DIGITAL ELECTRONICS

THEORY AND EXPERIMENTATION

FREDRICK W. HUGHES

DIGITAL ELECTRONICS:

Theory and Experimentation

PRENTICE-HALL, Englewood Cliffs, New Jersey 07632

Library of Congress Cataloging-in-Publication Data

Hughes, Fredrick W., 1936-
Digital electronics.

1. Digital electronics. 2. Digital electronics—Laboratory manuals. I. Title.
TK7868.D5H825 1986 621.3815 85-19186
ISBN 0-13-212556-0

Editorial/production supervision
and interior design: Tom Aloisi
Cover design: George Cornell
Manufacturing buyer: Gordon Osbourne

This manual is dedicated to all technical authors that have given the time and effort required to researching, testing and reviewing materials for such a book.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN: 0-13-212556-0 025

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Prentice-Hall of Southeast Asia Pte. Ltd., *Singapore*
Whitehall Books Limited, *Wellington, New Zealand*

Preface

This manual can be used with existing textbooks and digital training equipment. It can be used as a practical laboratory workbook for training in the use and understanding of digital circuits. The manual can also be used as a stand-alone text and/or laboratory manual or workbook for teaching the basics of digital electronics.

A step-by-step method is used throughout the book to enable the reader to master each section so that the accumulation of knowledge can be used in each succeeding section in a building-block fashion, from basic to more complex. The material is presented in a repetitious manner, which is essential in acquiring a skill, but with varying methods which are easy, challenging, and fun to perform.

The book is designed as an individualized learning package and involves the reader in the activities of learning. Many illustrations are included to familiarize students with logic gate symbols and the operation of various devices and circuits. It provides the instructor with student-centered instructional material which does not require preparation.

Each unit follows the same format so the reader can become accustomed to the learning procedure. The first section introduces the topic and provides basic theory for a fundamental understanding. Section 2 consists of basic drawing exercises for familiarity of symbols, concepts, and operating procedures. In Section 3 a definition exercise provides a review of the topics covered. Section 4 involves experiments to enable students to gain manipulative skills and knowledge in working with digital circuits. Fill-in questions are given at the end of each experiment to emphasize the important points gained from the experiment.

An instant review of the topics covered in the first part of the unit is given in Section 5 to reinforce the student's essential knowledge. Section 6 involves more exercises on basic principles covered and some contain more complex circuits. A basic troubleshooting application on digital devices is provided in Section 7 to further the student's hands-on skills. Section 8 has two self-checking quizzes to aid students in gaining experience taking digital electronic tests and as a final review. Answers to the experiments and quizzes follow each unit.

A SPECIAL MESSAGE TO STUDENTS

You are studying digital electronics to obtain employment or upgrade yourself in a lucrative, exciting, and challenging industry. It is up to you, not your instructor (or anyone else, for that matter), how well you master the knowledge and skills required for such a fascinating mainstream career. To gain full value from this manual:

1. Perform all the experiments, exercises, and self-checking quizzes.
2. Review each section of the book from time to time to refresh your memory as to the basic concepts of the various logic gates, flip-flops, and digital devices.
3. Keep this book and review it before you take a job entrance examination.
4. Refer to this book when you are on the job to become a more competent technician and to prepare for a higher-level position.
5. Have this book handy when you are servicing equipment, to refer to the sections on testing digital logic devices and troubleshooting circuits. It can serve as a valuable aid to reducing time spent on repairing electronic devices.
6. Review the material in this book when you are preparing to take professional license examinations, such as those for the FCC radio telephone operator's license and the CET (Certified Electronic Technician).

PERFORMING EXPERIMENTS

Most, if not all experiments can be performed on the commercial logic trainer boards existing in most schools. If these trainers are not available, the experiments can still be performed by constructing the inexpensive digital test equipment described in the appendix and using breadboards with 1-mil-on-center holes.

SPECIAL NOTE TO INSTRUCTORS

Some of the more complex circuits in the experiments can be hard-wired on perforated board modules (it is advisable to use IC sockets). To meet laboratory time requirements, these modules can be passed out to groups of students to use in performing the experiments.

