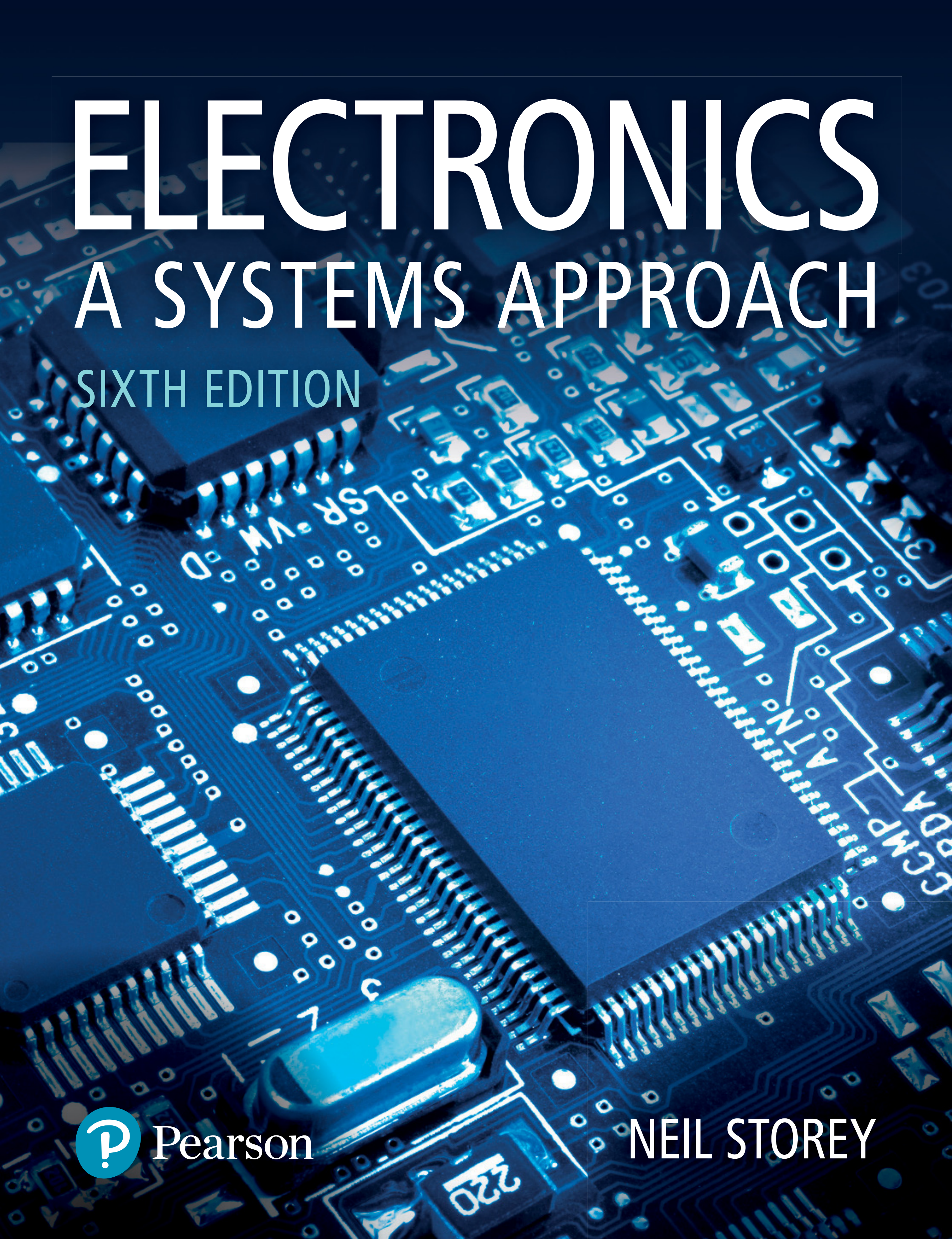

ELECTRONICS
A SYSTEMS APPROACH

SIXTH EDITION

Pearson

NEIL STOREY

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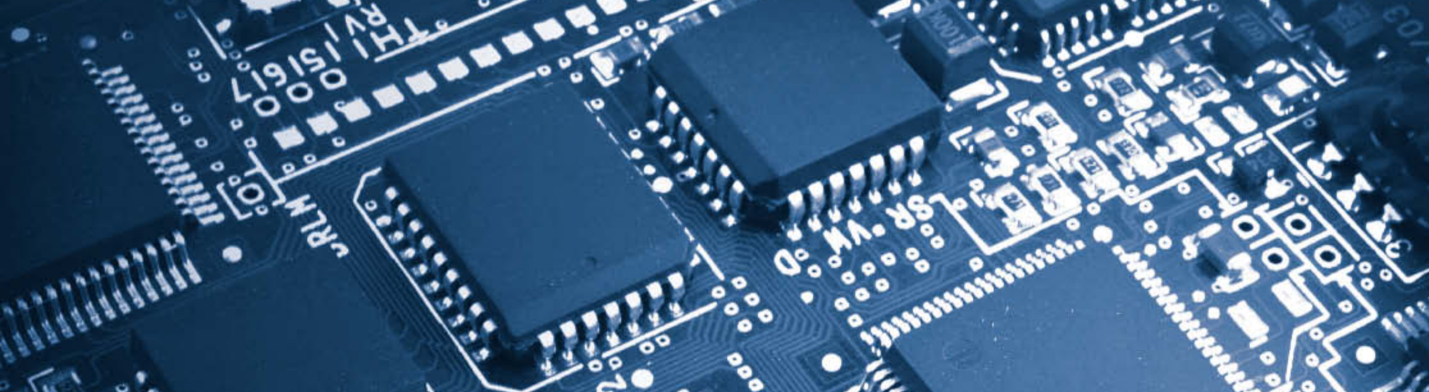

Sixth Edition

ELECTRONICS

A SYSTEMS APPROACH

Neil Storey

Pearson

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PEARSON EDUCATION LIMITED
Edinburgh Gate
Harlow CM20 2JE
United Kingdom
Tel: +44 (0)1279 623623
Web: www.pearson.com/uk

First published 1992 (print)
Second published 1998 (print)
Third published 2006 (print)
Fourth published 2009 (print)
Fifth published 2013 (print and electronic)
Sixth edition published 2017 (print and electronic)

ISBN: 978-1-292-11406-4 (print)
978-1-292-11411-8 (PDF)
978-1-292-13341-6 (ePub)

British Library Cataloguing-in-Publication Data
A catalogue record for the print edition is available from the British Library

Library of Congress Cataloging-in-Publication Data
Names: Storey, Neil, author.
Title: Electronics : a systems approach / Neil Storey.
Description: Sixth edition. | Harlow, England ; New York : Pearson, 2017.
Identifiers: LCCN 2016055942| ISBN 9781292114064 (print) | ISBN 9781292133416 (ePub) | ISBN 9781292114118 (PDF)
Subjects: LCSH: Electronic systems. | Electronic circuits.
Classification: LCC TK7870 .S857 2017 | DDC 621.381—dc23
LC record available at https://lccn.loc.gov/2016055942

10 9 8 7 6 5 4 3 2 1
21 20 19 18 17

Print edition typeset in Ehrhardt MT Pro 10/11.5pt by iEnergizer Aptara®, Ltd.
Printed and bound in Malaysia

NOTE THAT ANY PAGE CROSS REFERENCES REFER TO THE PRINT EDITION

Brief Contents

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Companion Website

ON THE WEBSITE

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Preface

