DIGITAL ELECTRONICS
Logic and Systems

Second Edition

John D. Kershaw

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Preface

For the first edition of this text, it was thought that TTL and CMOS circuits would be the dominant logic family through the end of the 1970s. Back then, both RTL and DTL logic were yielding to TTL as the ideal logic family. In retrospect, that judgment has proven correct, for although microprocessor circuitry, gate array, and other custom LSI circuits have taken over large segments of the hardware, these advances have merely brought about the economies necessary for a massive expansion in the amount of digital circuitry that could be put to practical use.

At the time of writing the second edition, most of the basic data and information pertaining to TTL and CMOS logic families are still relevant. Although for mass-scale production, gate array and other forms of custom circuits may supply ever increasing portions of the circuitry in use, the TTL and CMOS standard family of circuits will continue to be used as the essential "glue" that binds many custom devices together. They will also be used in small-scale production and in prototyping many of the custom devices. The term *TTL compatible* continues to be a keyword in integrated circuit design and will continue to be through the next decade.

Significantly, improved versions of both TTL and CMOS circuits are now being released to the marketplace. They provide speed and power improvements without any radical change in other operating parameters. In most cases, the old pin-outs are still available. Therefore, for the second edition of this text, Chapter 9 has been expanded to provide a detailed discussion of the AC and DC parameters of both current and newer versions of TTL and CMOS families.

In the area of memory circuits, change has been even more dramatic. Accordingly, this new edition includes the latest in memory technology. The parallel development of three classes of integrated circuits—RAMs, ROMs, and microprocessors—has led to a virtual explosion in the application of digital electronics. Each year, new generations of these devices reach the marketplace, and each generation is an improvement. The new devices are likely to be faster, cheaper, of higher capacity, and more reliable and less power consuming than the devices they replace.

To bring users of this book up to date with the recent improvements in memory technology, the latter chapters have been extensively revised. Furthermore, a chapter has been added on the important subject of multiplexers and demultiplexers, which are commonly used in the handling of microprocessor buses. A relatively new and promising family of devices, the programmable array logic, has also been added with this edition.

The application of devices such as these places a renewed emphasis on the use of Boolean algebra. The dispersed and somewhat incomplete coverage of this topic in the first edition has been expanded and is now included in a single section. Moreover, in recognition of the fact that microprocessor op codes and address numbering are commonly expressed in hexadecimal, coverage of this number system has been added to Chapter 2.

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Finally, thanks are due to numerous individuals and firms within the electronics industry for providing up-to-date information that was helpful in preparing the second edition and, in many cases, for giving their permission to reprint copyrighted material in the book. My appreciation is extended to the following firms:

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Preface to the First Edition

This text is aimed at providing students with an easy understanding of digital logic and digital logic systems. Although I discuss some circuitry in introducing the logic elements, there is no attempt to present detailed mathematical circuit analysis. To make effective use of this text the reader needs only knowledge of basic algebra and basic electricity. A knowledge of semiconductor theory would be highly desirable but is not an absolute prerequisite.

Digital electronics, like other areas of electronic technology, presents both student and instructor with a problem of too much: too much to learn, too much to teach, in too little time. Unless the course hours allotted this subject are increased, we face hard choices about what to include and what to leave out. A count of the new application sheets issued by circuit manufacturers each year shows how much new and perhaps necessary information is being added. Ideally, culling obsolete information from the program will create the time to discuss new developments. In practice, though, the pressure to include more information means that some basic principles of logic systems may receive inadequate coverage. Mindful of this problem, I have left out of this text what is obviously obsolete, and where doubt exists I leave the choice to the user. The four basic logic gates and the flip-flop storage elements are given full coverage, with a wealth of applications. Although individual gates and flip-flops are currently used only to tie together large- or medium-scale integrated circuits into larger logic units, one must still master their application.

For the sake of simplicity, I explain logic subassemblies such as adders, counters, and shift registers in their simplest logic form before presenting them as medium-scale integrated circuits. The circuits presented are primarily TTL and CMOS, except in the area of memory circuits, where large-scale ECL and MOS have a substantial share of the market.

