Basic Electronics for Scientists and Engineers

Ideal for a one-semester course, this concise textbook covers basic electronics for undergraduate students in science and engineering.

Beginning with basics of general circuit laws and resistor circuits to ease students into the subject, the textbook then covers a wide range of topics, from passive circuits through to semiconductor-based analog circuits and basic digital circuits. Using a balance of thorough analysis and insight, readers are shown how to work with electronic circuits and apply the techniques they have learnt. The textbook's structure makes it useful as a self-study introduction to the subject. All mathematics is kept to a suitable level, and there are several exercises throughout the book. Solutions for instructors, together with eight laboratory exercises that parallel the text, are available online at www.cambridge.org/Eggleston.

Dennis L. Eggleston is Professor of Physics at Occidental College, Los Angeles, where he teaches undergraduate courses and labs at all levels (including the course on which this textbook is based). He has also established an active research program in plasma physics and, together with his undergraduate assistants, he has designed and constructed three plasma devices which form the basis for the research program.

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CAMBRIDGE
UNIVERSITY PRESS

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University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314-321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi - 110025, India

103 Penang Road, #05-06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9780521154307

First published 2011
9th printing 2019

A catalogue record for this publication is available from the British Library

Library of Congress Cataloging in Publication data
Eggleston, Dennis L. (Dennis Lee), 1953-
Basic Electronics for Scientists and Engineers / by Dennis L. Eggleston.
p. cm
Includes bibliographical references and index.
ISBN 978-0-521-76970-9 (Hardback) – ISBN 978-0-521-15430-7 (Paperback) 1. Electronics.
I. Title.
TK7816.E35 2011
621.381–dc22

2010050327

ISBN 978-0-521-76970-9 Hardback
ISBN 978-0-521-15430-7 Paperback

Additional resources for this publication at www.cambridge.org/Eggleston

Cambridge University Press & Assessment
978-0-521-15430-7 — Basic Electronics for Scientists and Engineers
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To my wife Lynne

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Preface

A professor of mine once opined that the best working experimentalists tended to have a good grasp of basic electronics. Experimental data often come in the form of electronic signals, and one needs to understand how to acquire and manipulate such signals properly. Indeed, in graduate school, everyone had a story about a budding scientist who got very excited about some new result, only to later discover that the result was just an artifact of the electronics they were using (or misusing!). In addition, most research labs these days have at least a few homemade circuits, often because the desired electronic function is either not available commercially or is prohibitively expensive. Other anecdotes could be added, but these suffice to illustrate the utility of understanding basic electronics for the working scientist.

On the other hand, the sheer volume of information on electronics makes learning the subject a daunting task. Electronics is a multi-hundred billion dollar a year industry, and new products of ever-increasing specialization are developed regularly. Some introductory electronics texts are longer than introductory physics texts, and the print catalog for one national electronic parts distributor exceeds two thousand pages (with tiny fonts!).

Finally, the undergraduate curriculum for most science and engineering majors (excepting, of course, electrical engineering) does not have much space for the study of electronics. For many science students, formal study of electronics is limited to the coverage of voltage, current, and passive components (resistors, capacitors, and inductors) in introductory physics. A dedicated course in electronics, if it exists, is usually limited to one semester.

This text grew out of my attempts to deal with this three-fold challenge. It is based on my notes for a one-semester course on electronics I have taught for many years in the Physics Department of Occidental College. The students in the course are typically sophomore, junior, or senior students majoring in physics or pre-engineering, with some from the other sciences and mathematics. The students have usually had at least two introductory physics courses and two semesters of calculus.

The primary challenge of such a course is to select the topics to include. My choices for this text have been guided by several principles: I wanted the text to be a rigorous, self-contained, one-semester introduction to basic analog and digital electronics. It should start with basic concepts and at least touch upon the major topics. I also let the choice of material be guided by those topics I thought were fundamental or have found useful during my career as a researcher in experimental plasma physics. Finally, I wanted the text to emphasize learning how to work with electronics through analysis rather than copying examples.