Electronics represents one of the most important, and rapidly changing, areas of engineering. It is used at the heart of a vast range of products that extends from mobile phones to computers, and from cars to nuclear power stations. For this reason, *all* engineers, scientists and technologists need a basic understanding of such systems, while many will require a far more detailed knowledge of this area.

When the first edition of this text was published it represented a very novel approach to the teaching of electronics. At that time most texts adopted a decidedly 'bottom-up' approach to the subject, starting by looking at semiconductor materials and working their way through diodes and transistors before eventually, several chapters later, looking at the uses of the circuits being considered. *Electronics: A Systems Approach* pioneered a new, 'top-down' approach to the teaching of electronics by explaining the uses and required characteristics of circuits, before embarking on detailed analysis. This aids comprehension and makes the process of learning much more interesting.

One of the great misconceptions concerning this approach is that it is in some way less rigorous in its treatment of the subject. A top-down approach does *not* define the depth to which a subject is studied but only the order and manner in which the material is presented. Many students *will* need to look in detail at the operation of electronic components and understand the physics of its materials; however, this will be more easily absorbed if the characteristics and uses of the components are understood first.

A great benefit of a top-down approach is that it makes the text more accessible for *all* its potential readers. For those who intend to specialise in electronic engineering the material is presented in a way that makes it easy to absorb, providing an excellent grounding for further study. For those intending to specialise in other areas of engineering or science, the order of presentation allows them to gain a good grounding in the *basics*, and to progress into the *detail* only as far as is appropriate for their needs.

