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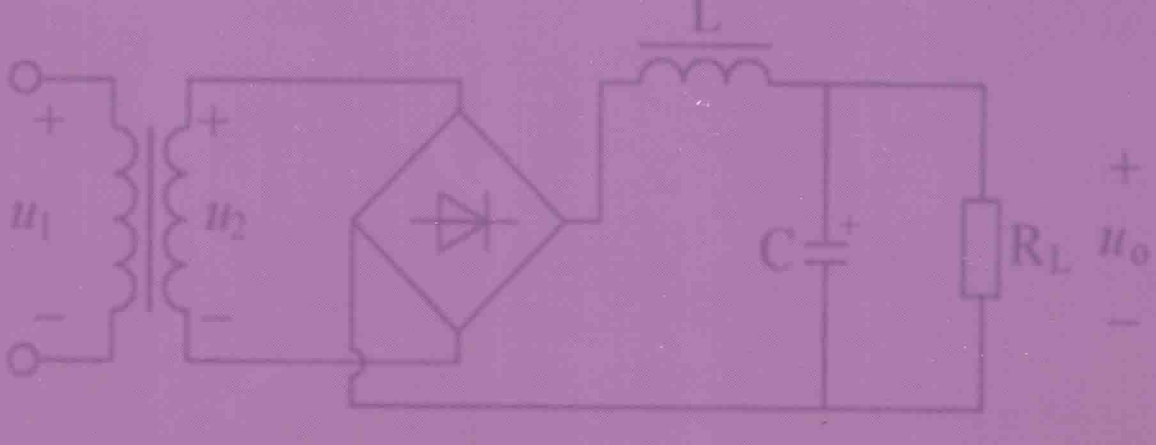
Electrical and Electronic Circuits

电工与电子电路

Edited by Shangzhi Xin

忻尚芝 编著



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Synopsis

This book has three parts, twelve chapters. Part one electrical circuits has six chapters. Part two analog circuits has three chapters. Part three digital circuits has three chapters. Electrical circuits covers basic DC circuit, first-order transient circuit, and sinusoidal AC circuit. Analog circuits covers diode, transistor, and operational amplifiers. Digital circuits introduces logic circuit constructed from logic gates and flip-flops.

The book is suitable for university students as a textbook to study electrical knowledge, and for electrical technicians to use as a reference book.

Preface

The book, Electrical and Electronic Circuits, covers electrical circuits, analog electronic circuits, and digital logic circuits. There are six chapters of electrical circuits (part one), three chapters of analog circuits (part two), and three chapters of digital circuits (part three). The emphases of each chapter are basic concepts, basic circuits, and applications. There are enough selected examples for every chapter to understand the electrical principles as well as the methods of analysis and design. At the end of the chapters there are a certain number of problems to improve the abilities to analyze and design the circuits.

This book is written for the non-electrical majors students in college and university to study electrical theories. The prerequisites are advanced mathematics and general physics. The suggested semester schedule of teaching using this book is four hours per week. The lab course will include sixteen hours for eight experiments.

The purposes of this book are training

- The ability to solve practical problems of electrical engineering.
- The ability to apply mathematics and physics knowledge to solve complex electrical problems.
- The ability to communicate with electrical engineers to solve the problems of different professional fields.

The author has been teaching the course for more than twenty years. This book includes the lesson preparation notes and teaching experience summaries. I think that many places in this book still need to be improved. The information or suggestion could improve the content description, chapter arrangement, example choice, problem selection, even the experiment content and quantity is especially valuable. Welcome the corrections, comments, and suggestions from the readers and users of this book. My email address is xinsz@usst.edu.cn.

I wish to thank the prize of 2015 Shanghai excellent teaching material (Electrical and Electronic circuits, in Chinese) award which is organized by all levels of educational administration offices of University of Shanghai for Science and Technology (USST) and Shanghai Education Commission. It is the financial support to publish this book. I also want to thank Andrew W. Ni from University of Michigan — Ann Arbor for helping review this book. I also thank the editor and staff at Shanghai Science & Technical Publishers. Their professional editorial work makes this book publish successfully. Finally, I also thank all of the people around me for their continuing support and encouragement.

Shangzhi Xin

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Part One Electrical Circuits

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Part One Electrical Circuits

Chapter 1 Main Circuit Elements

In this chapter we will introduce main elements of circuits. They are power sources、resistors、capacitors, and inductors. We describe the characteristics of each component, discuss the relation of voltage and current of them. We will learn about both the series and parallel connection circuit, and how to calculate the total resistance、capacitance and inductance.

It is important to note that in the textbook we use lowercase letters to represent time-varying alternating current (AC) signals and capital letters to represent not time-varying direct current (DC) signals. We also use subscript letters in same way if it is necessary. For example:

U, I —— DC voltage, DC current.

u, i —— AC voltage, AC current.