Chapters 1 and 2 start with basic concepts and cover the three passive components. Key concepts such as Thevenin's theorem, time- and frequency-domain analysis, and complex impedances are introduced. Chapter 3 uses the band theory of solids to explain semiconductor diode operation and shows how the diode and its cousins can be used in circuits. The use of the load line to solve the transcendental equations arising from the diode's non-linear *I–V* characteristic is introduced, as well as common approximation techniques. The fundamentals of power supply construction are also introduced in this chapter.

Bipolar junction transistors and field-effect transistors are covered in Chapters 4 and 5. Basic switching and amplifier circuits are analyzed and transistor AC equivalents are used to derive the voltage and current gain as well as the input and output impedance of the amplifiers. A discussion of feedback in Chapter 4 leads into the study of operational amplifiers in Chapter 6. Linear and non-linear circuits are analyzed and the limitations of real op-amps detailed.

Several examples of relaxation and sinusoidal oscillators are studied in Chapter 7, with time-domain analysis used for the former and frequency-domain analysis used for the latter. Amplitude- and frequency-modulation are introduced as oscillator applications. Finally, a number of basic digital circuits and devices are discussed in Chapter 8. These include the logic gates, flip-flops, counters, shift-registers, A/D and D/A converters, multiplexers, and memory chips. Although the digital universe is much larger than this (and expanding!), these seem sufficient to give a laboratory scientist a working knowledge of this universe and lay the foundation for further study.

Exercises are given at the end of each chapter along with texts for further study. I recommend doing all of the exercises. While simple plug-in problems are avoided, I have found that most students will rise to the challenge of applying the techniques studied in the text to non-trivial problems. Answers to some of the problems are given in Appendix A, and a solution manual is available to instructors.

At Occidental this course is accompanied by a laboratory, and I enthusiastically recommend such a structure. In addition to teaching a variety of laboratory skills, an instructional laboratory in electronics allows the student to connect the analytical approach of the text to the real world. A set of laboratory exercises that I have used is available from the publisher.

The original manuscript was typeset using LaTeX and the figures constructed using *PSTricks: Postscript macros for Generic TeX* by Timothy Van Zandt and *M4 Macros for Electric Circuit Diagrams in Latex Documents* by Dwight Aplevich. I am indebted to the makers of these products and would not have attempted this project without them.

Dennis L. Eggleston — Los Angeles, California, USA

"*Basic Electronics for Scientists and Engineers* by Dennis Eggleston is an example of how the most important material in the introduction to electronics can be presented within a one-semester time frame. The text is written in a nice logical sequence and is beneficial for students majoring in all areas of the Natural Science. In addition, many examples and detailed introduction of all equations allows this course to be taught to students of different background – sophomores, juniors, and seniors. Overall, the effort of the author is thrilling and, definitely, this text will be popular among many instructors and students."
Anatoliy Glushchenko, Department of Physics and Energy Science, University of Colorado at Colorado Springs

"This text is an excellent choice for undergraduates majoring in physics. It covers the basics, running from passive components through diodes, transistors and op-amps to digital electronics. This makes it self-contained and a one-stop reference for the student. A brief treatment of the semiconductor physics of silicon devices provides a good basis for understanding the mathematical models of their behaviour and the end-of-chapter problems help with the learning process. The concise and sequential nature of the book makes it easier to teach (and study) from than the venerable but somewhat overwhelming Art of Electronics by Horowitz and Hill."
David Hanna, W C Macdonald Professor of Physics, McGill University

"I have been frustrated in the past by my inability to find a suitable book for a one-semester Electronics course that starts with analog and progresses to basic digital circuits. Most available books seem to be out of date or aimed at electrical engineers rather than scientists. Eggleston's book is exactly what I was looking for – a basic course ideal for science students needing a practical introduction to electronics. Written concisely and clearly, the book emphasizes many practical applications, but with sufficient theoretical explanation so that the results don't simply appear out of thin air."
Susan Lehman, Clare Boothe Luce Associate Professor and Chair of Physics, The College of Wooster