While a top-down approach offers a very accessible route to understanding electronics, it is much more effective if one starts with a thorough understanding of the basic components used in such circuits. Some readers of this text will already be familiar with this material from previous study, while others will have little or no knowledge of such topics. For this reason, the book is divided into two parts. Part 1 provides an introduction to **Electrical Circuits and Components** and makes very few assumptions about prior knowledge. This section gives a gentle and well-structured introduction to this area, and readers can select from the various topics depending on their needs and interests. Part 2 then provides a thorough introduction to **Electronic Systems**, adopting the well-tried, top-down approach for which this text is renowned. The text therefore provides a comprehensive introduction to both Electrical and Electronic Engineering, making it appropriate for a wide range of first-level courses in areas such as **Electronic Engineering**, **Electrical Engineering** and **Electrical and Electronic Engineering**.

New in this edition

This sixth edition gives an opportunity to enhance the treatment of several key topics and also to update the text in several areas that are undergoing rapid change.

- A new section on **single-board computers**, including an overview of devices such as the Raspberry Pi® and the Arduino®.
- A new section on **microwave communication**, outlining its characteristics and applications.
- A new section on **fibre-optic communication**, which looks at the nature of optical fibres, and how they are used in a range of situations.
- An expansion of the chapters on **sensors** and **actuators**, to include additional material on image sensors and the devices used in fibre-optic communications.
- An expanded range of **end of chapter exercises**, to help readers to more effectively assess their understanding of the material.
- A number of additional **video tutorials** which not only help students to understand the material in the text, but also enable them to see how the various techniques can be applied in real world situations.

Video Tutorials

A major feature of the text is the provision of over a hundred supporting videos. These provide tutorial support for topics throughout the text and also aim to provide guidance and encourage creativity within the various 'further study' exercises. These videos are *not* hour-long 'lectures' covering broad-ranging themes, but are short, succinct tutorials, lasting only a few minutes, that describe in detail various aspects of design or analysis.

Video 0

Accessing the tutorials couldn't be easier. Icons of the form shown on the left are placed throughout the text to indicate the topics covered. If you are using a paper copy of the text, simply scan the QR code in the icon with your phone or laptop to go straight to the video. If you are using an e-book it's even easier, as the icon contains a direct link to the video. Alternatively, you can go to the companion website (see below) which gives a full list of all the videos available and provides direct access.

Who should read this text

This text is intended for undergraduate students in all fields of engineering and science. For students of electronics or electrical engineering it provides a first-level introduction to electronics that will give a sound basis for further study. For students of other disciplines it includes most of the electronics material that they will need throughout their course.

Assumed knowledge

The book assumes very little by way of prior knowledge, except for an understanding of the basic principles of physics and mathematics.

Companion website

The text is supported by a comprehensive companion website that will greatly increase both your understanding and your enjoyment. The site contains a range of support material, including computer-marked self-assessment exercises for each chapter. These exercises not only give you instant feedback on your understanding of the material, but also give useful guidance on areas of difficulty. The website also gives easy access to the numerous video tutorials mentioned above. To visit the site, go to www.pearsoned.co.uk/storey-elec.

To the instructor

A comprehensive set of online support material is available for instructors using this text as course reading. This includes a set of editable **PowerPoint slides** to aid in the preparation of lectures, plus an **Instructor's Manual** that gives **fully worked solutions** to all the numerical problems and **sample answers** for the various non-numerical exercises. Guidance is also given on **course preparation** and on the selection of topics to meet the needs of students with different backgrounds and interests. This material, together with the various online study aids and self-assessment tests, should greatly assist both the instructor and the student to gain maximum benefit from courses based on this text. Instructors adopting this text should visit the companion website at www.pearsoned.co.uk/storey-elec for details of how to gain access to the secure website that holds the instructor's support material.