Fredrick W. Hughes

Contents

PREFACE, xi

A SAFETY (Preliminary Review Unit) 1

A-1 Introduction, 1
A-2 Current Hazards and Voltage Safety Precautions, 1
A-3 Neat Working Area, 2
A-4 Hand Tool Safety Precautions, 2
A-5 In Case of Electrical Shock, 2

B BASIC DIGITAL LOGIC TEST INSTRUMENTS (Preliminary Review Unit) 4

B-1 The Logic Probe, 4
B-2 The Logic Pulser, 5
B-3 Use of the Logic Pulser and Logic Probe, 5
B-4 IC Test Devices, 6

C PROCEDURE FOR TESTING A DIGITAL CIRCUIT (Preliminary Review Unit) 7

1 BINARY REPRESENTATION AND NUMBER SYSTEMS 8

1-1 Identification, Theory and Operation, 8
- 1-1a Introduction: Why the Use of Various Number Systems, 8
- 1-1b Binary Number System, 9
- 1-1c Converting from Decimal to Binary, 9
- 1-1d Converting from Binary to Decimal, 10
- 1-1e Operating with Binary Fractions, 11
- 1-1f Binary Representation of Positive and Negative Logic, 12
- 1-1g The Octal Number System, 13
- 1-1h The Hexadecimal Number System, 14
- 1-1i The Binary-Coded-Decimal 8421 Code, 16
- 1-1j Comparison of Number Systems, 16

1-2 Exercises I, 17
1-3 Definition Exercises, 23
1-4 Experiments, 24
- Exp. 1. Identifying Equivalent Binary/Decimal Numbers, 24

1-5 Instant Review, 26
1-6 Exercises II, 26
1-7 Troubleshooting Application: Number Conversion, 27
1-8 Self-Checking Quizzes, 28
- 1-8a Number Systems: True-False Quiz, 28
- 1-8b Number Systems: Multiple-Choice Quiz, 28

Answers to Experiments and Quizzes for Unit 1, 29

2 LOGIC GATES 30

2-1 Identification, Theory, and Operation, 30
- 2-1a Introduction, 30
- 2-1b The AND Gate, 30
- 2-1c The OR Gate, 31
- 2-1d The Buffer/Driver and Inverter, 32
- 2-1e Negated-Input Gates, 33
- 2-1f The Exclusive-OR Gate, 33
- 2-1g The NAND Gate, 34
- 2-1h The NOR Gate, 35
- 2-1i The Exclusive-NOR Gate, 36
- 2-1j Equivalent Gates, 37
- 2-1k Expanding Gate Inputs, 37

2-2 Exercises I, 38

2-3 Definition Exercises, 41

2-4 Experiments, 42
- Exp. 1. The AND Gate, 42
- Exp. 2. The OR Gate, 43
- Exp. 3. The Inverter, 44
- Exp. 4. The Negated-Input Gate, 45
- Exp. 5. The Exclusive-OR Gate, 46
- Exp. 6. The NAND Gate, 47
- Exp. 7. The NOR Gate, 48
- Exp. 8. The Exclusive-NOR Gate, 48

2-5 Instant Review, 50

2-6 Exercises II, 50

2-7 Troubleshooting Application: Logic Gates, 53

2-8 Self-Checking Quizzes, 54
- 2-8a Logic Gates: True-False Quiz, 54
- 2-8b Logic Gates: Multiple-Choice Quiz, 55

Answers to Experiments and Quizzes for Unit 2, 56

3 BASIC COMBINATIONAL LOGIC GATES AND BOOLEAN ALGEBRA 58

3-1 Identification, Theory, and Operation, 58
- 3-1a Introduction, 58
- 3-1b The AND-to-OR Circuit, 58
- 3-1c The OR-to-AND Circuit, 59
- 3-1d Laws of Boolean Algebra, 60

3-1d.1 Commutative Laws, 60 •
3-1d.2 Associative Laws, 60 •
3-1d.3 Distributive Law (Factoring), 61 •
3-1d.4 Complementary Laws, 61 •
3-1d.5 AND Laws, 62 • *3.1d.6 OR Laws, 62* • *3-1d.7 De Morgan's Laws, 63* •
3-1d.8 Reduction Laws, 64

- 3-1e Simplifying Basic Boolean Expressions, 67

3-1e.1 Simplifying 6-Gate-to-2-Gate Logic Diagram, 67 • *3-1e.2 Simplifying NAND-to-NOR Logic Diagram, 68* • *3-1e.3 Simplifying NOR-to-NAND Logic Diagram, 69*

- 3-1f Constructing Logic Diagrams from Boolean Expressions, 70

3-2 Exercises I, 70

3-3 Definition Exercises, 76

3-4 Experiments, 77
- Exp. 1. Equivalent Circuits for $AB + AC = A(B + C)$, 77
- Exp. 2. Equivalent Circuits for $AC + BC + AD + BD = (A + B)(C + D)$, 78
- Exp. 3. Equivalent Circuits for $\overline{AB} = \overline{A} + \overline{B}$, 80
- Exp. 4. Equivalent Circuits for $\overline{A + B} = \overline{A}\,\overline{B}$, 81
- Exp. 5. Equivalent Circuits for $\overline{\overline{AB} \cdot \overline{CD}} = AB + CD$, 82
- Exp. 6. Equivalent Circuits for $\overline{(\overline{A + B}) + (\overline{C + D})} = (A + B)(C + D)$, 83

