Electric Circuits

ELECTRIC CIRCUITS

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Preface

I have attempted to write a textbook for electrical engineering technology programs that can be used in both two-year terminal programs and in the introductory courses of four-year programs. It can also be used in other technology disciplines in which a knowledge of electrical principles is considered essential.

The first few chapters require only a knowledge of basic physics and algebra. Although determinants should be covered in a prerequisite or concurrent algebra course, they are reviewed in the appendix. Some basic FORTRAN programs for the solution of determinants are also presented. This material can be introduced before the circuit analysis concepts of Chapter 6. Similarly, complex algebra is reviewed in Chapter 11, with particular emphasis on its application to ac circuits. The chapters on alternating current also require the understanding and use of trigonometry.

Since many technology programs include introductory calculus courses, the exactness of calculus is used in some formula derivations, but not until Chapter 7. Even then, calculus is only used as a tool in explaining certain electrical concepts.

Approximately the first half of the book is devoted to dc circuits. The basic quantities of current, voltage, and resistance are extensively presented. Circuit analysis is considered, followed by discussions of capacitance, transients, magnetic circuits, and inductance.

The part devoted to ac circuits contains the fundamental ac relationships, phasor algebra, single-phase circuits, polyphase circuits, resonance, and nonsinusoidal waves. Network analysis and the associated theorems are also presented in the section on ac to emphasize their use and to show their application when ac voltage and reactances are in a circuit.

Electrical measurements are often studied in associated laboratory course work and therefore, a chapter on measurements, Chapter 17, is included. The use of direct and alternating currents and analog and digital instruments, such as ammeters, voltmeters, and ohmmeters, is integrated in this chapter.

The voltage versus current characteristics of nonlinear resistances and electrical sources are first introduced in Chapters 4 and 5, respectively. Both of these concepts are then combined in Chapter 18, which is devoted to dc graphical analysis. This chapter is particularly useful for the study of nonlinear circuits and can also serve as an introduction to electronic load line analysis.

Conventional current is used in the book. Also, in keeping with the current recommendations of the Institute of Electrical and Electronics Engineers, the MKSA (SI) units are used wherever possible.

Questions and problems are provided at the end of each chapter. Most of these have been used in examinations and quizzes and have been chosen to reinforce the concepts presented within the chapters. Answers to odd-numbered problems are provided in the appendix. These and the examples presented in the text are only to slide rule accuracy.

I wish to thank Robert D. Thomas, Jr., for his help with some of the photographs and Professors Edward A. Dreisbach and Irving Engelson for their helpful suggestions. I also thank my wife Michalene for typing the manuscript and constantly offering encouragement.

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Introduction

1.1 UNITS AND CONVERSION FACTORS

Throughout man's history, he has developed methods of describing, measuring, and correlating various phenomena in the natural sciences. The three basic quantities concerned with motion in physics are length, mass, and time. Over the years the measurement of these three quantities has led to three systems of measurement, the *centimeter-gram-second* (CGS), the *meter-kilogram-second* (MKS) and the *English* systems of units, which are shown in Table 1-1.

Each of the units of measurement is based on some internationally accepted standard; for example, the second was originally defined in terms of the mean solar day but has most recently been defined in terms of the atomic radiation of cesium. The CGS and MKS units, which derive their names from the units used in each system, are known as the metric

Table 1-1. Physical Units.

Unit System	Length	Mass	Time
CGS	centimeter (cm)	gram (g)	second (sec)
MKS (MKSA)	meter (m)	kilogram (kg)	second
English	foot (ft)	slug (32 lbf)	second

system. The English units are sometimes called the *British Engineering* units. Most other units, such as those used in describing electrical quantities, have been based on the units listed in Table 1-1.

In some instances it is advantageous or even necessary to convert from one set of units to another by the use of a *conversion factor*, which is an equality that relates the two different units. Some common conversion factors are listed in Table 1-2. A systematic approach to the use of conversion factors is to divide either side of the equality by the other side, thus obtaining a ratio equal to 1. For example, 1 in. = 2.54 cm can be expressed as

Table 1-2. Common Conversion Factors.

1 inch = 2.54 centimeters (cm)
1 meter = 39.37 inches (in.)
1 pound = 453.6 grams (g)
1 kilogram = 2.2046 pounds (lb)
1 newton = 0.224 pound-force (lbf)
1 foot pound-force = 1.3549 joules (J)
1 horsepower = 746 watts (W)

$$\frac{1 \text{ in.}}{2.54 \text{ cm}} = 1 \quad \text{or} \quad 1 = \frac{2.54 \text{ cm}}{1 \text{ in.}}.$$

An equation can then be multiplied by either of the ratios without changing the value of the equation, since the net effect is a multiplication by 1. By choosing the correct ratio, a cancellation of the desired unit results.

Example 1-1

Convert 0.577 horsepower (hp) to its equivalent in watts.

