R.A. Gilbert
J.A. Llewellyn

Basic Elements of DIGITAL SYSTEMS

IRP Instructional Resource Package

STUDENT TEXT

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ISA

INSTRUMENT SOCIETY OF AMERICA

BASIC ELEMENTS OF DIGITAL SYSTEMS

Printed in the United States of America.

The Instrument Society of America
67 Alexander Drive, P.O. Box 12277
Research Triangle Park, NC 27709

ISBN 0-87664-674-7

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Cover and text design by Sidney Solomon

First printing October 1982

Basic Elements of DIGITAL SYSTEMS

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Developed by
THE EDUCATION DEPARTMENT
Instrument Society of America

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SECTION **1**

INTRODUCTION TO THE STUDENT

1-1 COURSE CONTENTS AND OBJECTIVES

"Basic Elements of Digital Devices" is the first of a two-part series that introduces you to a selection of important digital devices. This text assumes that you have no previous knowledge of digital electronics. Each section of the text introduces a new device group and its properties, examines representative devices in the group, and presents a set of review questions that will help you organize the material just presented.

The text begins with an overview of the ASCII code as a method for representing data in a digital manner. Section 2 also includes a brief discussion of data representation in general. Section 3 shows you how a few devices can make a variety of logic decisions and perform signal gating operations.

Counting and counters are the topics of Section 4. This presentation illustrates how decade and binary counters work. You will learn about the ripple characteristics of the particular counters used in this section. The review questions present problems that direct you to create some simple counting circuits which reinforce the concepts used with digital counters.

Section 5 covers the ideas associated with encoders and decoders. These devices are important in a variety of digital circuits and the section discusses the properties of two useful decoders. Related subjects, data selection and data distribution, are studied in Section 6. That section provides a general view of multiplexers and demultiplexers and describes a specific example of each type of device.

The characteristics of devices that provide timing pulses are presented in Section 7. Two devices are reviewed and two types of timing events are explained. This section also illustrates how to wire your own pulse generator circuit and briefly discusses the output properties of digital devices.

Section 8 is dedicated to the process of latching digital signals. Latching is accomplished with latches and flip-flops and each of these devices is explained with examples. A discussion of shift registers and their properties follows in Section 9. Finally, the characteristics of memory devices are explained in Section 10. The properties of read/write memory are presented and a specific memory device is explained.

The pinout diagrams in this text are not in conventional form. The illustrations show the pins connected in functional groupings in order to clarify the device operations and facilitate the construction of circuits from wiring diagrams, which are more easily understood.

1-2 AUDIENCE

This course is especially appropriate for those who plan to work with microcomputers or microprocessor-based equipment who would like a preliminary introduction to the concepts and devices used in support of such systems. The instruction is designed for technical and non-technical people interested in developing a basic understanding of digital devices and fundamental skills in digital circuit construction. Previous electronics study and knowledge of higher mathematics are not required.

1-3 TERMS AND DEFINITIONS

ASCII — American Standard Code for Information Interchange.

ASCII code — A popular code that uses seven bits to encode 128 possible characters.

Algorithm — A set of instructions used by a computer or controller to manipulate incoming signals or data into a desired form.

Analog signal — An electrical signal that has an amplitude that can vary in essentially infinitesimal increments.

Astable device — A device that can be triggered to respond in one of two possible logic states.

Bit — The term that represents one place in a set of binary digital signals.

Breadboard — A workspace that provides a convenient place to build and test digital circuit sections before placing them in their final circuits.

Byte — 8 bits that collectively represent a character, number, status, or control message.

Cascading — The process of connecting counters in series so that the first counter triggers the next after the first has completed one count cycle.

Control bus — A group of wires that transmit control bits to and from equipment.

Counters — A digital device that responds to input pulses, then presents an output pattern that counts the number of input pulses.

Data bus — A group of wires shared by all of the digital equipment to accept or send numbers or characters from or to a controller.

Data distributor — A device that is capable of routing one line of input data to any one of a number of output lines.

Data selectors — A group of devices that allow one of several input pins to be internally connected to the output pin of the device.

Decoder — A digital device that translates an input code to a different output pattern.

Digital signal — A response that can only be made in a two-level manner, Hi/Lo, 1/0, etc., so that a set of digital signals represents a specific integer or character.

Encoder — A device that converts independent input signals into some form of binary code at its output.

Falling edges — That portion of a clock's pulse that is changing from its highest value to its lowest value.