3-5 Instant Review, 84

3-6 Exercises II, 85

3-7 Troubleshooting Application: Combinational Logic Gates, 92

3-8 Self-Checking Quizzes, 94
- 3-8a Combinational Logic Gates: True-False Quiz, 94
- 3-8b Combinational Logic Gates: Multiple-Choice Quiz, 94

Answers to Experiments and Quizzes for Unit 3, 96

4 CLOCK AND TRIGGER CIRCUITS 97

4-1 Identification, Theory, and Operation, 97
- 4-1a Introduction, 97
- 4-1b The Inverter Clock, 97
- 4-1c NAND and NOR Gate Clocks, 98
- 4-1d Crystal-Controlled Clock, 99
- 4-1e The 555 Precision Timer IC Clock, 100

4-1e.1 Basic Operation of the 555 Timer IC, 101 • *4-1e.2 Basic 555 Clock, 101* • *4-1e.3 555 Duty Cycle, 102*
- 4-1f Pulse Nomenclature and Frequency, 102
- 4-1g 555 Timer One-Shot Trigger Circuit, 104
- 4-1h 74121 Monostable Multivibrator, 105
- 4-1i The Schmitt Trigger Circuit, 106

4-2 Exercises I, 107

4-3 Definition Exercises, 110

4-4 Experiments, 113

Exp. 1. Inverter Clock, 114
Exp. 2. NAND/NOR Clocks, 115
Exp. 3. Crystal-Controlled Clock, 116
Exp. 4. 555 Timer IC Clock, 117
Exp. 5. Two-Tone Alarm Circuit, 119
Exp. 6. 555 Timer One-Shot Trigger Circuit, 121
Exp. 7. 74121 IC One-Shot Trigger Circuit, 123
Exp. 8. The Schmitt Trigger Circuit, 125

4-5 Instant Review, 127

4-6 Exercises II, 128

4-7 Troubleshooting Application: 555 Timer IC Clock, 129

4-8 Self-Checking Quizzes, 129
- 4-8a Clocks and Trigger Circuits: True-False Quiz, 129
- 4-8b Clocks and Trigger Circuits: Multiple-Choice Quiz, 130

Answers to Experiments and Quizzes for Unit 4, 131

5 FLIP-FLOPS 133

5-1 Identification, Theory, and Operation, 133
- 5-1a Introduction, 133
- 5-1b *R-S* Flip-Flop, 133
- 5-1c The Bounceless Switch, 135
- 5-1d Clocked *R-S* Flip-Flop, 136
- 5-1e Toggle (T-Type) Flip-Flop, 137
- 5-1f *J-K* Flip-Flop, 137
- 5-1g D-Type Flip-Flop, 138

5-2 Exercises I, 140

5-3 Definition Exercises, 142

5-4 Experiments, 144

Exp. 1. NAND Gate *R-S* Flip-Flop, 144
Exp. 2. The Universal *J-K* Flip-Flop, 146
Exp. 3. D-Type Flip-Flop, 148

5-5 Instant Review, 150

5-6 Exercises II, 151

5-7 Troubleshooting Application: Testing the *J-K* Flip-Flop, 153

5-8 Self-Checking Quizzes, 153
- 5-8a Flip-Flops: True-False Quiz, 153
- 5-8b Flip-Flops: Multiple-Choice Quiz, 154

Answers to Experiments and Quizzes for Unit 5, 155

6 BINARY REGISTERS 156

6-1 Identification, Theory, and Operation, 156
- 6-1a Introduction, 156
- 6-1b The Basic 4-Bit Word Binary Register, 157

6-1b.1 Serial Data Input, 158 • *6-1b.2 Shift Right Operation, 158* • *6-1b.3 Serial Output Data, 158* • *6-1b.4 Parallel Output Data, 158* • *6-1b.5 Serial-to-Parallel Data Conversion, 158* • *6-1b.6 Parallel Input Data, 159* • *6-1b.7 Parallel-to-Serial Data Conversion, 159* • *6-1b.8 Clearing Data from a Register, 159*
- 6-1c Shift Right/Shift Left Register, 159

