

HERBERT TAUB

DIGITAL



CIRCUITS AND MICRO  
PROCESSORS

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# DIGITAL CIRCUITS AND MICROPROCESSORS

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To  
Esther

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## PREFACE

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This book is an introductory text suitable for a one-semester course. It covers all the basic principles of digital systems and logic design and provides as well an introductory presentation to microprocessor and microprocessor-based systems. The present and growing importance of microprocessors makes it important that these versatile components be introduced into an engineering or computer science curriculum at the earliest opportunity.

The subject of logical variables and boolean algebra is covered in Chapter 1. Logic gates and logical connectives are described and analyzed. The binary number system is introduced here principally to allow some systemization of truth tables. Chapter 2 deals with the standard forms of logic functions and with Karnaugh maps. Chapter 3 considers basic combinational circuits including decoders, encoders, code converters, multiplexers and demultiplexers. It is emphasized that all these components are available as integrated-circuit chips, and a brief discussion is provided of *families* of integrated circuits. Conventions dealing with the characterization of control terminals on chips are explained, and this discussion leads to a consideration of the convention of *mixed logic* which, in certain applications, is gaining popularity. Examples are given of the newer logic symbols which are presently being introduced for combinational and other components. The basic storage element, the flip-flop, is examined in some detail in Chapter 4. A careful distinction is drawn between a latch and a flip-flop. The characteristics required of a flip-flop in order that it be able to function properly in a synchronous system are examined. Assemblages of flip-flops into storage registers, shift registers, and counters are also considered. Again, in this chapter it is emphasized that the components described are available as integrated-circuit packages and examples of such devices are described. Chapter 5 deals with the subject of arithmetic operations, principally addition. The look-ahead carry principle is explained and analyzed. Memory is the subject of Chapter 6. This chapter covers the RAM, both static and dynamic, the ROM, the PLA, serial memories, and memories for bulk storage. Also



described are timing considerations in reading from and writing into memories. Chapter 7 introduces the subject of the analysis and design of sequential systems, both synchronous and fundamental mode. The concepts of flow diagrams, state diagrams, and tables are presented, and also described are procedures for eliminating redundant states. While there is some discussion of sequential circuits in Chapter 4 in connection with shift registers and counters, the formal organized and systematized presentation is given in Chapter 7.

The material on controllers in Chapter 8 is written with a view toward microprocessors. A microprocessor consists of a number of storage and working registers, and ALU, and a controller. The controller appears to be endowed with uncanny abilities. It does exactly the right thing at the right time in precisely the right sequence and, having completed one task, proceeds unerringly to the next. Truly enough, the controller is nothing more than a special-purpose sequential circuit involving no difficult concepts. Still, to the beginning student, the vagueness associated with the controller is inevitably a source of uneasiness. It is very difficult to accept the generalizations with which controllers are described when there is no concrete and specific example that can serve as a model. Chapter 8 is written in a manner which will, hopefully, provide some reassurance to the uninitiated. It makes clear at the outset that all of the digital operations which are possible are relatively few and fundamentally simple, and that all are executed in response to the enabling of a gate or set of gates. Next there is presented the architecture of a very simple system which then requires a controller to be effective. A controller is designed in detail, first by using the procedures of Chapter 7 which yield a sequential system with a minimum number of states. Next this initial controller is replaced by a shift-register controller. The shift-register controller uses more hardware but has the great merit that the details of its operation are easily apparent and that required modifications for the purpose of elaboration can be added almost by inspection. Finally a controller is designed in detail to serve a very simple minded (4-instruction) "computer." The design makes clear in an entirely unambiguous manner how a controller can be made to modify its behavior in response to an *instruction*. Also in this chapter the student encounters the concepts of the *program counter*, the *memory address register*, and the *instruction register*. The reader sees, in simple form, the overall architecture which characterizes a microprocessor as well as the typical content of a memory which holds instruction and data for a stored program computation.

Chapter 9 is also written with an eye toward microprocessors. Here there is presented the architecture of a simple (16-instruction) computer. The structure provides a preview of the type of instructions to be encountered in more sophisticated systems. The *jump* and *subroutine call* instructions are presented and some simple programs are written in an assembly language. Also in this chapter the subject of control by *microprogramming* is presented and simple examples given.