Fan out — The number of separate TTL inputs that can be controlled by a single TTL output.

Gate — A logic device that controls the transfer of a signal from one section of a circuit to another.

Inverting gate — A gate that also changes the value of the digital signal as it goes through the gate.

Latch — A digital device that retains a digital signal after the signal has been placed in the device.

Logic train — A set of positive or negative clock pulses traveling to or from a device.

Modulus — The number of count input pulses a counter uses for a complete count cycle.

Monostable device — A device that can be triggered to change logic states but must return to its starting logic state.

Parallel data transfer — The process of sending signals from several sources on different wires to the same receiver at the same time.

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Negative clock pulses — A digital signal that begins at its highest value, changes to its lowest value, and then returns to its highest value again.

Positive edge — See *Rising edge.*

Propagation delay — The time delay between the input of a signal to a digital device and the expected response from the device.

Radix — A number taken as the base of a system of numbers, i.e., 10 is the radix of the decimal system.

Read — The act of retrieving a bit pattern from a memory location of a memory device.

Register — A series of latches connected together that allow more than one digital signal to be stored.

Rising edge — The portion of a clock pulse that is changing from the lowest value to the highest value.

Serial data transfer — The process of sending signals from one source to another receiver one bit at a time.

Strobe — A digital signal used to activate the operation of a digital device.

Synchronous counter — A counter that changes all of its output pins at the same time.

TTL — Transistor-transistor logic.

Write — The act of placing a bit pattern into a memory location of a memory device.

Word — The collection of parallel bits that a computer or controller normally uses in its operations.

STUDENT'S SUMMARY NOTES and QUESTIONS FOR INSTRUCTOR

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SECTION 2

ELECTRONIC DATA REPRESENTATIONS

2-1 INTRODUCTION

The essence of monitoring and control operations involves the evaluation of information that describes the state of the machine or process being monitored or controlled. A primary consideration is the representation and transmission of this process data. Analog and digital representations provide the two principal methods of representing data electrically.

In the analog method, a continuous electrical variable is made to change in a way that reflects those changes in the data. As an example, a range of pressure measurements might be represented by currents varying between 4 and 20 mA or by voltages between 0 and 10 V, with a unique relationship between a particular pressure and a specific voltage or current. The relationship is often linear or very nearly so. The method of representation is usually the one that produces the most cost effective reproduction of the data.

The digital method is based on discontinuous patterns of currents or voltages to represent, or encode, the conditions in the system. In order to minimize the possibility of distorting the information and to make it easy to manufacture the encoders, the electrical patterns are usually restricted to two fundamental signals, e.g., current on or off, voltage on or off, or some parallel variation between two specified current or voltage levels. This produces a relatively corruption-resistant representation of data. For information that is two-state or binary in nature, this is a natural representation: contact closed or open, motor on or off, or pressure in or out of limits.

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A more subtle situation requires representations that can distinguish between levels, e.g., between 500 and 700 rpm, 5.2 and 7 volts, 20 and 21 psi. The signals must represent numbers. The representation should also facilitate the comparison and choice processes, making it possible to perform mathematical operations. This would allow the conversion of signals representing certain variables into those representing other variables, such as converting speed and time into distance travelled, or pressure into gallons per minute.

The most popular approach to these problems is to encode the information as voltage patterns, using a combination of 0 and 5 V (within certain specified tolerances). This is not the only way in which information is represented by digital electronics, but a study of this particular version (binary representation) is valid for other methods.

2-2 ASCII REPRESENTATION

Perhaps the simplest approach to encoding is provided by the American Standard Code for Information Interchange, usually referred to by its initials, ASCII. This technique uses a pattern of seven digits or bits to represent letters and numbers and sometimes uses an extra bit (parity bit) that can be used for checking to make sure that the pattern has been properly encoded. Each bit in the pattern can have only one of two values, either 0 or 5 V. These two values are also referred to in a variety of other ways, such as low and high, or logic 0 and logic 1, or false and true. We will use low and high or logic 0 and logic 1 to refer to the 0 and 5 V conditions respectively. Using 0 and 1, some of the ASCII encoding is shown below:

	Numbers		Letters
0	011 0000	A	100 0001
1	011 0001	B	100 0010
2	011 0010	C	100 0011
3	011 0011	D	100 0100
4	011 0100	a	110 0001
5	011 0101	b	110 0010
6	011 0110	c	110 0011
		d	110 0100

The extra parity bit is not included in these patterns; we will discuss it later.

