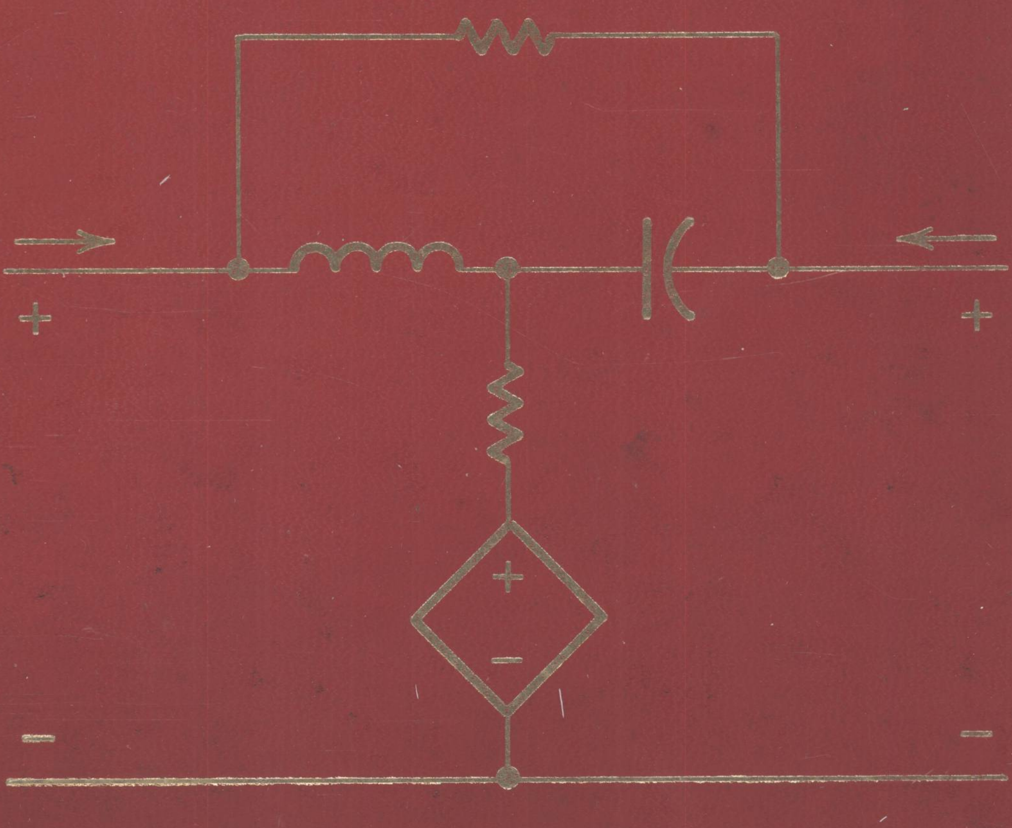
MATRIX SERIES IN CIRCUITS AND SYSTEMS

FUNDAMENTALS OF ELECTRICAL ENGINEERING ANALYSIS

Paul M. Chirlian



Fundamentals of Electrical Engineering Analysis

Paul M. Chirlian
Professor
Department of Electrical Engineering and Computer Science
Stevens Institute of Technology

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Fundamentals of Electrical Engineering Analysis
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Preface

This book is intended to be used as a text in the first course(s) for Electrical Engineering students. It presumes that they have had a basic course in differential and integral calculus. The material presented in the introductory Electrical Engineering courses is prerequisite for the more advanced courses. As such, the first Electrical Engineering course has, classically, provided the student with the basic tools for the analysis of electric circuits. The discussion in this text starts at a simple level using resistive circuits. However, once the basic ideas are established more complete concepts are introduced. To clarify the presentations, many numerical examples are used throughout the book.

A chapter on operational amplifiers, treated from a circuits viewpoint, is included. This helps to motivate the student. In addition, such an early discussion will allow the incorporation of operational amplifier experiments early in the Electrical Engineering curriculum.

The Laplace transform is introduced early in the book. In this way, the student can apply this powerful tool to the analysis of circuits. In addition, sinusoidal steady state response can be developed from the Laplace transform so that the student can gain a thorough understanding of the significance of sinusoidal steady state behavior.

The early chapters of the book consider resistive circuits since all the basic concepts of nodal and loop analysis can be developed using them. Once the student is familiar with the basic ideas, inductance and capacitance are introduced and the concepts are extended to general circuits.

In Chapter 1, the basic concepts of charge, current, voltage, energy and power are introduced. Independent and dependent voltage and current generators are also considered.

Kirchhoff's laws are introduced in Chapter 2 and the analysis of simple series and parallel resistive circuits is discussed.

Nodal, mesh, and loop analysis are presented in Chapter 3. Many examples using resistive circuits are given. These examples include both independent and dependent generators.

The analysis techniques that have been developed are applied to a discussion of operational amplifiers in Chapter 4. Numerous voltage amplifier circuits are considered. The summing amplifier is discussed. The comparator and Schmitt trigger are presented. The use of these in control applications is discussed.