The timing diagram has grown in importance as an instrument for analyzing digital logic circuits, and therefore it is introduced early in the text and is given continual emphasis thereafter.

Each chapter is preceded by a set of objectives to be accomplished by students as a result of reading the chapter and performing the many problems and exercises. As an additional study aid, summaries and glossaries are included at the end of the chapters.

The glossaries are written to support the material in the chapter and may not provide all possible meanings of the terms. They are arranged in logical rather than alphabetical order. In many chapters, the glossary can provide an effective review of the material covered. Students should be encouraged to refer to the glossaries whenever they have difficulty understanding something in the text.

I have relied heavily on drawings of logic symbols, waveforms, and wiring diagrams to make the exercises more meaningful. Two kinds of exercises have been provided, allowing the instructor greater flexibility in making assignments. The "Questions" are easier and less time consuming. They provide a test of the student's understanding of the material. The "Problems" are more time consuming and test performance as well as understanding. They require the student to perform calculations, make simple logic drawings, select the correct logic unit for an application, indicate the proper wiring of logic circuits, and complete timing diagrams. The wiring diagram problems are ideal for assembly and checkout in the lab. Only a few of the problems require the student to do extensive drawings; these should be assigned when practice in logic drawing is desirable.

Students will find it useful to have a drawing template MIL-STD-806C (available at most drafting supply stores), which contains the most widely accepted set of logic symbols used in the field. It would also be useful for students to have access to catalogues of standard TTL and CMOS circuits. These are available from numerous manufacturers. The majority of the circuits called for in exercises, however, have been presented as figures in the text.

In the formation of this text I have received frequent advice and guidance from colleagues and reviewers, for which I am grateful. John Bakum (Middlesex County College), Frederick Driscoll (Wentworth Institute), John Nagi (Hud-

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John D. Kershaw

Contents

■ CONTENTS iii

■ PREFACE ix

■ PREFACE TO THE FIRST EDITION xi

Chapter 1
■ INTRODUCTION TO DIGITAL MACHINES 1

Objectives 1
Introduction 2
Digital Electronic Equipment 2
The General Purpose Stored-Program Digital Computer 2
Special-Purpose Computers 3
Accounting Machines 3
Digital Test Equipment 3
Digital Scales 4
Digital Communication 4
Employment Opportunities 6
Drawings and Instructions 6
Drawing Systems 6
The Flow Diagram 6
Summary 8
Glossary 8
Questions 9
Problem 9

Chapter 2
■ NUMBER SYSTEMS 11

Objectives 11
Introduction 12
General Number System 12
Binary Number System 12
Importance to Electronic Computers 12
Decimal-to-Binary Conversion 13
Binary-to-Decimal Conversion 15
Octal Number System 15
General 15
Decimal-to-Octal Conversion 16
Octal-to-Decimal Conversion 16
Binary-to-Octal Conversion 17
Binary-Coded Decimal (BCD) 17
Decimal-to-BCD Conversion 17
BCD-to-Decimal Conversion 18
Hexadecimal Number System 18
Binary-to-Hexadecimal Conversion 19
Hexadecimal-to-Binary Conversion 19
Hexadecimal-to-Decimal Conversion 19
Decimal-to-Hexadecimal Conversion 19
Comparison of Number Systems 20
Summary 20
Glossary 21
Questions 21
Problems 22

Chapter 3
■ BINARY ARITHMETIC 25

Objectives 25
Introduction 26
Binary Addition 26
Binary Subtraction 28
Direct Subtraction 28
Subtraction by Complement 29
Ones Complement 30
Twos Complement Subtraction 32
Nines Complement Subtraction 33
Binary Multiplication 34
Binary Division 35
Summary 36
Glossary 37
Questions 37
Problems 37

Chapter 4
■ DIGITAL SIGNALS AND SWITCHES 39

Objectives 39
Introduction 40
Binary States 40
Digital Signals 40
Timing 41
Signals Representing Binary Numbers 42
Serial Numbers 42
Parallel Numbers 43
Switching of Digital Signals 44
Binary State of Electrical Devices 44
The Ideal Switch 44
The Manual Switch 45
Shorting Switch 46
The Relay as a Switch 46

