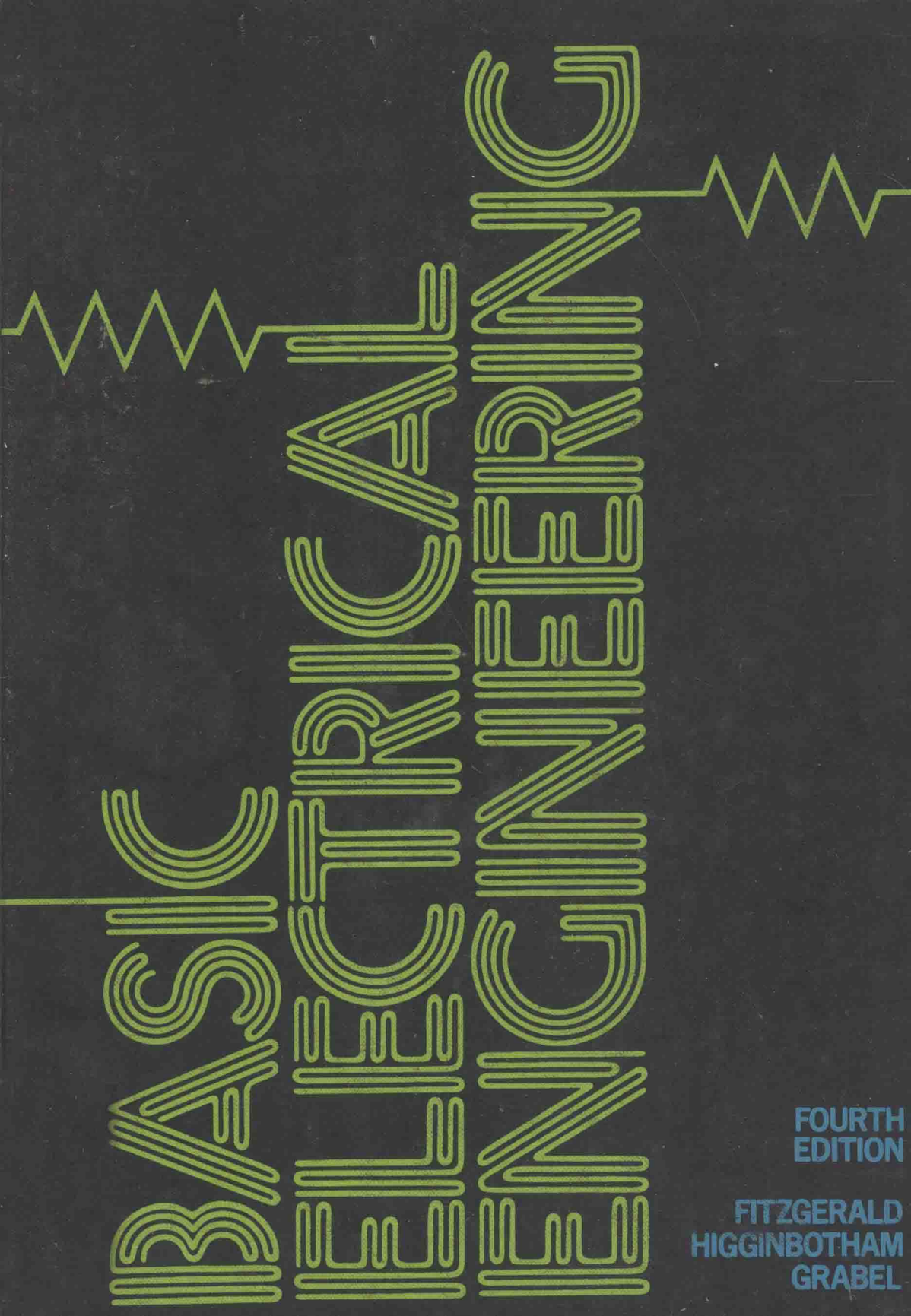
BASIC
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FOURTH
EDITION
FITZGERALD
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FOURTH EDITION

# BASIC ELECTRICAL ENGINEERING

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**BASIC ELECTRICAL ENGINEERING**

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# BASIC ELECTRICAL ENGINEERING

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# PREFACE

This book, like the three earlier editions, is intended to present a one-volume treatment of the essentials of electrical engineering suitable for use by engineering students in the second, third, or fourth year of an undergraduate curriculum. To attain this objective in the context of the technological world of today and tomorrow, we have reorganized and rewritten much of the book and have added a considerable amount of new material.

Thoughtful selectivity is obviously just as important a requisite for the authors of the book as for the instructors using it. Our guidelines have been these four:

**1** To present the basic physical concepts and laws of circuit theory, solid-state electronics, electromechanical energy conversion, and analog and digital control with sufficient description and analysis to make applications meaningful

**2** To carry the treatment in each area sufficiently beyond a bare introduction so that the reader can make the transition to specialized texts without undue intellectual embarrassment

**3** To introduce the reader, at least conceptually, to exciting modern techniques made possible by integrated circuits, including logic gates and operational amplifiers, power semiconductors, digital control, etc.

**4** To provide optimum flexibility in arrangement of material so that large chunks may be omitted without loss of continuity when lack of time or interest dictates

Thus, in studying electric circuits, some users of the book will wish to give predominant emphasis to steady-state dc and ac theory. They may therefore omit Chapter 3 entirely, take up only Sections 4-1 through 4-4 in Chapter 4, and proceed to those parts of Chapter 5 which are of importance to them. They may also, of course, omit some details of Chapter 2 (such as some of the network-simplification ideas) if they plan to skip the analytic details in the electronics chapters which employ these techniques.