Inductance and capacitance are introduced in Chapter 5. A simple discussion of the classical procedure for the solution of differential equations is given. There is a thorough discussion of initial conditions. Circuit response is illustrated using RL, RC, and RLC circuits. Nodal and loop differential equations are considered. Although there is some discussion of the classical procedures for solving differential equations, it is primarily intended to provide motivation for the use of the Laplace transform.

In Chapter 6 we present the Laplace transform. The 0− form, rather than the 0+ form is used here. It is demonstrated that the 0− form is less tedious to use than the 0+ form in many circumstances. This chapter introduces the basic ideas of the Laplace transform, and then applies them to nodal, mesh and loop analyses. Transformed networks are discussed. Mutual inductance is introduced in this chapter. The discussion was deferred to this point since it was felt that the analysis using transformed networks was simpler. The ideas of impedance and admittance are introduced here. The unit step and unit impulse responses are considered. Various theorems are discussed.

Sinusoidal steady state analysis is discussed in Chapter 7. The concept of the sinusoidal steady state is derived from the Laplace transform of the response of a circuit to sinusoidal generators. This leads to a better understanding of the concept of phasors. Nodal and mesh analysis are discussed. Impedance and admittance on a sinusoidal steady state basis are presented and power is thoroughly considered.

Network theorems are discussed in Chapter 8. The superposition theorem, Thévenin's theorem, Norton's theorem, maximum power transfer, reciprocity, and the concept of duality are considered here.

Twoport networks are discussed in Chapter 9. The idea of a twoport and the various twoport parameters are presented. The relations among the parameters are given.

State variables and state space analysis techniques are discussed in Chapter 10. The ideas of computer solution of state variable equations are considered.

The Fourier series and Fourier integral are introduced in Chapter 11. The Fourier series is considered first and the solution of networks with periodic generators is presented. These ideas are then extended to the Fourier transform. Convolution is discussed as is the relationship between the Fourier and Laplace transforms.

I would like to express my thanks to Profs. E.C. Barbe, N.K. Bose, J.F. Delansky and A. Sage for their many valuable comments.

Very much love and heartfelt thanks are again due my wife, Barbara, who provided me with constant encouragement. She made numerous corrections to the manuscript and also typed all the drafts.

Paul M. Chirlian
East Brunswick, NJ

To Barbara, Lisa and Peter

Contents

Chapter 1

Basic Definitions

In this book we shall study the fundamental techniques used to analyze electric and electronic circuits. These techniques are useful in a wide variety of applications. For instance, the electronics in integrated circuit chips can be analyzed using the procedures to be presented in this book. In addition, electric power distribution systems can be studied using these techniques. In general, *electric circuit analysis* is indispensable to the electrical engineer, who uses it constantly in analysis and design.

1-1. CHARGE AND CURRENT

We shall start our discussion by considering the basic definitions and concepts of electric circuits. Once this has been done, the analysis techniques can be developed.

All atoms consist of a positively-charged nucleus surrounded by negatively-charged electrons. Charged particles exert forces upon each other. The motion of these charged particles constitutes an *electric current*. We shall now quantitatively define the basic units of charge and current.

The fundamental unit of charge is the *coulomb* (q.) which represents the charge of 6.24×10^{18} electrons. Note that a coulomb represents the charge of a very large number of electrons. By convention, electrons have a negative charge. hence, 6.24×10^{18} electrons represent a charge of -1 coulomb.

Example:

Compute the charge of one million electrons.

$$Q=\frac{-10^6}{6.24\times10^{18}}=-0.1602\times10^{-12} \text{ coulombs}$$

Thus, the charge of one million electrons represents a very small fraction of a coulomb.

In electrical engineering we often deal with very small or very large numbers. Prefixes are added to various quantities to aid in their expression. For instance, the prefix *pico* represents 10^{-12} so that the answer to the previous example could be expressed as

$$Q=-0.1602 \text{ picocoulomb}=-0.1602 \text{ pc.}$$

In Table 1-1 we list the fundamental prefixes, their values, and abbreviations.

TABLE 1-1
Prefixes Commonly Used in Electrical Engineering

Prefix	Value	Abbreviation
pico	10^{-12}	p
nano	10^{-9}	n
micro	10^{-6}	μ
milli	10^{-3}	m
kilo	10^{3}	k
mega	10^{6}	M
giga	10^{9}	G
tera	10^{12}	T

The motion of charge is said to constitute an *electric current.* The basic unit of current is the *ampere* (A).

$$1 \text{ ampere}=1 \text{ coulomb/second} \tag{1-1}$$

That is, suppose that through some mechanism you could look into a wire and observe the charge flowing in it. If you observe the charge flowing in it. If you observe that one coulomb is passing a given cross section each second, then the current in that wire is said to be one ampere. We choose to let conventional current flow in the same direction as positive charge flow. This is opposite to the direction of electron or negative charge flow.