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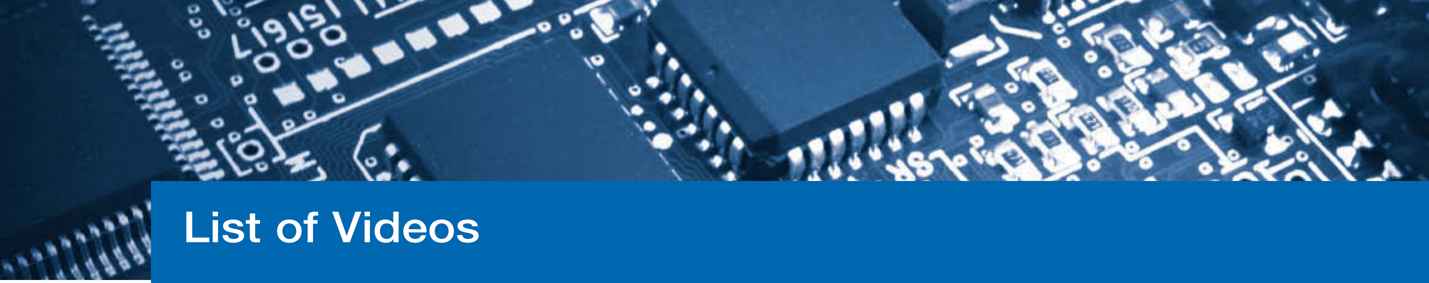

List of Videos

Acknowledgements

I would like to express my gratitude to the various people who have assisted in the preparation of this text. In particular I would like to thank my colleagues at the University of Warwick who have provided useful feedback and ideas.

I would also like to thank the companies who have given permission to reproduce their material: RS Components for the photographs in Figures 2.14, 10.15, 12.2(a) and (b), 12.3(a) and (b), 12.4, 12.5(a) and (b), 12.8, 12.9, 12.11(a) and (b), 12.14, 13.1, 13.3, 13.4 and 13.5; Farnell Electronic Components Limited for the photographs in Figures 2.12; Texas Instruments for Figures 21.4(a) and (b), 21.6, 21.7(a) and (b), 26.22, 26.34; Lattice Semiconductor Corporation for Figures 27.11, 27.12, 27.13; Anachip Corporation for Figure 27.14; Microchip Technology for Figures 27.41 and 27.42. Certain materials herein are reprinted with the permission of Microchip Technology Incorporated. No further reprints or reproductions may be made of said materials without Microchip Technology Inc.'s prior written consent. Photos on pages 17, 34, 36, 38, 63, 80, 99, 121, 133, 164, 180, 196, 207, 215, 216 (Figure 12.7 (b)), 227, 232, 239, 258, 274, 279, 302, 333, 381, 442, 471, 486, 524, 580, 625, 683, 735, 746, 747, 748 749, 766, 791 and 793 courtesy of Shutterstock; photos on page 216 (Figure 12.7 (a)), and 806 courtesy of Fotolia; photo on page 510 courtesy of Jaguar Land Rover Limited.

Finally, I would like to give special thanks to my family for their help and support during the writing of this text. In particular I wish to thank my wife Jillian for her never-failing encouragement and understanding.