Some authors invent a hypothetical microprocessor to have an example through which to introduce the subject. This procedure has the unfortunate fea-

ture that the student misses the exposure to a real device while the hypothetical microprocessor eventually turns out to be very nearly as complicated as a real component. Other authors undertake to include a number of real microprocessors in their descriptions and explanations. This approach, all too often, leads to vague generalizations. A third widely used approach, also used in this text, is to concentrate on a single real device. This method allows the analysis to be pointed and specific and, furthermore, a good familiarity with one device provides a background that allows an easy understanding of other devices. In this text, the microprocessor selected for study is the 8080 which is widely known and used and is highly regarded. Even though the 8080 has been updated by the 8085, we have stayed with the 8080 precisely because it is somewhat less sophisticated and, therefore, better suited to an introductory presentation. The 8080, its architecture, instructions, and programming is the subject of Chapter 10. Chapter 11 is devoted entirely to input-output operation of the 8080.

There is some more material in the text than can be covered conveniently in one semester. From the author's prejudicial point of view an effective way of employing the book is to use it for one full semester and for about one fifth of a second semester. Thereafter, for the remainder of the second semester, a new text should be adopted that covers microprocessors and microcomputers generally and in greater depth. On the other hand, it is entirely feasible to cover the book in one semester by omitting some material which is not essential in a first approach. Candidates for omission include the following sections: 1.17, 1.25, 1.26, 2.12, 5.10 through 5.12, 6.10 through 6.17, 7.6 through 7.9, 7.11 through 7.19, 8.12 and 8.13.

A large number of homework problems have been provided. A solutions manual is available that instructors can obtain from the publisher.

I am grateful to Professor Mansour Javid, chairman of the Department of Electrical Engineering at the City College of New York, who read a large part of the manuscript and made many valuable suggestions. Mr. Lewis Jay Taub provided a great deal of very effective assistance in the preparation of the manuscript and I am pleased to express to him my most sincere thanks. Mrs. Joyce Rubin's skillful typing of the manuscript is appreciated.

*Herbert Taub*

	Preface	xv
<b>Chapter 1</b>	<b>Algebra of Logical Variables</b>	<b>1</b>
1.1	Variables and Functions	1
1.2	Logical Variables	2
1.3	Values for a Logical Variable	3
1.4	Functions of a Single Logical Variable	4
1.5	Functions of Two Logical Variables	4
1.6	The OR Function	7
1.7	An Implementation of a Logical System	7
1.8	Electric Voltage Representation of Logical Variables	9
1.9	Inversion	10
1.10	The 0,1 Notation	10
1.11	The Binary Number System	12
1.12	Conversions between Decimal and Binary Numbers	13
1.13	The Octal and Hexadecimal Number Systems	14
1.14	Binary Numbers and Logical Variables	16
1.15	Boolean Algebraic Theorems	17
1.16	De Morgan's Theorem	21
1.17	Venn Diagrams	21
1.18	The Functions of Two Variables	25
1.19	The EXCLUSIVE-OR Function	26
1.20	The NAND and NOR Functions	27
1.21	The Implication Functions	29
1.22	Relationship between Operations	29
1.23	Sufficiency of Operations	30
1.24	Sufficiency of NAND; Sufficiency of NOR	31
1.25	Examples of Application of Boolean Algebraic Theorems	32
1.26	Additional Examples	34
1.27	Logic Diagrams	37
1.28	Numerical Codes	39

1.29	Nomenclature	41
1.30	Data Codes	41
<b>Chapter 2</b>	<b>Logical Functions</b>	<b>43</b>
2.1	Standard Forms for Logical Functions: The Standard Sum of Products	43
2.2	The Standard Product of Sums	45
2.3	Numbering of Minterms and Maxterms	48
2.4	Specification of Functions in Terms of Minterms and Maxterms	48
2.5	Relationship between Minterms, Maxterms, and the Truth Table	49
2.6	Two-Level Gate Structures	51
2.7	Structures Using One Gate Type	53
2.8	Karnaugh Maps	57
2.9	Simplification of Logical Functions with Karnaugh Maps	62
2.10	Additional Logical Adjacencies	64
2.11	Larger Groupings on a K Map	66
2.12	Karnaugh Maps for Five and Six Variables	69
2.13	Use of Karnaugh Maps	71
2.14	Mapping When the Function is Not Expressed in Minterms	78
2.15	Incompletely Specified Functions	80
<b>Chapter 3</b>	<b>Basic Combinational Circuits</b>	<b>82</b>
3.1	Introduction	82
3.2	Families of Logic Circuits	84
3.3	The TTL Series	85
3.4	The CMOS Family	89
3.5	The ECL Family	90
3.6	Packaging	90
3.7	The Logic-Operated Switch	90
3.8	Logic-Operated Switch OR Gate; the Wired-AND Connection	92
3.9	Totem-Pole Output	94
3.10	The Three-State Output	96
3.11	Example of IC Gates	98
3.12	Control-Terminal Symbols: Mixed Logic	100
3.13	Control-Signal Symbols	103
3.14	Mixed Logic Applied to Gate Structures	105
3.15	Decoders	108
3.16	Encoders	112
3.17	Code Converters	116
3.18	Multiplexers	118
3.19	Multiplexing with Open-Collector and Tristate Outputs	122
3.20	Demultiplexing	126
<b>Chapter 4</b>	<b>Flip-Flops, Registers, and Counters</b>	<b>128</b>
4.1	Introduction	128
4.2	A Latch with NOR gates	130

