COMPLETE GUIDE TO

Digital Test Equipment

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About This Book

If you have ever used a slide rule and if you now use an electronic calculator, you'll appreciate the difference between an analog and a digital device. With the calculator we set up the problem and get the answer accurately and directly in the actual numbers, while we have to use our judgment in reading and interpreting the scales of the slide rule. Digital test equipment has the same advantages as the calculator. No wonder, then, that this new type of test equipment is replacing the older analog types just as fast as we can justify buying a new test instrument.

A few types of digital test instruments appear to be simply digital versions of their analog predecessors. Most of the digital equipment, however, performs different tests and measures and does it in a different way. What's more important, if you want to align, calibrate, or troubleshoot this new equipment, you'll find entirely different circuits. Just think of the difference between operating a slide rule and a calculator—devices that are much less complex than, for example, a multimeter. Troubleshooting a slide rule requires only a few mechanical adjustments, while troubleshooting a calculator requires a thorough knowledge of electronics. As this book will show you, you'll find a lot more circuitry in a digital multimeter than in the old-fashioned volt-ohm-milliammeter (VOM). You'll see circuitry that was, until recently, only used in the most sophisticated computerized instruments. Single-chip integrated circuits performing functions such as sample-and-hold, analog-to-digital and digital-to-analog conversion, binary-to-decimal and binary-to-seven-segment decoding must be understood if you want to use and maintain your digital test equipment.

If you know the fundamentals of electronics and if you can use volt-ohm-milliamp (VOM) meters and other basic test equipment, then you will enjoy acquiring all the practical information you need to know about your new digital test equipment. Without skimping on essential details, this book will provide usable information, rather than theoretical concepts, to the reader who uses this new type of test equipment. If you are still in the market for test equipment, the essential information in this book will help you select the particular instruments to meet your requirements best.

The first two chapters deal with key fundamental elements—the basic circuits, controls, and displays used in all digital test equipment. Once you are familiar with these "building blocks," each of the basic equipment types is covered by a unique, two-chapter approach. One chapter tells you how it works, what circuits are used, what different features are available, and how to troubleshoot it. The second chapter tells you how to get the most out of this type of test instrument. You'll learn which probes to use for which application, how to get the most accurate readings, and how to check and maintain calibration. Two chapters each are devoted to digital multimeters, to counters, to pulse generators, to frequency synthesizers, and to logic testers. In each case the organization of each two chapters is the same, which makes it easy to use as a reference book. What makes this book especially useful are the practical application notes, the many servicing shortcuts, the insider's time-saving tricks and suggestions that come from the daily experience of those in the field who use digital test equipment and have agreed to share their experience with us.

Wherever we use detailed circuit diagrams, they are preceded by a block diagram with a brief signal description and a functional explanation. This approach helps you to understand what the circuit is designed to do. In many cases, one look at the block diagram will tell you that you are already familiar with some of the functional elements and that you can concentrate on those circuits that are new to you.

Once you have read through the first two chapters, you will find you can tackle almost *any* kind of digital test equipment. These basic "building block" circuits are used, with some variation, in all digital instruments. You can then concentrate on the particular kind of test equipment that's most important to you. No need to read about multimeters, counters, or pulse generators first if you have just bought a frequency synthesizer and want to put it to productive use.

Because of its chapter organization and practical technical content, this book will serve you as a valuable reference for many years. You will be able to quickly locate troubleshooting hints, circuit explanations, and alignment and calibration procedures for test instruments that may be working fine now, but become troublesome years from now. Most important, however, you'll understand how each instrument works and how you can get the most out of it.

Walter H. Buchsbaum

Acknowledgments

Like most technical books, this volume is based on the cooperation of many different people. I want to thank all of my friends who have shared their knowledge and experience in digital instrumentation with me and the many test equipment manufacturers who supplied technical material concerning their products. Where specific illustrations were obtained from a manufacturer, a credit line shows the source. I also want to thank Mrs. Ursula Marshall for transcribing my dictation into a beautifully typed manuscript.