Boolean Algebra 48
The Boolean Equation 48
Logic Gates and Symbols 48
Operations with 1 and 0 50
Powers and Multiples of a Boolean Variable 51
The Inversion (Complement) 51
The NAND and NOR Functions 52
DeMorgan's Theorem 53
Boolean Functions in Parallel 54
Summary 54
Glossary 55
Questions 56
Problems 57

Chapter 5
■ ELECTRONIC SWITCHES: DISCRETE AND INTEGRATED 63

Objectives 63
Introduction 64
The Diode as a Switch 64
The Vacuum Tube as a Switch 65
The Bipolar Transistor as a Switch 66
Discrete Component Common Emitter Switch 66
Discrete Component Emitter Follower Switch 67
Integrated Circuit RTL Switch 67
Integrated Circuit TTL Switch 67
The Field Effect Transistor as a Switch 70
Types of Discrete Component FETs 70
Depletion-Mode MOS Field Effect Transistors 70
Enhancement-Mode MOS Field Effect Transistor 72
MOS Integrated Circuit Switches 73
Summary 73
Glossary 75
Questions 76
Problems 77

Chapter 6
■ LOGIC GATE CIRCUITS 81

Objectives 81
Introduction 82
The AND Gate 82
The OR Gate 85
Boolean Manipulation 87
Enable or Inhibit Functions by AND Circuits 88
Enable or Inhibit Functions by OR Circuits 90
Analysis by Timing Diagram 90
Decimal-to-BCD Conversion Using OR Gates 93
BCD-to-Decimal Conversion 94
Summary 95
Glossary 96
Questions 97
Problems 98

Chapter 7
■ INVERTING LOGIC GATES (NOR, NAND) 105

Objectives 105
Introduction 106
The NOR Gate 106
NOR Gate Symbol and Truth Table 106
NOR Gate Discrete Circuits 106
TTL Integrated Circuit NOR Gate 106
CMOS Integrated Circuit NOR Gate 107
Boolean Functions with NOR Gates 109
The NAND Gate 110
NAND Gate Symbol and Truth Table 110
NAND Gate Discrete Circuits 110
TTL Integrated Circuit NAND Gate 110
CMOS Integrated Circuit NAND Gate 111
Boolean Functions with NAND Gates 113
Analysis by Timing Diagram 114
Enable or Inhibit Functions of the NOR Gate 116
Enable or Inhibit Functions of the NAND Gate 118
DeMorgan's Theorem 120
Single-Gate Logic 122
Complete Logic Capability 122
NOR to OR 122
NOR to AND 122
NAND to AND 122
NAND to OR 122
Conversion by Complementary (Inverted) Inputs 124
Summary 124
Glossary 126
Questions 127
Problems 128
Boolean Algebra (Problems 7-24 through 7-26) 133

Chapter 8
■ EXCLUSIVE OR AND EXCLUSIVE NOR GATES 137

Objectives 137
Introduction 138
The Exclusive NOR Gate 138
The Exclusive OR Gate 139
Complementing Switch 140
Analysis by Timing Diagram 140
Parity Generator 142
The Parallel Comparator 146
Complementing Switch for Parallel Data 146
Summary 147
Glossary 148
Questions 149
Problems 150

Chapter 9
■ LOGIC GATE SPECIFICATIONS 153

Objectives 153
Introduction 155
Unit Load 155
Unit Sink Load 155
Unit Source Load 156
Output-Level Parameters 156
Input-Level Parameters 157
Noise Immunity 158
Switching Time Parameters (Rise Time, Fall Time, Propagation Delay Time) 159
Power Drain 160
Speed versus Power 161
Special Circuits for High Speed 161
Integrated Circuit Technologies 164
TTL Specifications 164
  TTL DC Parameters 164
  Operating Conditions and Power Supply Current 166
  Absolute Maximum Ratings 166
  TTL AC Parameters 166
  Other 7400 Series Families 166
  TTL Output Drivers 168
CMOS Specifications 170
  Introduction 170
  DC Voltage Parameters 170
  Noise Immunity 172
  CMOS Power Requirements 175
  CMOS Output Circuits 177
  Switching Frequency 180
  Input Circuit Protection 182
  Absolute Maximum Ratings 184
  Temperature Variations 185
Interfacing CMOS with TTL 185
  TTL-to-CMOS 185
  CMOS-to-TTL 187
74C and 74HC Series Devices 188
Summary 188
Glossary 190
Questions 191
Problems 192