6-1c.1 Shift Left Operation, 159 • *6-1c.2 Multiplication by Factors of 2, 159*

• *6-1c.3 Division by Factors of 2, 160*
6-1d Rotating Data, 161
6-1d.1 Normal Data Rotate, 161 •
6-1d.2 Complement Data Rotate, 161
6-1e Register Data Transfer, 162
6-2 Exercises I, 163
6-3 Definition Exercises, 165
6-4 Experiments, 167
Exp. 1. Basic 4-Bit Shift Register, 167
Exp. 2. Shift Right/Shift Left Register, 170
Exp. 3. The 7495 as a More Versatile Register, 173
Exp. 4. Rotating Data in a Register, 175
6-5 Instant Review, 177
6-6 Exercises II, 178
6-7 Troubleshooting Application: Testing the Binary Register, 180
6-8 Self-Checking Quizzes, 180
6-8a Binary Register: True-False Quiz, 180
6-8b Binary Register: Multiple-Choice Quiz, 181
Answers to Experiments and Quizzes for Unit 6, 183

7 BINARY COUNTERS 184

7-1 Identification, Theory, and Operation, 184
7-1a Introduction, 184
7-1b Ring Counter, 185
7-1c Switch-Tail Ring Counter, 186
7-1d Binary Up-Counter, 186
7-1e Binary Down-Counter, 188
7-1f Synchronous Counters, 189
7-1g Other Modulo Counters, 191
7-2 Exercises I, 192
7-3 Definition Exercises, 194
7-4 Experiments, 195
Exp. 1. Ring Counter/Switch-Tail Ring Counter, 195
Exp. 2. Binary Up/Down-Counters, 197
Exp. 3. Modulo Counters, 200
7-5 Instant Review, 202
7-6 Exercises II, 202
7-7 Troubleshooting Application: Testing a 2-Bit Binary Up-Counter, 204
7-8 Self-Checking Quizzes, 205
7-8a Binary Counters: True-False Quiz, 205
7-8b Binary Counters: Multiple-Choice Quiz, 205
Answers to Experiments and Quizzes for Unit 7, 207

8 ARITHMETIC CIRCUITS 208

8-1 Identification, Theory, and Operation, 208
8-1a Introduction, 208
8-1b Binary Addition, 208
8-1c Binary Half-Adder, 210
8-1d Binary Full-Adder, 210
8-1e Binary Subtraction, 211
8-1f Binary Subtraction Using Complementation, 212
8-1f.1 The 1's-Complement Method of Subtraction, 212 • *8-1f.2 The 2's-Complement Method of Subtraction, 213*
8-1g Serial Adder/Subtracter, 214
8-1h Parallel Adder/Subtracter, 216
8-1i Assigned Numbers and 2's-Complement Notation, 218
8-2 Exercises I, 220
8-3 Definition Exercises, 223
8-4 Experiments, 225
Exp. 1. Binary Adders, 225
Exp. 2. Serial Adder/Subtracter, 226
Exp. 3. Parallel Adder/Subtracter, 229
8-5 Instant Review, 230
8-6 Exercises II, 231
8-7 Troubleshooting Application: Testing a Binary Full-Adder, 233
8-8 Self-Checking Quizzes, 233
8-8a Binary Adders: True-False Quiz, 233
8-8b Binary Adders: Multiple-Choice Quiz, 234
Answers to Experiments and Quizzes for Unit 8, 235

9 DATA CONVERSION AND TRANSMISSION CIRCUITS 236

9-1 Identification, Theory, and Operation, 236
- 9-1a Introduction, 236
- 9-1b Encoders, 236
- 9-1c Decoders, 237
- *9-1c.1 Basic AND Gate Decoders, 237* •
- *9-1c.2 8421 BCD-to-Decimal Decoder, 238* •
- *9-1c.3 8421 BCD-to-Seven-Segment Decoder, 239*
- 9-1d Parity Circuits, 239
- 9-1e Multiplexer/Demultiplexer Circuits, 240

9-2 Exercises I, 242

9-3 Definition Exercises, 244

9-4 Experiments, 246
- Exp. 1. NAND Gate Encoder, 246
- Exp. 2. Basic AND Gate Decoders, 248
- Exp. 3. BCD-to-Decimal Decoder, 249
- Exp. 4. Parity Circuits, 250
- Exp. 5. Multiplexer/Demultiplexer System, 252

9-5 Instant Review, 254

9-6 Exercises II, 255

9-7 Troubleshooting Application: Testing a Multiplexer and a Demultiplexer, 256

9-8 Self-Checking Quizzes, 256
- 9-8a Digital Conversion Devices: True-False Quiz, 256
- 9-8b Digital Conversion Devices: Multiple-Choice Quiz, 258