The parts of the book relating to electronics and machines may be taken up interchangeably. The introductory chapters for these parts (Chapters 7 and 8 for electronics and Chapters 13 and 14 for machines) present integrated and unified physical pictures of the respective fields. These chapters may be supplemented by as many of the following more detailed and analytical chapters as are appropriate in view of technical objectives. By focusing on control aspects, Chapter 17 pulls together many of the considerations of the preceding chapters.

Accordingly, we hope that browsing in the book for an hour or two will enable an instructor to outline a variety of courses of different length, content, and sequence. As teachers, we envy those who may be able to take up everything, possibly even with their own amplification or extension in some areas.

During the 30 years since the first edition of the book was written, we have taken part in many formal and informal discussions and conferences on electrical-engineering teaching. All of these have influenced the present edition in one way or another. We especially wish to acknowledge the valuable advice and suggestions of many instructors who used the earlier editions.

*A. E. Fitzgerald*
*David E. Higginbotham*
*Arvin Grabel*

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# ELECTRICAL ELEMENTS AND CIRCUITS

A basic study of electrical engineering resolves essentially into treatments of circuit theory, of electronics and electronic devices, of energy conversion and electromechanical conversion devices, and of control devices and systems. This chapter will lay the groundwork for such a study by developing the elementary concepts and defining the basic terms. The typical reader will already have encountered much of this material. Thus, for many, it will simply be a coordinated review reflecting the general viewpoint of the remainder of the book.

## 1-1 ENERGY AND ENERGY TRANSFER

The primary concern of electrical engineering is the doing of work by the delivery of energy in the right place, in the right form, and at sufficient power for any of a multitude of purposes. The general import of the preceding sentence can be gathered by thinking of the words *work*, *energy*, and *power* as they are used in ordinary speech. However, these terms, so basic to engineering, must be considered in their more precise and quantitative meanings.

*Work* is done when something is moved against a resisting force. For example, work is done when a weight is lifted against the pull of gravity or when a body is pushed into motion against the force of inertia. Quantitatively, the work done is found by multiplying the force applied by the distance through which the force moves. That is

$$\text{Work} = \text{force} \times \text{distance} \tag{1-1}$$

The unit of work in the meter-kilogram-second (MKS) system of units is the *joule* (abbreviated J). It is the work done when a force of one *newton* (0.225 lb) acts through a distance of one meter. The English unit of work is the *foot-pound*. (1 J = 1 N-m = 0.738 ft-lb.)[1]

*Energy* is the capacity for doing work; another way to think of work is as a transfer of energy. Mechanical energy is measured in the same units as work. When a weight is raised, energy is expended by the human body or by some hoisting device. The weight, on the other hand, acquires *potential energy*. That is, by virtue of being raised above the ground, it can do work. It can raise another weight by means of a pulley, or it can be allowed to fall, as in a pile driver, transferring its energy when it hits the pile at the bottom. In this case, the potential energy at the beginning of the fall would be changed into *kinetic energy* as the bottom was neared. That is, the body would have the ability to do work because of its motion. At impact the energy of a pile driver is transferred to the pile.

[1] In general, units are abbreviated in this book when they follow numerical values; otherwise they are spelled out. A listing of abbreviations is given in Appendix B.

A general principle applicable to all physical systems in which mass is neither created nor destroyed is the *principle of conservation of energy*, which states that energy then is neither created nor destroyed; it is merely changed in form. Energy can be changed into heat, light, or sound; it may be mechanical energy of position or of motion; it may be stored in a battery or in a spring; but it is not created or destroyed. The twentieth-century interconversion of matter and energy is a refinement which does not affect the usefulness of the law for nonrelativistic processes.

For practical purposes we are very much concerned with the *rate* of doing work or otherwise delivering energy. This rate is called *power*. In MKS units, power is measured in *watts*, one watt equaling one joule per second. In English units, power may be measured in *horsepower*, equivalent to 550 foot-pounds per second (1 hp = 746 W). Thus, from the definition of power, if $W$ is the work accomplished or energy expended or delivered in time $t$, the average power for that period is

$$P = \frac{W}{t} \tag{1-2}$$

just as we get our average speed on a trip by dividing the distance traveled by the time required. We are also interested in the *instantaneous power*, however, just as we are interested in the momentary reading of the speedometer of the car. The expression for instantaneous power may be written

$$p = \frac{dW}{dt} \tag{1-3}$$

where the lowercase letter $p$ indicates an instantaneous quantity and the term $dW/dt$ is, of course, the usual mathematical notation for the time rate at which work is being done.

Because of the intimate relationship between power and energy, we often find energy expressed in such units as *watt-seconds* or *kilowatthours* (= 1,000 × 3,600 or $3.6 \times 10^6$ watt-seconds). A watt-second is, of course, the same as a joule; the picture conveyed is the amount of energy delivered in one second by a constant power of one watt.

**Example 1-1**

Electric energy is delivered to a battery, wherein it is converted to chemical energy and stored at a constant rate of 400 W. In addition, 20 percent of the power delivered to the battery is converted into heat and lost.

Find the cost of charging the battery for 10 hours (abbreviated h) with electricity costing 2 cents/kWh.

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