Chapter 10
■ PARALLEL ADDER CIRCUITS 195

Objectives 195
Introduction 196
Binary Addition 196
Half Adder 197
Full Adder 198
Multibit Adders 201
Binary-Coded Decimal Adder 205
Summary 206
Glossary 208
Questions 208
Problems 209

Chapter 11
■ PARALLEL SUBTRACTION 213

Objectives 213
Introduction 214
Binary Subtraction 214
Half Subtractor 214
Full Subtractor 215
Multibit Parallel Subtractor 216
Parallel Comparator 217
Summary 218
Glossary 218
Questions 219
Problems 219

Chapter 12
■ STORAGE REGISTER ELEMENTS 221

Objectives 221
Introduction 222
Set-Reset Flip-Flop 222
Strobe Gates 224
Trigger Flip-Flop 224
Master-Slave Flip-Flop 225

Serial Parity 227
Steerable Flip-Flop (J-K) 228
Strobing Data into the J-K Flip-Flop 229
Integrated Circuit J-K Flip-Flops 230
Timing Parameters of J-K Flip-Flops 230
Bistable Latch (D Latch) 231
D Flip-Flop 233
Integrated Circuit D Flip-Flops 234
Timing Parameters of D Flip-Flops 234
Summary 236
Glossary 237
Questions 239
Problems 240

Chapter 13
■ SHIFT REGISTERS 245

Objectives 245
Introduction 246
Shift Registers 247
Serial-to-Parallel Conversion 249
Parallel-to-Serial Conversion 250
Arithmetic Operation with Shift Registers 250
Four-Bit Universal Shift Register (MSI) 252
MOS Registers 253
Right-Shift-Left-Shift Register 255
Summary 258
Glossary 259
Questions 260
Problems 260

Chapter 14
■ COUNTER CIRCUITS 265

Objectives 265
Introduction 266
Ripple Counter (Trigger Counter) 266
Divide-by-N Ripple Counter 269
Digital Clock 271
Synchronous Counter 272
Binary-Coded Decimal Counter 273
D Flip-Flop Counter 275
Down Counter 276
Up/Down Counters 277
Timing Parameters of Counter Circuits 278
The Digital Counter as a Test Instrument 278
CMOS MSI Synchronous Counter 280
Summary 281
Glossary 282
Questions 283
Problems 284

Chapter 15
■ SERIAL ADDER CIRCUITS 287

Objectives 287
Introduction 288
Serial Addition 288
Serial Adder-Subtractor 288
Twos Complement Adder-Subtractor 290
Serial Comparator 294
Serial Adder with Comparator 294
Binary-Coded Decimal Serial Adder 295
Summary 299
Glossary 300
Questions 300
Problems 301

Chapter 16
■ DIGITAL MULTIPLEXERS AND DEMULTIPLEXERS 303

Objectives 303
Introduction 304
Multiplexer 304
Integrated Circuit Digital Multiplexers 308
Demultiplexer 310
Decoder Glitches 312
Demultiplexed Signal 312
Integrated Circuit Demultiplexers 315
Summary 318
Glossary 319
Questions 319
Problems 320

Chapter 17
■ CLOCK AND TIMING CIRCUITS 321

Objectives 321
Introduction 322
Astable Multivibrator 322
Integrated Circuit Astable Multivibrator 323
Astable Multivibrators from CMOS ICs 324
Unijunction Pulse Generator 325
Schmitt Trigger Circuit 326
LC and Crystal Oscillators 328
Integrated Circuit Crystal Oscillators 329
Cycling 335
Delayed Clock (Clock Phases) 337
Monostable (One-Shot) Multivibrator 338
Need for the Monostable Multivibrator 338
Transistor Monostable Multivibrator 338
Integrated Circuit One-Shot 340