Finally, this book would not have been possible without the encouragement of my wife, Ann, who also arranged the index.

Other books by the author:

Color TV Servicing, Third Edition

Tested Electronics Troubleshooting Methods

Buchsbaum's Complete Handbook of Practical Electronic Reference Data

Fundamentals of Television, Second Edition (Hayden Books)

Electrical Safety in the Hospital with Bonnie Goldsmith, R.N. (Medical Economics)

Contents

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How the Key Digital Circuits Work

Clocks and watches indicate the time by the position of the pointers on the dial. The thermometer shows the temperature by the relative length of a mercury column against a fixed scale. Weight, speed, voltage, current, and many other physical parameters are measured by the position of a pointer moving over a fixed scale. In all of these devices the display is analogous to the quantity measured. If the quantity is increased, the pointer moves a corresponding amount on the scale. Until a few years ago almost all devices used for measuring physical quantities used the analog principle.

In the new family of digital clocks, watches, thermometers, scales, and electrical meters, the measurement is indicated directly in actual numbers. Where the analog wristwatch, for example, allows us to read the time as approximately ten minutes after three, the digital wristwatch will read exactly 3:10. This instant precision of the display is the essential advantage of digital versus analog instrumentation.

In addition to precision, digital test equipment also has a number of other advantages. Digital meters, for example, usually include automatic polarity sensing and automatic range setting. The key to these new instruments is the use of digital circuits to perform binary logic functions. This chapter presents a brief review of the fundamentals of the binary logic system and the most widely used digital circuits.

THE BINARY SYSTEM

The numbers we use in everyday work are based on the decimal system, while the numbers used in computers and almost all other digital equipment are based on the binary, or two-value, system. In this system all of the numbers are based on powers of *two*.

Figure 1-1 illustrates how the binary system works. Assume that we have seven lamps mounted on a panel. When a lamp is on, as indicated by the shaded circle, it means a binary or logic "1," and when the lamp is off, it indicates a binary or logic "0." Look at row A. The lamp at the extreme right will have the value *one* when it is on. The lamp next to it will have the value *two* when it is on. The third lamp will have the value *four* when it is on, and so on down the line. The decimal numbers, 1, 2, 4, 8, 16, 32, and 64 are all powers of *two*, as indicated in Figure 1-1. In the example of row A, the shaded lamps indicate a *four* and a *one*, which are the equivalent of the decimal number *five*.

