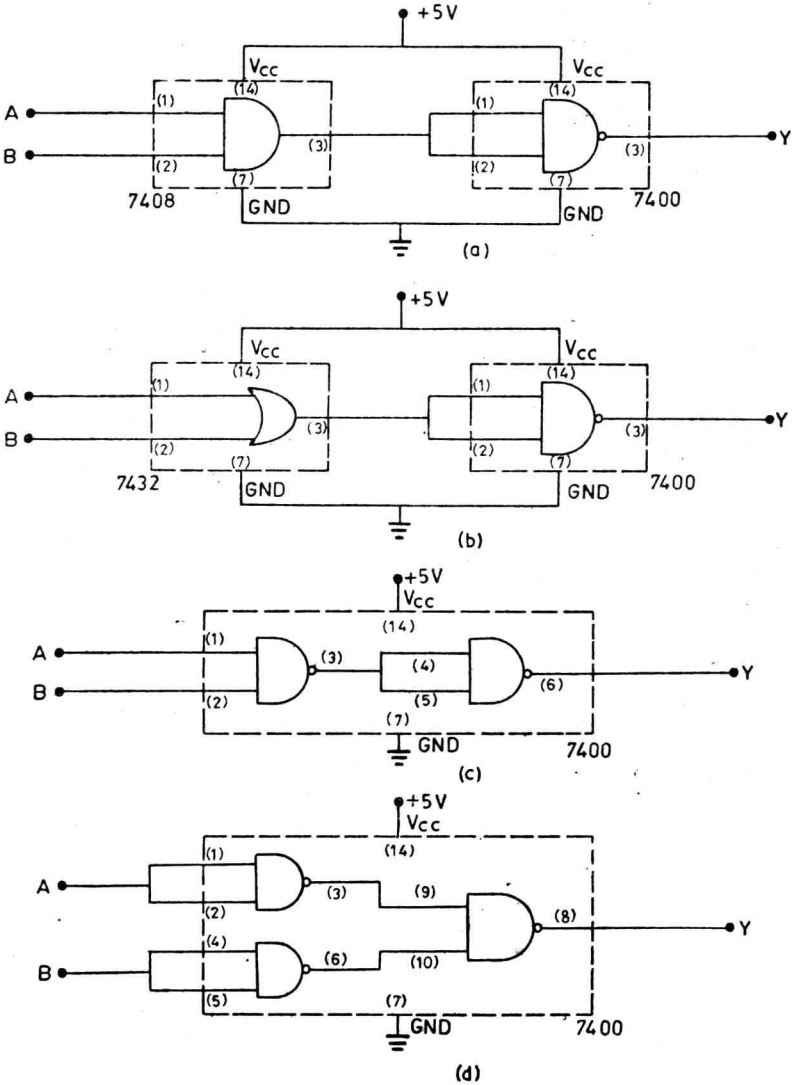


Fig. 1.3 Combinations of gates

REVIEW QUESTIONS

- 1.1 Give the name of the IC package used in the experiment.
- 1.2 How many gates are there in the following ICs?
 (a) 7400, (b) 7404, (c) 7410, (d) 7430, and (e) 74260.

- 1.3 How do you identify the pins of an IC package?
 1.4 Identify the IC no. of the packages shown in Fig. 1.4.

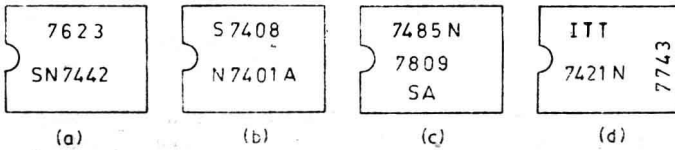


Fig. 1.4 IC packages

- 1.5 What is the difference between the logic symbols of:
 (a) AND and NAND gate;
 (b) OR and NOR gate; and
 (c) OR and EX-OR gate.
 1.6 Figure 1.5 gives an equivalent logic representation of a NAND gate. Make its truth table and compare it with the actual truth table of the NAND gate.

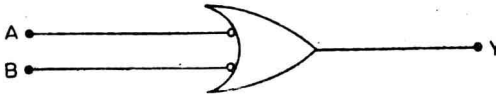


Fig. 1.5 An equivalent representation of NAND gate

- 1.7 Make a truth table for the logic symbol shown in Fig. 1.6 and name the operation performed by this circuit.

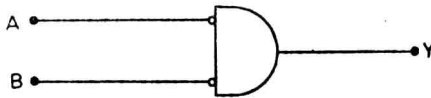


Fig. 1.6

- 1.8 Make a NOT gate using:
 (a) a 2-input NAND gate;
 (b) a 2-input NOR gate;
 (c) a 3-input NAND gate;
 (d) a 3-input NOR gate; and
 (e) an EX-OR gate.
 1.9 How will you use a 3-input
 (a) NAND gate as a 2-input NAND gate?
 (b) NOR gate as a 2-input NOR gate?
 (c) AND gate as a 2-input AND gate?
 (d) OR gate as a 2-input OR gate?
 1.10 Can you use an EX-OR gate to compare two digital signals A and B and determine whether they are equal or not? If yes, explain how you will obtain it.
 1.11 In the 74135 EX-OR/NOR IC, find the logic level to be applied at C to obtain

- (a) $Y = A \oplus B$ and
 (b) $Y = \overline{A \oplus B}$