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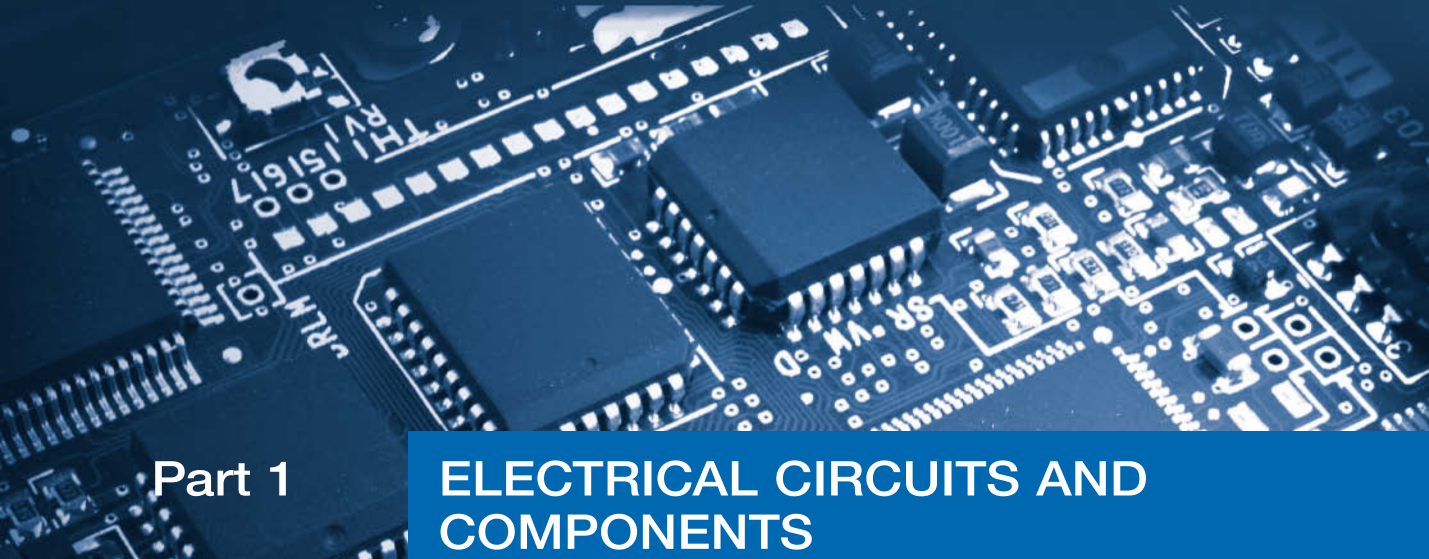
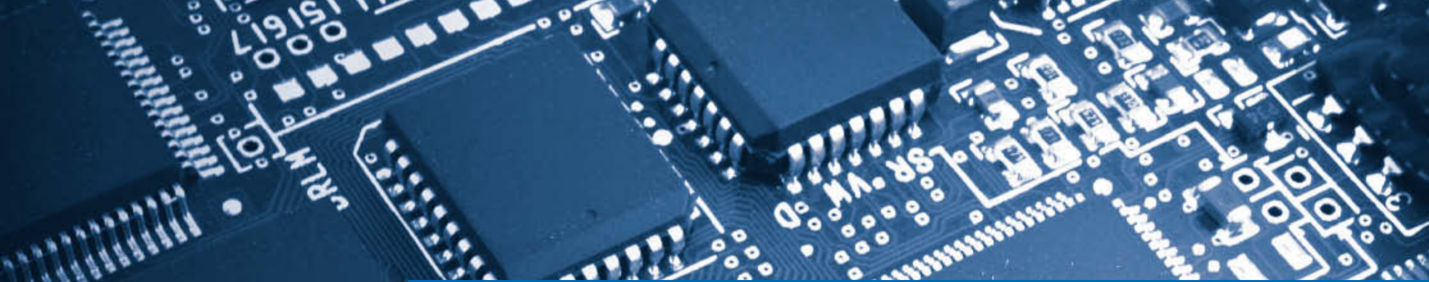


Part 1 ELECTRICAL CIRCUITS AND COMPONENTS



Chapter 1 Basic Electrical Circuits and Components

Objectives

When you have studied the material in this chapter, you should be able to:

- give the Système International (SI) units for a range of electrical quantities
- use a range of common prefixes to represent multiples of these units
- describe the basic characteristics of resistors, capacitors and inductors
- apply Ohm's law, and Kirchhoff's voltage and current laws, to simple electrical circuits
- calculate the effective resistance of resistors in series or in parallel, and analyse simple resistive potential divider circuits
- define the terms 'frequency' and 'period' as they apply to sinusoidal quantities
- draw the circuit symbols for a range of common electrical components.

1.1 Introduction

While the title of this text refers to 'electronic systems', this first part refers to 'electrical circuits and components' and it is perhaps appropriate to start by explaining what is meant by the terms 'electronic' and 'electrical' in this context. Both terms relate to the use of electrical energy, but *electrical* is often used to refer to circuits that use only simple passive components such as resistors, capacitors and inductors, while the term *electronic* implies circuits that also use more sophisticated components such as transistors or integrated circuits. Therefore, before looking in detail at the operation of electronic systems, we need to have a basic understanding of the world of electrical engineering, as the components and circuits of this domain also form the basis of more sophisticated electronic applications.

Unfortunately, while this use of the words electrical and electronic is common, it is not universal. Engineers sometimes use the term *electrical* when describing applications associated with the generation, transmission or use of large amounts of electrical energy, and use *electronic* when describing applications associated with smaller amounts of power, where the electrical energy is used to convey information rather than as a source of power. For this reason, within this text we will be fairly liberal with our use of the two terms, because much of the material covered is relevant to all forms of electrical and electronic systems.

Most readers will have met the basic concepts of electrical circuits long before embarking on study at this level, and later chapters will assume that you are familiar with this elementary material. In the chapters that follow we will look at these basic concepts in more detail and extend them to give a greater understanding of the behaviour of the circuits and systems that we will be studying. However, it is essential that you are familiar with some elementary material before continuing.