CMOS Gate Monostable Multivibrator 342
Pulse Delay by One-Shot Multivibrator 342
555 Timer as a Monostable Multivibrator 343
Variable Pulse Width Multivibrator 344
Summary 345
Glossary 347
Questions 347
Problems 348

Chapter 18
▪ DISPLAY 351

Objectives 351
Introduction 352
Lamps and Lamp Drivers 352
Relay Driver 354
BCD or Binary Readouts 356
In-Line Readouts 356
Segmented Readouts 357
Description 357
Automatic Blanking 358
Types of Segmented Readouts 363
Incandescent 363
Fluorescent 363
Neon and Other Gas Tubes 363
Light-Emitting Diode (LED) 364
Display Multiplexing 365
Power Averaging 366
Failsafe Circuits 368
LED Dot Matrices 368
Summary 368
Glossary 371
Questions 372
Problems 372

Chapter 19
▪ CONTROL WAVEFORM GENERATORS 375

Objectives 375
Introduction 376
Ring Counter 376
Binary Counter 378
Shift Counter 381
Dual Clock Gating 384
Summary 384
Glossary 386
Questions 387
Problems 387

Chapter 20
▪ DIGITAL-TO-ANALOG CONVERTERS 389

Objectives 389
Introduction 390
Resistor Network 390
Binary Ladder Network 390
Voltage Source D/A Converter 392
Test Waveforms of a Digital-to-Analog Converter 395
Current Source D/A Converter 396
Monolithic D/A Converters 398
Transistor Curve Tracer Using D/A Converters 400
Summary 401
Glossary 403
Questions 403
Problems 403

Chapter 21
▪ ANALOG-TO-DIGITAL CONVERTERS 405

Objectives 405
Introduction 406
Analog Comparator 406
Function 406
Integrated Circuit Comparators 406
A/D Simultaneous Conversion 408
Counter-Controlled A/D Converter 409
Successive Approximation A/D Converter 410
Operation 410
Clock and Delayed Clock Timing 410
Timing and Control Circuits 412
Conversion Waveforms 413
Successive Approximation Registers 415
Sample-and-Hold Amplifier 416
Azimuth and Elevation Data Corrector 416
Summary 419
Glossary 420
Questions 420
Problems 421

Chapter 22
▪ MEMORY TECHNOLOGY 423

Objectives 423
Introduction 424
The Memory Bit 424
Words and Bytes 424

Memory Terms 425
Ferrite Core Memory 427
Semiconductor Memory Circuits 431
Semiconductor Memory Applications 434
Integrated Circuit Memory Technologies 434
Summary 435
Glossary 436
Questions 437
Problems 438

Chapter 23
- **SEMICONDUCTOR READ/WRITE MEMORIES 439**

Objectives 439
Introduction 440
Memory Buses 440
  Address Bus 440
  Address Read Timing 444
  Data Bus and Data Bus Expansion 447
  Write Cycle Timing 448
Bipolar Random Access Memories 448
  TTL Random Access Memories 448
  Emitter-Coupled Logic Memory 452
CMOS Static RAMs 453
MOS Random Access Memories 458
  Static versus Dynamic 458
  Static RAM Cell 458
  Work-Organized Static RAMs 459
Dynamic RAM 460
  Dynamic RAM Cells 460
  Sense Amplifier 461
  Dynamic RAM Organization and Timing 464
  Hardware for Refresh and Multiplexing 470
  Power Drain of Dynamic RAMs 471
  Errors in Dynamic RAMs 472
  Error Detection 473
  Error Correction 473
Summary 476
Glossary 476
Questions 477
Problems 479

