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.
To my wife Lynne
Contents

Preface

1 Basic concepts and resistor circuits
   1.1 Basics
   1.2 Resistors
   1.3 AC signals
       Exercises
       Further reading

2 AC circuits
   2.1 Introduction
   2.2 Capacitors
   2.3 Inductors
   2.4 RC circuits
   2.5 Response to a sine wave
   2.6 Using complex numbers in electronics
   2.7 Using the complex exponential method for a switching problem
   2.8 Fourier analysis
   2.9 Transformers
       Exercises
       Further reading

3 Band theory and diode circuits
   3.1 The band theory of solids
   3.2 Diode circuits
       Exercises
       Further reading

4 Bipolar junction transistors
   4.1 Introduction
   4.2 Bipolar transistor fundamentals
## Contents

4.3 DC and switching applications 108  
4.4 Amplifiers 110  
   Exercises 131  
   Further reading 132  

5 Field-effect transistors 133  
5.1 Introduction 133  
5.2 Field-effect transistor fundamentals 134  
5.3 DC and switching applications 140  
5.4 Amplifiers 141  
   Exercises 150  
   Further reading 151  

6 Operational amplifiers 152  
6.1 Introduction 152  
6.2 Non-linear applications I 153  
6.3 Linear applications 154  
6.4 Practical considerations for real op-amps 159  
6.5 Non-linear applications II 165  
   Exercises 168  
   Further reading 170  

7 Oscillators 171  
7.1 Introduction 171  
7.2 Relaxation oscillators 171  
7.3 Sinusoidal oscillators 185  
7.4 Oscillator application: EM communications 193  
   Exercises 198  
   Further reading 199  

8 Digital circuits and devices 200  
8.1 Introduction 200  
8.2 Binary numbers 200  
8.3 Representing binary numbers in a circuit 202  
8.4 Logic gates 204  
8.5 Implementing logical functions 206  
8.6 Boolean algebra 208  
8.7 Making logic gates 211
Contents

8.8 Adders 213
8.9 Information registers 216
8.10 Counters 220
8.11 Displays and decoders 223
8.12 Shift registers 224
8.13 Digital to analog converters 227
8.14 Analog to digital converters 228
8.15 Multiplexers and demultiplexers 229
8.16 Memory chips 232
     Exercises 234
     Further reading 235

Appendix A: Selected answers to exercises 236
Appendix B: Solving a set of linear algebraic equations 238
Appendix C: Inductively coupled circuits 241
References 245
Index 247
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,
Preface

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
Preface

“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