The list below gives an indication of the topics that you should be familiar with before reading the following chapters:

- The Système International (SI) units for quantities such as energy, power, temperature, frequency, charge, potential, resistance, capacitance and inductance. You should also know the symbols used for these units.
- The prefixes used to represent common multiples of these units and their symbols (for example, 1 kilometre = 1 km = 1000 metres).
- Electrical circuits and quantities such as charge, e.m.f. and potential difference.
- Direct and alternating currents.
- The basic characteristics of resistors, capacitors and inductors.
- Ohm's law, Kirchhoff's laws and power dissipation in resistors.
- The effective resistance of resistors in series and parallel.
- The operation of resistive potential dividers.
- The terms used to describe sinusoidal quantities.
- The circuit symbols used for resistors, capacitors, inductors, voltage sources and other common components.

If, having read through the list above, you feel confident that you are familiar with all these topics, you could move on immediately to Chapter 2. However, just in case there are a few areas that might need some reinforcement, the remainder of this chapter provides what might be seen as a *revision* section on this material. This does not aim to give a detailed treatment of these topics (where appropriate this will be given in later chapters) but simply explains them in sufficient detail to allow an understanding of the early parts of the text.

In this chapter, worked examples are used to illustrate several of the concepts involved. One way of assessing your understanding of the various topics is to look quickly through these examples to see if you can perform the calculations involved, before looking at the worked solutions. Most readers will find the early examples trivial, but experience shows that many will feel less confident about some of the later topics, such as those related to **potential dividers**. These are very important topics, and a clear understanding of these circuits will make it much easier to understand the remainder of the book.

The exercises at the end of this chapter are included to allow you to test your understanding of the 'assumed knowledge' listed above. If you can perform these exercises easily you should have no problems with the technical content of the next few chapters. If not, you would be well advised to invest a little time in looking at the relevant sections of this chapter before continuing.

1.2 Système International units

The Système International (SI) d'Unités (International System of Units) defines units for a large number of physical quantities but, fortunately for our current studies, we need very few of them. These are shown in Table 1.1. In later chapters we will introduce additional units as necessary, and Appendix B gives a more comprehensive list of units relevant to electrical and electronic engineering.

Table 1.1 Some important units.

Quantity	Quantity symbol	Unit	Unit symbol
Capacitance	C	farad	F
Charge	Q	coulomb	C
Current	I	ampere	A
Electromotive force	E	volt	V
Frequency	f	hertz	Hz
Inductance (self)	L	henry	H
Period	T	second	s
Potential difference	V	volt	V
Power	P	watt	W
Resistance	R	ohm	Ω
Temperature	T	kelvin	K
Time	t	second	s

1.3 Common prefixes

Table 1.2 lists the most commonly used unit prefixes. These will suffice for most purposes although a more extensive list is given in Appendix B.

Table 1.2 Common unit prefixes.

Prefix	Name	Meaning (multiply by)
T	tera	10^{12}
G	giga	10^{9}
M	mega	10^{6}
k	kilo	10^{3}
m	milli	10^{-3}
μ	micro	10^{-6}
n	nano	10^{-9}
p	pico	10^{-12}

1.4 Electrical circuits

1.4.1 Electric charge

Charge is an amount of electrical energy and can be either positive or negative. In atoms, protons have a positive charge and electrons have an equal negative charge. While protons are fixed within the atomic nucleus, electrons are often weakly bound and may therefore be able to move. If a body or region develops an excess of electrons it will have an overall negative charge, while a region with a deficit of electrons will have a positive charge.

1.4.2 Electric current

An electric current is a flow of electric charge, which in most cases is a flow of electrons. Conventional current is defined as a flow of electricity from a positive to a negative region. This conventional current is in the opposite direction to the flow of the negatively charged electrons. The unit of current is the **ampere** or **amp** (A).

1.4.3 Current flow in a circuit

A sustained electric current requires a complete circuit for the recirculation of electrons. It also requires some stimulus to cause the electrons to flow around this circuit.

1.4.4 Electromotive force and potential difference

The stimulus that causes an electric current to flow around a circuit is termed an electromotive force or e.m.f. The e.m.f. represents the energy introduced into the circuit by a source such as a battery or a generator. The circuit or component in which the current is induced is sometimes called a load.

All real loads will oppose the flow of current to some extent, and the magnitude of this opposition is termed its resistance. The source must do work to drive a current through the resistive load, and therefore during this process energy is transferred from the source to the load.

The energy transferred from the source to the load results in a change in the electrical potential at each point in the load. Between any two points in the load there will exist a certain potential difference, which represents the energy associated with the passage of a unit of charge from one point to the other.

Both e.m.f. and potential difference are expressed in units of **volts**, and clearly these two quantities are related. Figure 1.1 illustrates the relationship between them: an e.m.f. is a quantity that produces an electric current, while a potential difference is the effect on the circuit of this passage of energy.