I_B, I_C, I_E—— Pure DC currents.

i_b, i_c, i_e—— Pure AC currents.

i_B, i_C, i_E—— AC and DC hybrid currents.

Also need to understand is that U and u letters represent the voltage, V and v letters represent the potential. Voltage is the difference of potentials between two points in a circuit. The voltage of one point in a circuit always means the voltage between this point and the reference zero in the circuit.

1.1 Power Sources

1.1.1 Voltage Sources

A voltage source supplies a specified voltage regardless of the current across its two terminals.

In Fig. 1.1(a) the voltage across the source is constant. It is a DC voltage source. In Fig. 1.1(b) it is an AC voltage source having a sinusoidal variation voltage with time. The unit of voltage is volt (V).

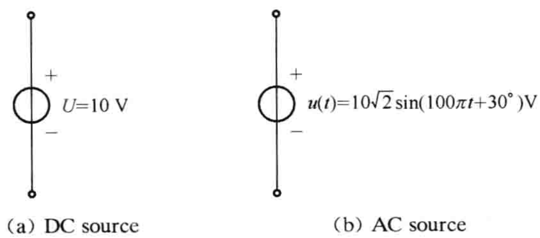


Fig. 1.1 Voltage sources

1.1.2 Current Sources

A current source supplies a specified current to flow through itself regardless of the voltage. The current sources have DC and AC current sources. They are shown in Fig. 1.2. The unit of current is ampere (A).

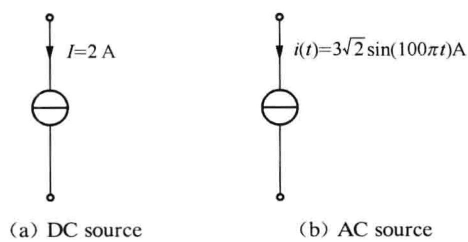


Fig. 1.2 Current sources

1.2 Resistors

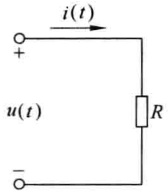


Fig. 1.3 A resistor including references of $u(t)$ and $i(t)$

A resistor is a physical device that can be in certain serial standard values. It is a basic element of a circuit, shown in Fig. 1.3.

1.2.1 Ohm's Law

Georg Simon Ohm (German, 1787~1854) found that for a given circuit the voltage to current ratio is equal to the resistor value. This is called Ohm's Law. Ohm's Law describes the relation of resistors' voltage and current. In equation form:

$$R = \pm \frac{u}{i} \tag{1.1}$$

where R=circuit resistance, unit ohm (Ω)

u=voltage, unit volt (V)

i=current, unit ampere (A)

The positive or negative of Ohm's Law equation is decided by voltage polarity and current direction. If the order of the subscripts is the same for the voltage and the current, the current reference direction is from voltage reference positive to negative polarity. Ohm's Law is:

$$R = \frac{u}{i} \tag{1.2}$$

shown in Fig. 1.4(a)(b).

On the other hand Ohm's Law becomes:

$$R = -\frac{u}{i} \tag{1.3}$$

shown in Fig. 1.4(c)(d).

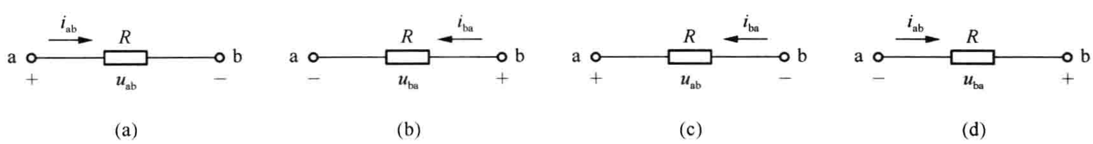


Fig. 1.4 Relation between voltage reference polarity and current reference direction

1.2.2 Resistors in Series and Parallel

Two resistors combine in series shown in Fig. 1.5(a). The same current flows through two of the components. Total of the resistances in series:

$$R = R_1 + R_2 \tag{1.4}$$

Two resistors combine in parallel shown in Fig. 1.5(b). The voltage across each component is the same. Now we have

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \tag{1.5}$$

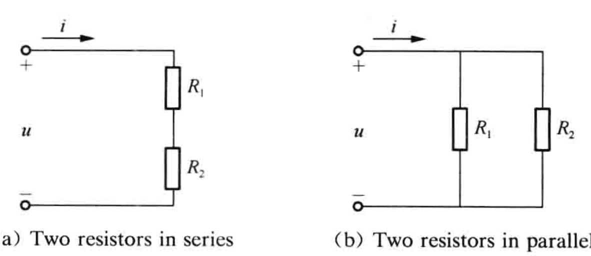


Fig. 1.5 Resistance in series and parallel

where $\frac{1}{R} = G$, G=conductance, unit Siemens (S)

The total resistance equations of resistors in series and parallel can apply to any number of resistors more than two.