4.3	A Latch with NAND Gates	132
4.4	The Chatterless Switch	134
4.5	Gated Latches	135
4.6	Clocking	137
4.7	A Limitation of the Latch as a Storage Element	139
4.8	The Master-Slave Flip-Flop	141
4.9	Timing Diagram for a Flip-Flop	145
4.10	Two-Phase Clocking	146
4.11	The <i>JK</i> Flip-Flop	147
4.12	The Ones-Catching Property of the Master-Slave Flip-Flop	149
4.13	An Edge-Triggered <i>JK</i> Flip-Flop	151
4.14	The Type D Flip-Flop	153
4.15	Setup, Hold, and Propagation Time	157
4.16	Register-to-Register Transfers	159
4.17	Shift Registers	161
4.18	Additional Features and Uses of Shift Registers	164
4.19	Counters	169
4.20	The Ring Counter	169
4.21	The Switchtail Counter	170
4.22	Other Synchronous Counters	172
4.23	Synchronous-Counter Speed Comparisons	174
4.24	Synchronous Counters of Arbitrary Modulo	175
4.25	Up-Down Synchronous Counter	180
4.26	Lockout	181
4.27	Ripple Counters	182
4.28	Integrated-Circuit Counter Chips	185
<b>Chapter 5</b>	<b>Arithmetic</b>	<b>188</b>
5.1	Representation of Signed Numbers	188
5.2	The Twos-Complement Representation of Signed Numbers	191
5.3	The Ones-Complement Representation of Signed Numbers	193
5.4	Addition of Two Binary Numbers	195
5.5	A Serial Adder	197
5.6	Parallel Addition	200
5.7	A Simple Addition-Subtraction Calculator	201
5.8	Subtractors	203
5.9	Fast Adders	204
5.10	The Look-Ahead Carry Adder	205
5.11	Look-Ahead Carry Applied to Groups	210
5.12	Use of Additional Look-Ahead Carry	212
5.13	The Arithmetic Logic Unit	215
5.14	BCD Addition	221
5.15	Multiplication and Division	223
<b>Chapter 6</b>	<b>Memory</b>	<b>224</b>
6.1	The Random-Access Memory	224
6.2	Structure of a Semiconductor RAM	226
6.3	Paralleling Memory Chips	228
6.4	One- and Two-Dimensional Internal Memory Organization	231

6.5	The Read-Only Memory	234
6.6	Implementation of a ROM Encoder	236
6.7	Programmable and Erasable ROMs	238
6.8	Volatility of Memory	239
6.9	Switching Times of Memories	239
6.10	The Programmable Logic Array	245
6.11	Dynamic Rams	247
6.12	Data Sensing in a Dynamic RAM	248
6.13	Features of a Dynamic Memory	250
6.14	Serial Memories	252
6.15	Charge-Coupled Devices; Serial Memories	256
6.16	Memory Stacks	259
6.17	Bulk Storage	261
6.18	Symbolism	265
<b>Chapter 7</b>	<b>Sequential Circuits</b>	<b>268</b>
7.1	States	268
7.2	Counters as Sequential Systems	268
7.3	An Up-Down Mod-4 Counter	275
7.4	A Sequence Detector	278
7.5	Moore and Mealy Circuits	285
7.6	Elimination of Redundant States	292
7.7	Elimination of Redundant States by Partitioning	294
7.8	An Example	296
7.9	State Assignments	300
7.10	Alternative Designs	302
7.11	Fundamental Mode Sequential Circuits	305
7.12	An Analysis Example	306
7.13	A Design Example	308
7.14	Races	310
7.15	Elimination of Critical Races	312
7.16	An Example	314
7.17	Elimination of Redundant States	316
7.18	Further Example of Redundant-State Elimination	319
7.19	Hazards and Asynchronous Circuits	324
<b>Chapter 8</b>	<b>Controllers</b>	<b>326</b>
8.1	Register Transfers	326
8.2	Other Operations	329
8.3	Register Responsive to Multiple Commands	332
8.4	A Simple Controller	335
8.5	Implementation of Controller	339
8.6	The Shift-Register Controller	343
8.7	Conditional Response of Controllers	347
8.8	Sequence for Subtraction	352
8.9	A Simple Computer	354
8.10	Operation of the Computer	359
8.11	Design of the Computer Controller	362