The examples in rows B, C, D, and E of Figure 1-1 illustrate how

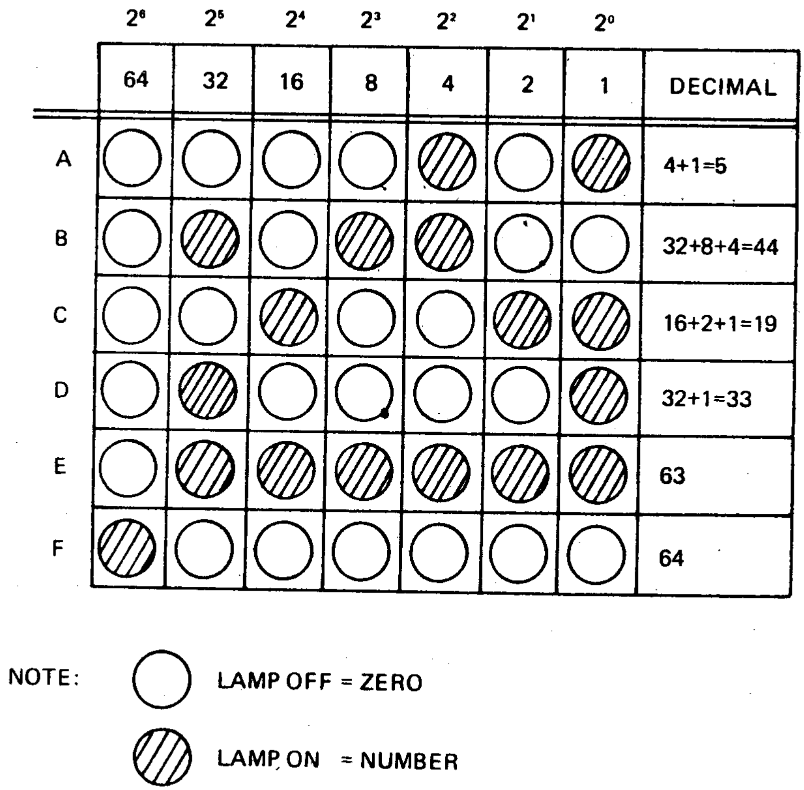


FIGURE 1-1 Fundamentals of Binary Numbers

different combinations of illuminated lamps are used to indicate different decimal numbers. We can see how efficient the binary system is by the example of row E. Six lamps, all illuminated, indicate the decimal number 63. We can display up to 63 different numbers by merely varying the on or off condition of only six lamps. In other words, a combination of *six* lamps of two states, off or on, can express 63 numbers. *Six* driving circuits or switches are required to express 63 different numbers. When we add a seventh lamp, as illustrated in row F of Figure 1-1, we can express 127 different decimal numbers. Each additional lamp doubles the amount of decimal numbers that can be expressed.

Each of the lamp positions in Figure 1-1 is called a "bit" in binary logic. It is customary to have the least significant bit, 2^0 at the right, and the most significant bit, 2^6 in Figure 1-1, at the left.

While we have shown seven bits in the example of Figure 1-1, it only requires four bits to express any decimal number from 0 to 10. In digital test equipment the display is always in familiar decimal numbers and the binary circuits are designed to deal with the output data in groups of *ten* (decade). These *four* bits, representing the numbers *zero* through *nine*, are called the "binary-coded-decimal" or BCD format.

Figure 1-2 shows how binary numbers, especially BCD numbers, are added and subtracted from each other. Addition is quite simple —we only have to remember that 1 plus 1 is 0 with a carry of 1 to the next higher bit, as illustrated in Example B.

The rules of subtraction are a little more complicated. Computers perform subtraction in a number of different ways, but the basic method uses the twos complement. In example C, to subtract *five* from *ten* the first step is to obtain the twos complement of the binary number *five*. We change every "0" to a "1" and every "1" to a "0" and then add "1" to the total number. Now we simply add the binary number *ten* to the twos complement of binary *five* as indicated in Step #2.

Example D shows the subtraction of *eight* from *ten* and is performed in a similar way.

Multiplication is nothing more than repeated addition. If we want the product of *four* and *eight*, we could simply add *eight four* times to itself. In digital logic this is how most multiplication is performed. In digital computers, where very large numbers and high speed is involved, a more direct method of multiplication is used.

Binary division can be performed by repeated subtraction. If we want to divide *sixty-four* by *five*, for example, we can subtract *five* as

ADDITION RULES:

0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 0 (carry 1 to next bit)

Example A:

```
  1010 = 10
 +0101 =  5
  1111 = 15
```

Example B:

```
  1010 = 10
 +1100 = 12
 10110 = 22
```

SUBTRACTION RULES: Change the subtrahend (the number being subtracted) into its twos complement and add the two numbers.

To form the twos complement, change every "1" to "0" and every "0" to "1" and then add "1" to the resulting number.

Example C:

```
  1010 = 10
 -0101 =  5 (subtrahend)
```

Step =1: Change 0101 to 1010 and add 1 = 1011. This is the twos complement.

Step =2: Add

```
    1010
   +1011
 (1)0101 = 5
```

Example D:

```
  1010 = 10
 -1000 =  8
```

Step #1: Change 1000 to 0111 and add 1 (0111 + 1 = 1000). The twos complement is 1000.