Chapter 24
- **SERIAL MEMORY AND READ-ONLY MEMORY 481**

Objectives 481
Introduction 482
Serial Memory 482
  Identity to Shift Registers 482
  Dynamic Shift Registers 482
  Static Shift Registers 484
Read-Only Memory 485
  Types of ROMs 485
  Mask Programmed ROMs 488
  ROM as a Mathematical Table 491
  CRT Display Circuit 493
  Character Generator 493
  Single-Character Deflection 498
  Display and Refresh of a Line of Characters 500
  Display of a Page 501
Fusible Link PROM 503
Programmable Array Logic (PAL) 507
  Programming of PALS 523
  Integrated Fuse Logic (Field Programmable Logic Arrays) 529
Ultraviolet Erasable PROMs (EPROMs) 529
  Ultraviolet Erasure of EPROMs 530
Summary 532
Glossary 533
Questions 534
Problems 536

- **SELECTED ANSWERS 538**
- **INDEX OF DIGITAL CIRCUITS 540**
- **INDEX 542**

CHAPTER

1

Introduction to Digital Machines

Objectives

Upon completion of this chapter, you will be able to:

- Name some benefits derived from digital electronics.
- Identify some job market opportunities open to technicians trained in digital electronics.
- Draw a block diagram of the general-purpose stored-program digital computer.
- Identify other noncomputer types of digital equipment.
- Use system drawings to describe digital equipment.
- Draw the three basic symbols of flow diagrams and state their use for describing the construction and functioning of digital equipment.

1.1 Introduction

Machines that can duplicate human motion have been with us now for many generations. The degree to which they benefit us may be a subject for debate, but there is no doubt they are responsible for a major reduction in the number of hours in our work week. Nevertheless, individual workers, like the fabulous John Henry, often feel the anxiety of being in competition with the machine.

Until recently, workers may have taken comfort from the fact that the machine could not think, make decisions, choose a course of action based on its decisions, or learn. But these elements of human superiority over the machine may no longer be valid. In 1962, a computer was programmed to play the game of checkers. In the beginning, it lost most of the time, but after playing thousands of games it became practically unbeatable. Here, obviously, was a machine that could make decisions, choose its alternatives, and learn.

In the past decade, computers of much greater capacity have been developed. Where now do we stand in light of our newest machines? What can humans do that machines cannot do better? Do we, like John Henry, persist in valiant competition with the machine, or do we conclude that the computer is superhuman and look to it to solve all our problems?

The computer is not superhuman. As complex as it may be, it is only a tool, and, as with any other tool, human beings play the key role in using it. Our key role requires knowledge of what the computer is, how it functions, and what it can and cannot do for us. That is the object of this book—to explain the surprisingly simple devices that can be assembled to produce these automatic machines and to show that sensible employment of computers can substantially enrich the quality of human life.

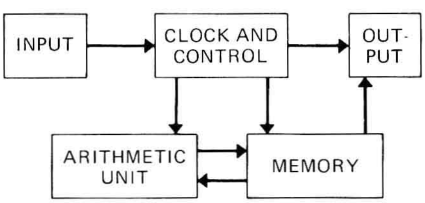

FIGURE 1-1

Block diagram of a general-purpose stored-program digital computer.

1.2 Digital Electronic Equipment

1.2.1 The General-Purpose Stored-Program Digital Computer

In size, complexity, and usefulness, the general-purpose stored-program digital computer is at the top of the list. The first generation of digital computers was produced in the 1940s. They employed vacuum tube and relay switches, consumed large amounts of power, and occupied considerable space. Yet, even with those components, they displayed a surprising degree of reliability and showed promise of a high level of usefulness in science, statistics, and accounting. With the introduction of semiconductor switches, other component and hardware improvements, and improvements in software (programming techniques), those promises have been fulfilled beyond the wildest expectations. The term *computer* is often used rather loosely, particularly in advertising, where even a simple cooking timer may be called a computer. To be termed a computer, a device should have at least the units shown in Figure 1-1.

Input-Output (I/O). The most versatile input-output (I/O) device is the teletypewriter. Depressing a key on the teletypewriter not only prints the letter or character on paper, but simultaneously sends the same character to the computer in digital code. Conversely, when the computer sends that digital code to the teletypewriter, it causes that same letter to print on the paper. Other input devices are the punched tape reader and the card reader, with their corresponding output devices, the tape punch, and the card punch.