Answers to Experiments and Quizzes for Unit 9, 259

10 OPTOELECTRONIC INDICATORS AND DISPLAYS 261

10-1 Identification, Theory, and Operation, 261
- 10-1a Introduction, 261
- 10-1b Light-Emitting Diode, 261
- 10-1c Seven-Segment LED Display, 263
- 10-1d Multidigit Displays, 264
- 10-1e Alphanumeric Displays, 265
- 10-1f Liquid Crystal Display, 266
- 10-1g Other Types of Displays, 268
- *10-1g.1 Gas Discharge Display, 268* •
- *10-1g.2 Vacuum Fluorescent Display, 268* •
- *10-1g.3 Incandescent Display, 270*
- 10-1h Comparison of Displays, 270

10-2 Exercises I, 270

10-3 Definition Exercises, 272

10-4 Experiments, 275
- Exp. 1. Binary Counter with Seven-Segment Display, 275

10-5 Instant Review, 276

10-6 Exercises II, 277

10-7 Troubleshooting Application: Testing Display Systems, 278

10-8 Self-Checking Quizzes, 279
- 10-8a Digital Displays: True-False Quiz, 279
- 10-8b Digital Displays: Multiple-Choice Quiz, 279

Answers to Experiments and Quizzes for Unit 10, 280

11 MEMORY DEVICES 281

11-1 Identification, Theory, and Operation, 281
- 11-1a Introduction, 281
- 11-1b The Random Access Memory, 281
- 11-1c Increasing the Word Length of a Memory, 283
- 11-1d Increasing the Number of Words in a Memory, 284
- 11-1e Organization of Other Memory ICs, 286
- 11-1f The Read-Only Memory, 286
- *11-1f.1 Factory-Programmed ROM, 286*
- *11-1f.2 Field-Programmable ROM, 286*
- *11-1f.3 Erasable PROM, 287* •
- *11-1f.4 Electrically Alterable PROM, 288*
- 11-1g Other Types of Memories, 288
- 11-1h Other Memory Terminology, 289

11-2 Exercises I, 289

11-3 Definition Exercises, 291

11-4 Experiments, 295
- Exp. 1. Binary-to-Hexadecimal Decoder Display, 295

Exp. 2. Alphanumeric 5 × 7 Dot Matrix Display, 298

11-5 Instant Review, 301

11-6 Exercises II, 301

11-7 Troubleshooting Application: Testing a RAM, 303

11-8 Self-Checking Quizzes, 304

11-8a Memory Devices: True-False Quiz, 304

11-8b Memory Devices: Multiple-Choice Quiz, 304

Answers to Experiments and Quizzes for Unit 11, 305

12 DIGITAL IC OPERATION AND SPECIFICATIONS 307

12-1 Identification, Theory, and Operation, 307

12-1a Introduction, 307

12-1b TTL Family ICs, 308

12-1b.1 Standard TTL IC, 308 • *12-1b.1a TTL NAND Gate Operation When Both Inputs Are High, 308* • *12-1b.1b TTL NAND Gate Operations When Any One or Both Inputs Are Low, 308* • *12-1b.2 Open-Collector TTL IC, 310* • *12-1b.3 High-Speed TTL IC, 310* • *12-1b.4 Low-Power TTL IC, 310* • *12-1b.5 Schottky-Diode Clamped TTL IC, 310* • *12-1b.6 Low-Power Schottky TTL IC, 311*

12-1c MOS Technology and CMOS Logic Circuits, 311

12-1c.1 P- and N-Channel MOS Technology, 311 • *12-1c.2 CMOS Inverter Circuits, 311* • *12-1c.3 CMOS NAND Gate Circuit, 312* • *12-1c.4 CMOS Logic Voltage Levels, 313* • *12-1c.5 CMOS IC Features, 313*

12-1d Three-State Logic Circuits, 314

12-1e Other Types of Logic Families, 314

12-1f DIP IC Identification, 315

12-1g General Digital IC Specifications, 316

12-1g.1 Fan-Out, 316 • *12-1g.2 Propagation Delay, 316* • *12-1g.3 Power Dissipation, 317* • *12-1g.4 Noise Margin, 317*