1.3 Capacitors

Physical capacitor components which provide a specified capacitance. They have the ability to store power energy.

1.3.1 Voltage and Current of a Capacitor

The relation between voltage and current of a capacitor is:

$$i(t) = \pm C\frac{du}{dt} \tag{1.6}$$

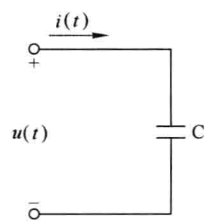


Fig. 1.6 Capacitor including references of $u(t)$ and $i(t)$

where C=capacitance, unit farad (F)

Equation 1.6 shows that as voltage changes, current flows through the capacitor. If the voltage remains constant, the current is zero. That means that a capacitor appears open circuit for a DC voltage.

If the current reference direction points voltage reference positive to negative, shown in Fig. 1.6.

$$i(t) = C\frac{du}{dt} \tag{1.7}$$

Opposite the equation will be:

$$i(t) = -C\frac{du}{dt} \tag{1.8}$$

To determine voltage in terms of current, we have

$$u(t) = \pm\frac{1}{C}\int_{t_0}^{t} i(t)\mathrm{d}t + u(t_0) \tag{1.9}$$

where $u(t_0)$=voltage of initial time.

1.3.2 Stored Energy

We know the energy is stored in a capacitor:

$$\begin{aligned} w(t) &= \int_{t_0}^{t} P(t)\mathrm{d}t \\ &= \int_{t_0}^{t} i(t)u(t)\mathrm{d}t \\ &= \int_{t_0}^{t} C\frac{\mathrm{d}u}{\mathrm{d}t}u(t)\mathrm{d}t \\ &= \int_{u(t_0)}^{u(t)} Cu(t)\mathrm{d}u \\ &= \frac{1}{2}C[u^2(t) - u^2(t_0)] \end{aligned}$$

Suppose a capacitor has $u(t_0) = 0$, so

$$w(t) = \frac{1}{2}Cu^2(t) \tag{1.10}$$

where w=energy, unit joule (J)

Equation 1.10 shows that stored energy of a capacitor decides by the voltage of capacitor. When the $u(t) = 0$, then the stored energy $w(t) = 0$.

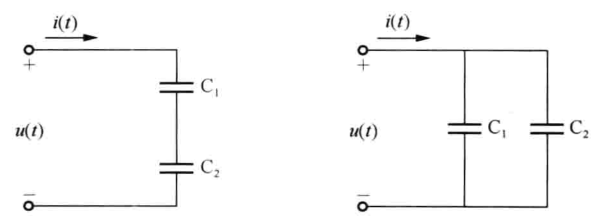
1.3.3 Capacitors in Series and Parallel

Capacitors in series are shown in Fig. 1.7(a). The total capacitance is:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \tag{1.11}$$

Capacitors in parallel are shown in Fig. 1.7(b). Then we have:

$$C = C_1 + C_2 \tag{1.12}$$



(a) in series (b) in parallel

Fig. 1.7 Capacitors in series and parallel

The equations of capacitors in series and parallel can apply to more than two capacitors.

1.4 Inductors

Physical inductor components constructed by coiling wire around air or some types of cores. They cannot be easily fabricated on an integrated circuit chip. Inductors can store power energy.

1.4.1 Voltage and Current of an Inductor

Michael Faraday (British, 1791～1867) invented Faraday's Law of electromagnetic induction. The voltage of an inductor is proportional to the change of the current and opposes the change in current.

In equation form the voltage and current of an inductor are

$$u(t) = \pm L \frac{di}{dt} \tag{1.13}$$

where L = inductance, unit henry (H)

As usual the current reference direction is from voltage reference positive to negative, shown in Fig. 1.8. We have

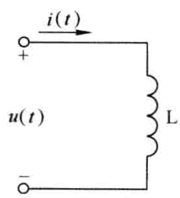


Fig. 1.8 Inductor including references of $u(t)$ and $i(t)$

$$u(t) = L \frac{di}{dt} \tag{1.14}$$

If not so the equation becomes

$$u(t) = -L \frac{di}{dt} \tag{1.15}$$

To compute the current in terms of voltage. We have

$$i(t) = \pm \frac{1}{L}\int_{t_0}^{t} u(t)dt + i(t_0) \tag{1.16}$$

where $i(t_0)$ = current of initial time.

1.4.2 Stored Energy

The energy stored in an inductor is:

$$\begin{aligned} w(t) &= \int_{t_0}^{t} P(t)dt \\ &= \int_{t_0}^{t} i(t)u(t)dt \\ &= \int_{t_0}^{t} i(t)L\frac{di}{dt}dt \\ &= \int_{i(t_0)}^{i(t)} Li(t)di \\ &= \frac{1}{2}L[i^2(t) - i^2(t_0)] \end{aligned}$$