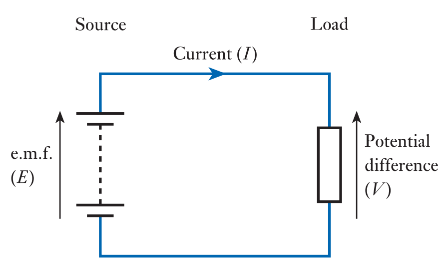


Figure 1.1 Electromotive force and potential difference.

If you have difficulty visualising an e.m.f., a potential difference, a resistance or a current, you may find it helpful to use an analogy. Consider, for example, the arrangement shown in Figure 1.2. Here a water pump forces water to flow around a series of pipes and through some form of restriction. While no analogy is perfect, this model illustrates the basic properties of the circuit of Figure 1.1. In the water-based diagram, the *water pump* forces water around the arrangement and is equivalent to the *voltage*

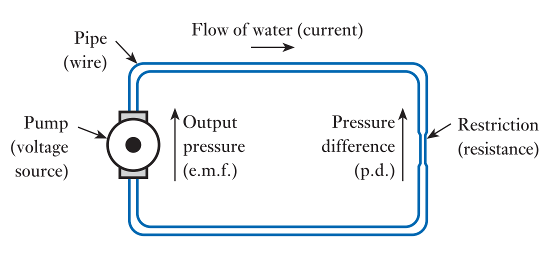


Figure 1.2 A water-based analogy of an electrical circuit.

source (or battery), which pushes electric charge around the corresponding electrical circuit. The flow of water through the pipe corresponds to the flow of charge around the circuit and therefore the *flow rate* represents the *current* in the circuit. The *restriction* within the pipe opposes the flow of water and is equivalent to the *resistance* of the electrical circuit. As water flows through the restriction the pressure will fall, creating a *pressure difference* across it. This is equivalent to the *potential difference* across the resistance within the electrical circuit. The flow rate of the water will increase with the output pressure of the pump and decrease with the level of restriction present. This is analogous to the behaviour of the electrical circuit, where the current increases with the e.m.f. of the voltage source and decreases with the magnitude of the resistance.

1.4.5 Voltage reference points

Electromotive forces and potential differences in circuits produce different potentials (or voltages) at different points in the circuit. It is normal to describe the voltages throughout a circuit by giving the potential at particular points with respect to a single reference point. This reference is often called the **ground** or **earth** of the circuit. Since voltages at points in the circuit are measured with respect to ground, it follows that the voltage on the ground itself is zero. Therefore, the ground is also called the **zero-volts line** of the circuit.

In a circuit, a particular point or junction may be taken as the zero-volt reference and this may then be labelled as 0 V, as shown in Figure 1.3(a). Alternatively, the ground point of the circuit may be indicated using the ground symbol, as shown in Figure 1.3(b).

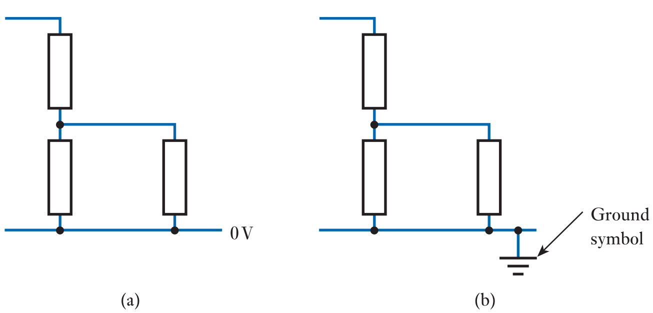


Figure 1.3 Indicating voltage reference points.

1.4.6 Representing voltages in circuit diagrams

Conventions for representing voltages in circuit diagrams vary considerably between countries. In the United Kingdom, and in this text, it is common to indicate a potential difference using an arrow, which is taken to represent the voltage at the head of the arrow with respect to that at the tail. This is illustrated in Figure 1.4(a). In many cases, the tail of the arrow will correspond to the zero-volt line of the circuit (as shown in V_A

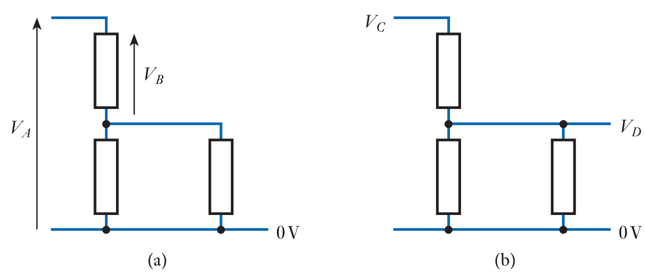


Figure 1.4 Indicating voltages in circuit diagrams.

in the figure). However, it can indicate a voltage difference between any two points in the circuit (as shown by V_B).