12-1h Interfacing Logic Families, 317

12-1h.1 Interfacing TTL to CMOS, 317 • *12-1h.2 Interfacing CMOS to TTL, 318*

12-1i Power Supply Decoupling, 318

12-2 Exercises I, 319

12-3 Definition Exercises, 321

12-4 Experiments, 325

Exp. 1. Comparison of TTL and CMOS Logic 1 Voltage Levels, 325

12-5 Instant Review, 327

12-6 Exercises II, 328

12-7 Troubleshooting Application: A Binary Counting System, 329

12-8 Self-Checking Quizzes, 332

12-8a Digital IC Operation: True-False Quiz, 332

12-8b Digital IC Operation: Multiple-Choice Quiz, 333

Answers to Experiments and Quizzes for Unit 12, 334

APPENDIX: BASIC DIGITAL TEST EQUIPMENT 335

General Construction Suggestions, 335

TTL/CMOS Logic Probe, 336

Logic Probe Parts List, 336

Logic Probe Theory of Operation, 336

Logic Probe Specific Construction Procedures, 336

Logic Probe Operation, 338

TTL/CMOS Logic Pulser, 338

Logic Pulser Parts List, 338

Logic Pulser Theory of Operation, 338

Logic Pulser Specific Construction Procedures, 338

Logic Pulser Operation, 340

Unit A
Preliminary Review

Safety

SECTION A-1
INTRODUCTION

The experiments in this manual do not use a voltage regulator greater than + 15 V dc; therefore, the chance of getting an electrical shock is greatly reduced. However, all voltages do have the potential to burn materials and start fires, to destroy electronic components, and present hazards to the person performing the operations. Common sense and an awareness of electrical circuits is important whenever you are working on these experiments. An electronic technician or student may have to work with high voltages, power tools, and machinery. Before actual work is performed, sufficient instruction should be acquired in the proper use and safety requirements of all electronic devices.

SECTION A-2
CURRENT HAZARDS AND VOLTAGE SAFETY PRECAUTIONS

It takes a very small amount of current to pass through the human body from an electrical shock to injure a person severely or fatally. The 60-Hz current values affecting the human body are as follows:

Current Value	*Effects*
1 mA (0.001 A)	Tingling or mild sensation
10 mA (0.01 A)	A shock of sufficient intensity to cause involuntary control of muscles, so that a person cannot let go of an electrical conductor
100 mA (0.1A)	A shock of this type lasting for 1 second is sufficient to cause a crippling effect or even death
Over 100 mA	An extremely severe shock that may cause ventricular fibrillation, where a change in the rhythm of the heartbeat causes death almost instantaneously

The resistance of the human body varies from about 500,000 Ω when dry to about 300 Ω when wet (including the effects of perspiration). In this case, voltages as low as 30 V can cause sufficient current to be fatal (I = voltage/wet resistance = 30 V/300 Ω = 100 mA).

Even though the actual voltage of a circuit being worked on is low enough not to present a very hazardous situation, the equipment being used to power and test the circuit (i.e., power supply, signal generator, meters, oscilloscopes) is usually operated on 120 V ac. This equipment should have (three-wire) polarized line cords that are not cracked or brittle. An even better safety precaution is to have the equipment operate from an isolation transformer, which is usually connected to a workbench. To minimize the chance of getting shocked, a person should use only one hand while making voltage measurements, keeping the other hand at the side of the body, in the lap, or behind the body. Do not defeat the safety feature (fuse, circuit breaker, interlock switch) of any electrical device by shorting across it or by using a higher amperage rating than that specified by the manufacturer. These safety devices are intended to protect both the user and the equipment.

SECTION A-3
NEAT WORKING AREA

A neat working area requires a careful and deliberate approach when setting it up. Test equipment and tools should be set out on the workbench in a neat and orderly manner. Connecting wires from the test equipment to the circuit under test should be placed so as not to interfere with testing procedures.

Before power is applied to a circuit, the area around the circuit should be cleared of extra wires, components, hand tools, and debris (cut wire and insulation).

SECTION A-4
HAND TOOL SAFETY PRECAUTIONS

Hand tools can be dangerous and cause severe injuries. Diagonal cutters, wire strippers, long-nose pliers, and crimping tools can pinch and cut. Use care in cutting wire since small pieces can become projectiles and hit another person in the face or eye.

Screwdrivers should be held properly so that they do not slip and puncture some part of the body. Do not use them as chisels or cutters.

A soldering iron should have a holder on which to place it. Care must be used not to burn the body or other materials. Be careful of hot solder, which can splash and cause severe burns, especially to the eyes and face.

SECTION A-5
IN CASE OF ELECTRICAL SHOCK

When a person comes in contact with an electrical circuit of sufficient voltage to cause shock, certain steps should be taken as outlined in the following procedure:

1. Quickly remove the victim from the source of electricity by means of a

switch, circuit breaker, pulling the cord, or cutting the wires with a well-insulated tool.

2. It may be faster to separate the victim from the electrical circuit by using a dry stick, rope, leather belt, coat, blanket, or any other nonconducting material.

   CAUTION: Do not touch the victim or the electrical circuit unless the power is off.