8.12	Interrupts	365
8.13	Handshaking	369
<b>Chapter 9</b>	<b>Computers</b>	<b>375</b>
9.1	An Improved Architecture	375
9.2	Instructions	380
9.3	Summary of Instructions	388
9.4	Addition and Subtraction	389
9.5	Use of JMP and ISZ	391
9.6	Program for Multiplication	393
9.7	Program Illustrating Subroutine Call	394
9.8	Microprogramming	398
9.9	Microprogram Branching	400
9.10	Conditional Branching	401
9.11	Pipelining	403
9.12	A Microprogrammed Controller	405
9.13	Control ROM Contents	407
9.14	Methods of Addressing	429
9.15	Stacks	410
<b>Chapter 10</b>	<b>Microprocessors</b>	<b>414</b>
10.1	Introduction	414
10.2	Programmer's Architecture of a Microprocessor	416
10.3	One-, Two-, and Three-Byte Instructions in the 8080	420
10.4	Instructions for Data Movement	421
10.5	Instructions Involving the Accumulator Directly	423
10.6	Arithmetic Instructions	426
10.7	Some Examples	431
10.8	Increment-Decrement Instructions	432
10.9	Logic Instructions	432
10.10	The Comparison Instructions	435
10.11	The Rotate Instructions	436
10.12	The Complement and Set Instructions	437
10.13	An Example	437
10.14	The Jump Instructions	438
10.15	The Call and Return Instructions	440
10.16	The Push and Pop Instructions	444
10.17	An Example: Multiplication	448
10.18	The Type 6800 Microprocessor	450
10.19	Type 6800 Addressing Modes	452
10.20	The 6800 Condition Code Register	452
<b>Chapter 11</b>	<b>Input-Output Operations</b>	<b>455</b>
11.1	The Generation of I/O Control Signals in the 8080	455
11.2	Isolated and Memory-Mapped Input-Output	459
11.3	Use of IN and OUT Instructions	464
11.4	An Unencoded Keyboard	466
11.5	Control of Peripheral Devices	470

11.6	Timing Loops	470
11.7	Interrupts	472
11.8	Interrupt Enable and Disable	476
11.9	Polled Interrupt	478
11.10	Other I/O Communication	481

## Appendixes

A	ASCII Code	487
B		489
C	8080 Instruction Set	491

Problems	495
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Index	533
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## ALGEBRA OF LOGICAL VARIABLES

## 1.1 VARIABLES AND FUNCTIONS

We are familiar with the concept of a *variable* and with the concept of a *function* of a variable. The *field* of a variable, i.e., the range of values which can be assumed by a variable  $x$ , can be specified in a limitless number of ways. For example,  $x$  may range over all the real numbers from minus to plus infinity; or  $x$  may be restricted to the range from  $-17$  to  $-4$ ; or  $x$  may be restricted to the positive integers from  $1$  to  $10$ ; and so on.

A *function* is a *rule* by which we determine the value of a second (dependent) variable  $y$  from the (independent) variable  $x$ , the dependency of  $y$  on  $x$  being written  $y = f(x)$ . Thus, for example, suppose we intend that  $y$  is to be determined from  $x$  through the rule that  $x$  is to be multiplied by itself, that this product is to be multiplied by  $5$ , and that thereafter  $3$  is to be added. We would then express the functional relationship between  $x$  and  $y$  by the equation  $y = 5x^2 + 3$ . In this simple example we determined  $y$  by applying the mathematical processes of multiplication and addition. However, when the number of allowable values of  $x$  is finite, it is possible to specify a function simply by making a *table* in which  $y$  is given for each value of  $x$ . When the number of possible values for  $x$  is small, it may well be feasible and most convenient to use such a table. Consider that in the example referred to above ( $y = 5x^2 + 3$ ) we restrict  $x$  to the integral values  $x = 0, 1, 2$ , and  $3$ . Then, as is indicated in Fig. 1.1-1, the functional relationship between  $y$  and  $x$  can be specified in tabular form.

By an easy extension of these elemental ideas, it is clear that the variables, dependent and independent, need not be numerical. For example, let the independent variable  $x$  have as its field the colors of the traffic light at an intersection, and let the dependent variable  $y$  represent the expected behavior of a mo-