In some cases, it is inconvenient to use arrows to indicate voltages in circuits and simple labels are used instead, as shown in Figure 1.4(b). Here the labels V_C and V_D represent the voltage at the corresponding points *with respect to ground* (that is, with respect to the zero-volt reference).

1.4.7 Representing currents in circuit diagrams

Currents in circuit diagrams are conventionally indicated by an arrow in the direction of the *conventional* current flow (that is, in the opposite direction to the flow of electrons). This was illustrated in Figure 1.1. This figure also shows that for positive voltages and currents the arrow for the current flowing out of a voltage source is in the *same direction* as the arrow representing its e.m.f. However, the arrow representing the current in a resistor is in the *opposite direction* to the arrow representing the potential difference across it.

1.5 Direct current and alternating current

The currents associated with electrical circuits may be constant or may vary with time. Where currents vary with time they may also be unidirectional or alternating.

When the current in a conductor always flows in the same direction this is described as a direct current (DC). Such currents will often be associated with voltages of a single polarity. Where the direction of the current periodically changes, this is referred to as alternating current (AC), and such currents will often be associated with alternating voltages. One of the most common forms of alternating waveform is the sine wave, as discussed in Section 1.13.

1.6 Resistors, capacitors and inductors

1.6.1 Resistors

Resistors are components whose main characteristic is that they provide resistance between their two electrical terminals. The **resistance** of a circuit represents its opposition to the flow of electric current. The unit of resistance is the **ohm (Ω)**. One may also define the **conductance** of a circuit as its ability to *allow* the flow of electricity. The conductance of a circuit is equal to the reciprocal of its resistance and is measured in **siemens** (**S**). We will look at resistance in some detail later in the text (see Chapter 3).

1.6.2 Capacitors

Capacitors are components whose main characteristic is that they exhibit capacitance between their two terminals. **Capacitance** is a property of two conductors that are electrically insulated from each other, whereby electrical energy is stored when a potential difference exists between them. This energy is stored in an electric field that is created between the two conductors. Capacitance is measured in **farads** (**F**), and we will return to look at capacitance in more detail later in the text (see Chapter 4).

1.6.3 Inductors

Inductors are components whose main characteristic is that they exhibit inductance between their two terminals. **Inductance** is the property of a coil that results in an e.m.f. being induced in the coil as a result of a change in the current in the coil. Like capacitors, inductors can store electrical energy and in this case it is stored in a magnetic field. The unit of inductance is the **henry** (**H**), and we will look at inductance later in the text (see Chapter 5).

1.7 Ohm's law

Ohm's law states that the current I flowing in a conductor is directly proportional to the applied voltage V and inversely proportional to its resistance R. This determines the relationship between the units for current, voltage and resistance, and the **ohm** is defined as the resistance of a circuit in which a current of 1 **amp** produces a potential difference of 1 **volt**.

The relationship between voltage, current and resistance can be represented in a number of ways, including:

$$V = IR \tag{1.1}$$

$$I = \frac{V}{R} \tag{1.2}$$

$$R = \frac{V}{I} \tag{1.3}$$

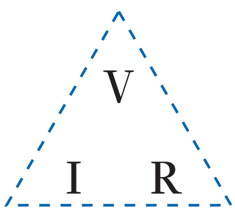


Figure 1.5 The relationship between V, I and R.

A simple way of remembering these three equations is to use the 'virtual triangle' of Figure 1.5. The triangle is referred to as 'virtual' simply as a way of remembering the order of the letters. Taking the first three letters of VIRtual and writing them in a triangle (starting at the top) gives the arrangement shown in the figure. If you place your finger on one of the letters, the remaining two show the expression for the selected quantity. For example, to find the expression for 'V' put your finger on the V and you see I next to R, so $V = IR$. Alternatively, to find the expression for 'I' put your finger on the I and you are left with V above R, so $I = V/R$. Similarly, covering 'R' leaves V over I, so $R = V/I$.

Example 1.1

Voltage measurements (with respect to ground) on part of an electrical circuit give the values shown in the diagram below. If the resistance of R_2 is 220 Ω, what is the current I flowing through this resistor?