Step #2: Add

```
    1010 = 10
   +1000 =  8
 (1)0010 =  2
```

FIGURE 1-2 Binary Addition and Subtraction

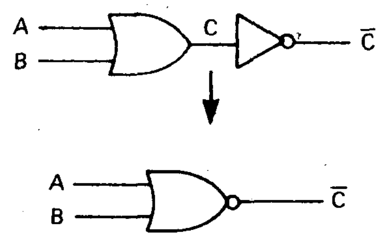
many times as possible and count how often it is done. We will find that we can subtract *five* 12 times and will have a remainder of *four*. As in multiplication, digital computers usually use a shortcut method to perform division of large numbers.

BASIC LOGIC FUNCTIONS

You are probably familiar with the basic logic functions, such as the AND, OR, NAND, and NOR circuits. A number of excellent books, including *Manual of Logic Circuits*, by Gerold M. Maley, Prentice-Hall, Inc., cover the subject of logic circuits in great detail. In this section we will provide a brief summary to serve as a refresher or ready reference for the more complex logic functions in later portions of this book.

Figure 1-3 shows the OR and the NOR circuit in the basic, two-input version with the Boolean notation and truth tables. Whether the OR circuit is made up of two diodes and some resistors, a TTL logic integrated circuit, or an MOS large-scale integrated circuit chip, its logic functions are always the same. If positive logic is used, meaning that the "1" is represented as a positive voltage and the "0" is represented as ground, the OR circuit simply says that, as long as either A or B or both signals are positive, the output at C will also be positive.

The NOR circuit operates in basically the same way as the OR circuit but its output signal C has been inverted, as indicated by the notation $\bar{C}$. As a result, the C column of the NOR circuit truth table will be the inverse or, as it is usually called in digital logic, the complement of C.



$A + B = C$

$A + B = \bar{C}$

A	B	C
0	0	0
1	0	1
0	1	1
1	1	1

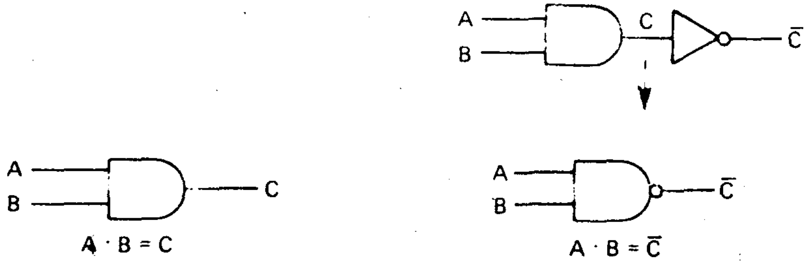
OR

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

NOR

FIGURE 1-3 OR and NOR Logic Gates

Figure 1-4 shows the AND circuit and its cousin the NAND circuit. To describe the OR section in Boolean algebra we used the plus sign; the AND function is described by indicating the product $A \cdot B$. As its truth table shows, C will only have a positive output if both A and B are also positive. Looking at the NAND circuit, we notice that the output signal has been inverted, just as in the case of the NOR circuit. Again, $\bar{C}$ is the inverse or the complement of C. The acronyms NOR and NAND stand for "not OR" and "not AND."



A	B	C
0	0	0
1	0	0
0	1	0
1	1	1

AND

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

NAND

FIGURE 1-4 AND and NAND Logic Gates

We have described the four basic logic elements in terms of positive logic but, in many instances, negative logic is used. Some types of logic circuits, such as CMOS (complementary metal oxide semiconductor), combine positive- and negative-going signals. You will find that most manufacturers indicate somewhere on the logic diagram the polarity and actual voltage range of the particular logic. Notices such as "1" = +5V or "1" = −10V will avoid any possible confusion.

All four basic logic circuits shown in Figures 1-3 and 1-4 are commonly called *gates*, because they control the flow of logic signals. They can have two or more inputs, but only a single output. The amplifier shown following the NOR and the NAND circuit is called an inverter and its function is indicated by the small circle placed at the output of the NAND or NOR circuit. Whenever you see this circle, it means that a "1" is changed to "0" or, in Boolean notation, an A is changed to $\bar{A}$.