Memory. Elaborate mathematical computations usually require mathematicians either to remember or to write down subtotals, partial answers, and so forth. To do those same functions, the computer must also have a memory. Memories have been constructed from acoustic tubes, magnetic drums, ferrite cores, and, more recently, semiconductor circuits. The terms used to describe the many different types of memories are explained in detail in Chapter 22. The time required to obtain a number from memory and deliver it to the arithmetic unit or other location in the computer is called the memory cycle time. Measured in microseconds or less, it is one key to the speed of computer operations.

Arithmetic Unit. This unit is the main functional section for most computer operations. It is essentially a high-speed digital adder with sufficient register circuits to perform all the basic arithmetic functions. The add cycle time—the time required to enter two numbers into the adder and produce a sum—is another measure of the speed of a computer.

Clock and Control Unit. A digital clock and its supporting circuits provide timing, cycling, and sequencing signals for the other units of the computer. The control unit contains digital circuitry that, when selected by number, will cause certain simple, logical, or mathematical routines to occur. Complex functions can be made to occur as a result of a stored program that produces many of those routines in a logical and useful sequence at extremely high speed. The software, or programming, provides the wealth of simple, routine combinations behind the powerful capabilities of today's computers.

1.2.2 Special-Purpose Computers

Another class of digital machines may be called special-purpose computers. The program they perform is hard wired and cannot readily be changed. They receive variable input data and subject it to a fixed mathematical routine for such purposes as navigation and industrial testing. They are seldom as elaborate as general-purpose computers, but they contain similar components.

1.2.3 Accounting Machines

Accounting machines, used to keep cash and inventory records, are becoming increasingly more digital. The price of the digital calculator has decreased from several hundred dollars to as low as ten dollars. The functions of the cash register have been expanded from merely counting cash taken in to computing change and transmitting data to a central terminal that keeps track of inventory and automatically prints out a purchasing list.

Even the cashier's operations have been speeded up by the use of a wand that senses a digitally coded machine-readable tag and transmits the description to the register. The universal product code (Figure 1–2) now appears on the labels of many grocery items. The bar code is scanned electronically, and the product description is sent in digital form to a small computer. The price is drawn from the computer memory rather than from the memory of a cashier or from a price stamped on by a store clerk.

FIGURE 1–2

Universal product code: a machine-readable code used on grocery and other products.

1.2.4 Digital Test Equipment

It is natural that the electronics industry should be the forerunner in using digital equipment. Many items of electronic test equipment that have long been analog in nature are now available in digital form. Figure 1–3 compares an analog volt ohmmeter with a digital VOM. The analog meter requires the user to select and interpret the correct scale. The digital meter can be read more rapidly and with less confusion.

Instruments that measure time and frequency are primarily digital circuits. Figure 1–4 shows the HP 5345A counter, an instrument that can count frequencies accurately as high as 500 MHz and time intervals as short as 50 nanoseconds. Its range can be extended with adapters and converters to as high as 18 GHz.

The cathode ray tube, which for some time has been used to display analog waveforms, can today be used to display printed data from a computer or digital information system. Figure 1–5 shows the Tektronix 4023 computer display terminal. This device uses digital and analog techniques to store and read out the data it receives for display.

Digital techniques have been successfully used to automate electronic testing. Many minor electronic components that were tested by hand a decade ago are today tested automatically and at much higher speed. Digital test terminals,

FIGURE 1–3

Dynascan analog meter (left) and digital meter (right).

which can be programmed for a wide variety of tests, do most of today's mass production testing.

Modern aircraft contain so much electronic equipment that automated, programmable test systems that are primarily digital in nature have been devised to check the air-frame periodically.

1.2.5 Digital Scales

Today even the scale used at the meat or produce counter at the grocery store may be digital. Figure 1–6 shows the Toledo 8201 digital scale, which displays not only the weight, but also the price per pound and the total price. It also provides both clerk and customer with an easy-to-read display.

1.2.6 Digital Communication

It has long been recognized that a trained operator can copy CW or Morse code through severe conditions of noise and interference with greater accuracy than can be accomplished by voice transmission. CW code is digital in nature, having

FIGURE 1–4

The Hewlett-Packard 5345A digital counter.