3. Call for assistance, since other persons may be more knowledgeable in treating the victim or can call for professional medical help while first aid is being given.
4. Check the victim's breathing and heartbeat.
5. If breathing has stopped but the victim's pulse is detectable, give mouth-to-mouth resuscitation until medical help arrives.
6. If the heartbeat has stopped, use cardiopulmonary resuscitation, *but only if you are trained in the proper technique.*
7. If both breathing and heartbeat have stopped, alternate between mouth-to-mouth resuscitation and cardiopulmonary resuscitation (*but only if you are trained*).
8. Use blankets or coats to keep the victim warm and raise the legs slightly above head level to help prevent shock.
9. If the victim has burns, cover your mouth and nostrils with gauze or a clean handkerchief to avoid breathing germs on the victim and then wrap the burned areas of the victim firmly with sterile gauze or a clean cloth.
10. *In any case, do not just stand there*—do something within your ability to give the victim some first aid.

Unit B
Preliminary Review

Basic Digital Logic Test Instruments

SECTION B-1
THE LOGIC PROBE

Testing analog (or linear) circuits usually involves a voltmeter to verify specific voltage levels at various points in a circuit. Very often, testing digital circuits requires only verifying the presence or absence of a voltage, not its specific level. Many digital circuits operate on a standard voltage level, such as +5, +12, or −12 V. Digital circuits are tested for 1s and 0s. In most circuits a 1 represents a positive voltage and a 0 represents zero voltage or ground.

The logic probe is a rather simple test instrument that detects the presence or absence of a voltage level. It is a small hand-held device as shown in Figure P-1. For proper operation the logic probe requires power, which it receives from the circuit being tested, by connecting the power leads to the appropriate power supply connections (assume that $+V_{CC} = +5$ V).

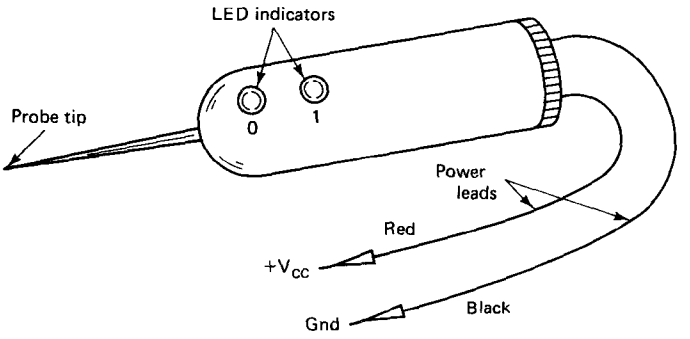

Figure P-1 Logic probe.

The logic probe is used by placing the probe tip at the point in the circuit to be tested. If a positive voltage (must be of sufficient voltage, approximately 2 V) is present, the LED indicator labeled 1 will light. If the voltage is 0 V, the LED indicator labeled 0 will light.

Some logic probes may have only one LED indicator, in which case the presence of a positive voltage will cause it to light and 0 V will cause it to be out. Other logic probes may be more sophisticated and have LED indicators to detect pulses and for special purposes. The appendix shows a schematic diagram and procedure for constructing a basic TTL/CMOS logic probe.

SECTION B-2
THE LOGIC PULSER

The logic pulser shown in Figure P-2 is similar to the lobic probe and can be used as its counterpart. While the logic probe is used to test the presence of a 1 or 0, the logic pulser is used to inject a 1 or 0 into a digital circuit. A momentary-action pushbutton switch is used to activate a positive voltage at the probe tip. Like the logic probe, the logic pulser also receives its operating power from the circuit being tested by connecting the power leads to the appropriate power supply points.

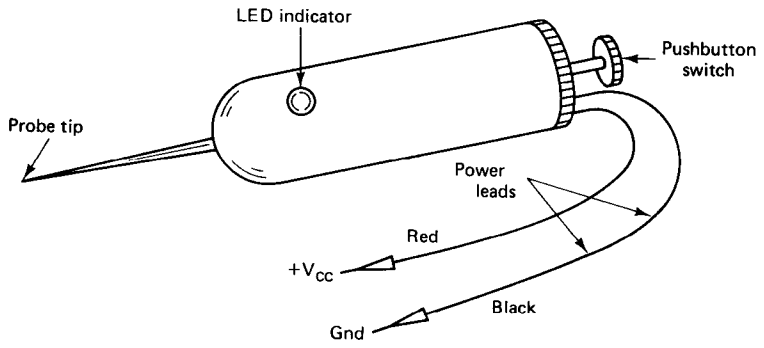

Figure P-2 Logic pulser.