The current need not be constant. In many electrical applications, the current varies with time. In a digital computer, current is constantly changing between two levels. In an audio amplifier, the current varies in accord with the sound signal.

Let us consider a time-varying current and mathematically relate current and charge flow. For instance, suppose that the current varies with time as shown in Fig. 1-1a. Let us determine the total charge transferred as a func-

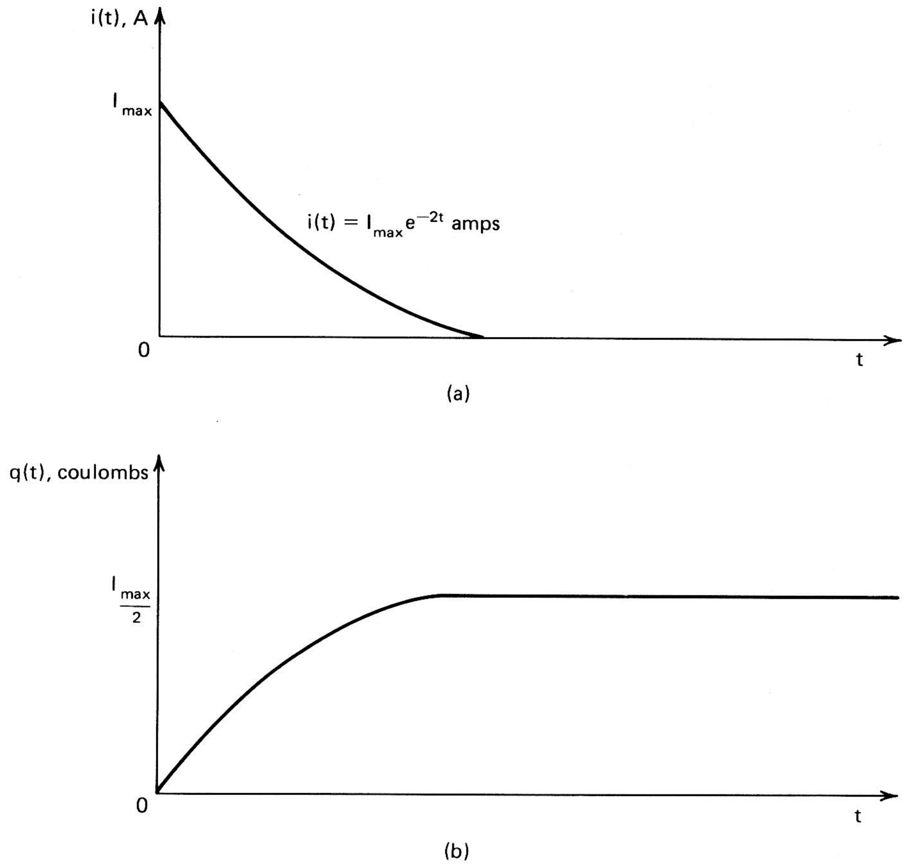

Fig. 1-1. (a) A current that falls off exponentially with time; (b) the charge transferred as a result of the current in (a)

tion of time. Current is defined as the amount of charge transferred in a unit time. Suppose that the current is constant. If, in a time interval of Δt seconds, a charge of Δq coulombs is transferred, then the current is:

$$I = \Delta q / \Delta t. \tag{1-2}$$

If the current varies, then Δq will not be constant over the interval Δt. In this case the definition of Eq. (1-2) is not meaningful. To define current in such cases we must make Δt so small that Δq can be considered to be a constant in each interval Δt. Doing this we arrive at the usual definition of the derivative. Then we can state:

$$i(t)=dq(t)/dt, \tag{1-3}$$

where the (t) indicates that the current and charge are functions of time.

Now let us obtain an expression for the charge transferred as a function of the current. To do this we integrate both sides of Eq. (1-3). For instance, if $i(t)$ represents the current through a given cross section in the time interval between $t=0$ and $t=T$ is

$$q(T)=\int_0^T i(t)dt. \tag{1-4}$$

Example:

The current through a wire is shown in Fig. 1-1a. Find the charge transferred as a function of time.

The current is given by

$$i(t)=I_{\max}e^{-2t}A; \text{ for } t\geqslant 0.$$

The charge transferred is given by

$$q(t) = \int_0^t I_{\max}e^{-2\tau}d\tau, Q. \tag{1-5}$$

That is, it is the area under the current curve for time between 0 and t. Integrating, we have

$$q(t)=\frac{I_{\max}}{2}\left[1-e^{-2t}\right], Q.$$

Note that in Eq. (1-5) we have used τ as the dummy variable of integration. This is done so that it is not confused with the upper limit, which is t. The curve of $q(t)$ is plotted in Fig. 1-1b.

Let us now consider a second example.

Example:

A current has the waveform shown in Fig. 1-2a. Find an expression for the charge transferred.