The patterns of ones and zeros would appear electrically on wires using 5 V or 0 V. Eight wires could be used to send the number 4, including its error check, from gadget A to gadget B, by imposing the voltage pattern shown:

Wire (bit)	7	6	5	4	3	2	1	0
Voltage	X	0	5	5	0	5	0	0

This is called *parallel data transmission.* Note the use of the X in wire #7. This denotes that the voltage is unspecified. An alternative procedure would be to agree on a timing schedule and change the voltage on a single wire in such a way that the pattern is sent down the wire one bit at a time. The voltage will switch from 0 to 5 volts according to the agreed upon timing and in the ASCII pattern until the necessary information is sent. We will discuss later in some detail this *serial data transmission*, which is similar to transmission by Morse Code.

2-3 BINARY CODE

Because of the emphasis placed on numbers, there are many alternative methods for electrically encoding numbers, but for the moment we will focus on the most powerful, simple, and crude method: binary code. Binary code provides signal patterns that allow us to represent data in a way that facilitates its manipulation, both in terms of its electrical generation, transmission and reception, and in terms of producing the results of mathematical operations like addition, subtraction, multiplication, and division.

Before we get into binary representation of numbers, it is worthwhile to look at the way we normally represent numbers in the non-digital electronic environment.

The common experience is with the decimal system; multiplier digits from 0 to 9 are in a pattern in which each place in the pattern carries an implicit weight. The implicit weight is in powers of ten, so that the decimal number 7520 implies:

7	5	2	0	decimal number
10^3	10^2	10^1	10^0	implicit place weight
1000	100	10	1	equivalent

$7 \times 10^3 + 5 \times 10^2 + 2 \times 10^1 + 0 \times 10^0 = 7520$

Because the place weights are incremented in powers of ten, the system is said to have a base or radix of ten or use modulo ten.

The binary system is restricted to two digits rather than ten and the place weighting is thus in powers of two rather than ten. As an example, we may consider the binary number 10110. Its decimal place weighting is shown below together with its translation into the decimal equivalent.

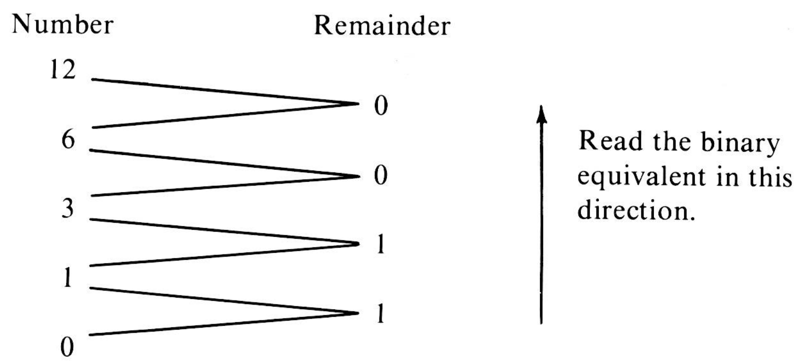
1	0	1	1	0	binary number
2^4	2^3	2^2	2^1	2^0	implicit place weight
16	8	4	2	1	equivalent

$(1 \times 16) + (0 \times 8) + (1 \times 4) + (1 \times 2) + (0 \times 1) = 22$ decimal

The ten decimal digits and their binary equivalents are shown below.

0	0000	5	0101
1	0001	6	0110
2	0010	7	0111
3	0011	8	1000
4	0100	9	1001

It is useful to have a technique (algorithm) for converting from decimal to binary. This can be accomplished by repeatedly dividing the decimal number by two, recording the remainder after each division, and continuing until the number to be divided is zero. The first remainder is the rightmost or least significant bit of the binary representation. For example, to convert 12_{10} to binary:



Binary equivalent 1100

The same technique works for converting decimal numbers to representations with any other radix; we will use this later.

2-4 REVIEW

We have seen that numerical information can be represented by binary patterns of voltages. This binary representation in 0 and 5 V signals can be transmitted and manipulated by a wide range of electronic devices. The following sections deal with the simplest and most powerful operations that can be performed on these signals. These fundamental operations provide the basis for all digital electronics and computer operations, from conditional control through complex mathematical analysis. A simple hypothetical application will be presented that will illustrate the fundamental operation and utility in a familiar context.