The logic pulser is used by placing the probe tip at the desired input point in the circuit and then injecting a 1 by pressing the pushbutton switch. The LED indicator shows when the probe tip is at a 1 and 0 level; 1 = on, 0 = off. The logic pulser may also be called a digital signal injector. The appendix shows a schematic diagram and procedure for constructing a basic TTL/CMOS logic pulser.

SECTION B-3
USE OF THE LOGIC PULSER AND LOGIC PROBE

Figure P-3 shows a basic procedure for using the logic pulser and logic probe together to test a digital circuit. First, the power leads of each test device are connected to the circuit. Next, the logic pulser is placed at the input to the circuit and the logic probe is placed at the output of the circuit. The logic probe may indicate a 1 or 0, depending on the function of the circuit being tested. Finally, the pushbutton on the logic pulser is activated to place a 1 at the input of the circuit. The LED indicator of the logic probe should

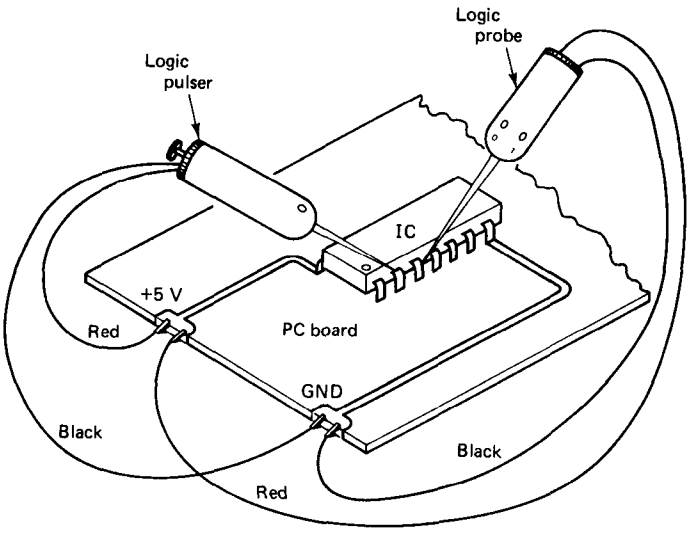

Figure P-3 Use of the logic pulser and logic probe.

change states (if 0, it goes to 1, and if 1, it goes to 0) provided that the circuit is functioning properly.

SECTION B-4
IC TEST DEVICES

Two other very useful IC test devices for testing digital ICs are shown in Figure P-4. If ICs are mounted close to the PC board and near other components, it is difficult to use logic pulsers and probes to test the circuits. An IC pin extender test clip (Figure P-4a) is placed over the IC and the protruding extender pins make it easier to test the circuit.

The logic monitor clip (Figure P-4b) is actually a more sophisticated logic probe that is placed over a digital IC and gives the state or status of each pin with the use of LEDs simultaneously. It uses diode circuitry that automatically selects the $+V_{CC}$ and Gnd pins, since the location of the power supply pins varies on different function ICs.

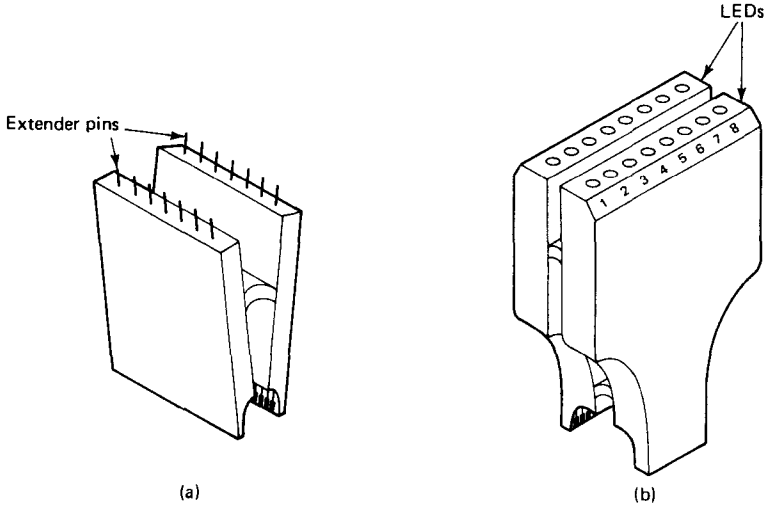

Figure P-4 IC test devices: (a) IC pin extender test clip; (b) logic monitor clip. (From F. Hughes, *Illustrated Guidebook to Electonic Devices and Circuits,* Prentice-Hall, Englewood Cliffs, N.J., © 1983, Fig. 14-25, p. 426. Reprinted with permission.)