Solution:

$$0.577 \text{ hp} \times \frac{746 \text{ W}}{\text{hp}} = 430 \text{ W}.$$

In October 1965, the Institute of Electrical and Electronics Engineers

(IEEE) adopted the *International System of Units* (SI units) proposed by the 11th General Conference on Weights and Measures held in France in 1960. The International System includes as subsystems the MKS system of units for mechanics and the MKSA system of units, which covers mechanics, electricity, and magnetism. The basic units of the MKSA system are the *meter*, the *kilogram*, the *second*, and the *ampere*. The ampere is discussed in Chapter 2 and is defined as an international standard in Chapter 8.

1.2 UNIT PREFIXES

Often the quantities being considered are much smaller or larger than the basic unit defined by the MKSA system. Rather than change the basic unit, a prefix is added to the unit to denote a multiple or submultiple of the basic unit. The prefixes to be used with the SI units are listed in Table 1-3.

Table 1-3. International-system Prefixes.

Prefix	Pronunciation	Factor by Which the Unit Is Multiplied	Symbol
tera	tĕr'ȧ	10^{12}	T
giga	jĭ'gȧ	10^{9}	G
mega	mĕg'ȧ	10^{6}	M
kilo	kĭl'ō	10^{3}	k
milli	mĭl'ĭ	10^{-3}	m
micro	mī'krō	10^{-6}	μ
nano	năn'o	10^{-9}	n
pico	pē'kō	10^{-12}	p
femto	fĕm'tō	10^{-15}	f
atto	ăt'tō	10^{-18}	a

1.3 THE CONCEPT OF CHARGE

Although man's interest in mechanics began in prehistoric time, most of our knowledge about electricity and magnetism has been developed during the last few centuries.

Thales, a Greek philosopher, made some brief observations on magnetism in 600 B.C., but it was not until 1600 that William Gilbert of England and some of his fellow experimenters observed that amber rubbed with fur acquired the ability to attract light objects to itself. The bodies were said to be "electrified," and it was found that sometimes a force of *repulsion*, as well as one of *attraction*, could exist between the electrified bodies. In 1747 Benjamin Franklin introduced the terms *positive* and *negative* as nomenclature for the two types of electrification. The term *charge* was introduced to imply electrification or the presence of electrical potential energy. Experimentation in the eighteenth century led to the following statements:

1. When electrification is brought about, equal positive and negative charges are simultaneously produced.
2. Unlike charges attract each other; like charges repel.

In 1785, Charles Coulomb, a French physicist, introduced what is now known as Coulomb's law. This law states that when two point charges Q_1 and Q_2 are separated by a distance r, as in Fig. 1-1, the force of attraction or repulsion is given by

$$F = k\frac{Q_1 Q_2}{r^2}. \tag{1-1}$$

The force given by Eq. 1-1 has the unit Newton (N), when r is in meters and Q_1 and Q_2 are in *coulombs*, the basic unit of charge. The constant of proportionality depends on the type of medium separating the charges; when air or free space is used, k equals 9×10^9 in the MKSA units. Even though the two charges do not touch each other, they exert a force on each other, and whenever a charge is acted on by an electric force, that charge is said to be in an *electric field of force* or simply *electric field*.

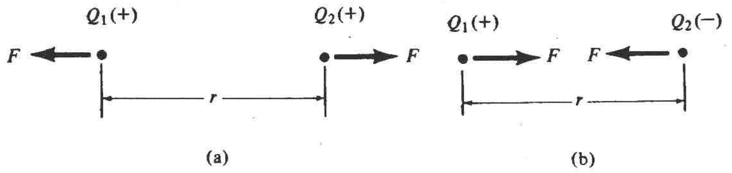

Figure 1-1 Two point charges: (a) like charges; (b) unlike charges

Questions

1. What is a conversion factor?
2. What is charge?
3. What is meant by the term *electric field*?

Problems

1. Make the following conversions:
   (a) 0.075 second to microseconds.
   (b) 1525 inches to meters.
   (c) 25 square inches (in.^{2}) to square meters (m^2).

(d) 250 yards to meters.
(e) 946 watts to horsepower.

2. Express the following in both milli and micro units:
(a) 0.00252 ampere.
(b) 0.0793 ampere.
(c) 0.321 second.
(d) 0.000047 second.

3. Express the following in both kilo and mega units:
(a) 1052 grams.
(b) 7252 watts.
(c) 7,252,000 watts.
(d) 542 watts.

4. Find the force of attraction between the charges of Fig. 1-1 if $Q_1 = +6 \times 10^{-4}$ coulomb, $Q_2 = -3 \times 10^{4}$ coulomb, and $r = 1$ m.

5. What will the force of attraction in Problem 4 become if the charge separation is increased by a factor of 10, that is, $r = 10$ m.

6. A concentrated positive charge of 1×10^{-9} coulomb is located in free space 2 meters from another positive charge of 4×10^{-6} coulomb. What force exists between the charges?

7. Two electric charges, one of which is twice the other, develop a mutually repulsive force of 12 newtons when located 0.08 meter apart. Determine the magnitude of the charges.