Hands-On Electronics

Packed full of real circuits to build and test, *Hands-On Electronics* is a unique introduction to analog and digital electronics theory and practice. Ideal both as a college textbook and for self-study, the friendly style, clear illustrations and construction details included in the book encourage rapid and effective learning of analog and digital circuit design theory. All the major topics for a typical one-semester course are covered, including *RC* circuits, diodes, transistors, op amps, oscillators, digital logic, counters, D/A converters and more. There are also chapters explaining how to use the equipment needed for the examples (oscilloscope, multimeter and breadboard), together with pinout diagrams for all the key components referred to in the book.

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A One-Semester Course for Class Instruction or Self-Study

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and

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Contents

Figures

Tables

About the authors

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Dr Christopher G. White is Assistant Professor of Physics at Illinois Institute of Technology. He received his Ph.D. in Physics from the University of Minnesota in 1990. He has authored or co-authored over 100 scientific articles in the field of high-energy particle physics, and his current research interests involve neutrinos and hyperons. Dr White is an enthusiastic and dedicated teacher who enjoys helping students to overcome their fear of electronics and to gain both confidence and competence.

To the Reader

Some of you may be encountering electronic circuits and instruments for the first time. Others may have 'played around' with such stuff if, for example, you were ever bitten by the 'ham radio' bug. In either case, this sequence of laboratory experiments has been designed to introduce you to the fundamentals of modern analog and digital electronics.

We use electronic equipment all the time in our work and recreation. Scientists and engineers need to know a bit of electronics, for example to modify or repair some piece of equipment, or to interface two pieces of equipment that may not have been designed for that purpose. To that end, our goal is that by the end of the book, you will be able to design and build any little analog or digital circuit you may find useful, or at least understand it well enough to have an intelligent conversation about the problem with an electrical engineer. A basic knowledge of electronics will also help you to understand and appreciate the quirks and limitations of instruments you will be using in research, testing, development, or process-control settings.

We expect few of you to have much familiarity with such physical theories as electromagnetism or quantum mechanics, so the thrust of this course will be from phenomena and instruments toward theory, not the other way round. If your curiosity is aroused concerning theoretical explanations, so much the better, but unfamiliarity with physical theory should not prevent you from building or using electronic circuits and instruments.

Acknowledgments

We are grateful to Profs Carlo Segre and Tim Morrison for their contributions and assistance, and especially to the IIT students without whom this book would never have been possible. Finally, we thank our wives and children for their support and patience. It is to them that we dedicate this book.

Introduction

This book started life as the laboratory manual for the course Physics 300, 'Instrumentation Laboratory', offered every semester at Illinois Institute of Technology to a mix consisting mostly of physics, mechanical engineering, and aeronautical engineering majors. Each experiment can be completed in about four hours (with one or two additional hours of preparation).

This book differs from existing books of its type in that it is faster paced and goes into a bit less depth, in order to accommodate the needs of a one-semester course covering the elements of both analog and digital electronics. In curricula that normally include one year of laboratory instruction in electronics, it may be suitable for the first part of a two-semester sequence, with the second part devoted to computers and computer interfacing – this scheme has the virtue of separating the text for the more rapidly changing computer material from the more stable analog and digital parts.

The book is also suitable for self-study by a person who has access to the necessary equipment and wants a hands-on introduction to the subject. We feel strongly, and experience at IIT has borne out, that to someone who will be working with electronic instrumentation, a hands-on education in the techniques of electronics is much more valuable than a blackboard-and-lecture approach. Certainly it is a better learning process than simply reading a book and working through problems.

The appendices suggest sources for equipment and supplies, provide tables of abbreviations and symbols, and list recommendations for further reading, which includes chapter-by-chapter correspondences to some popular electronics texts written at similar or somewhat deeper levels to ours: the two slim volumes by Dennis Barnaal, *Analog Electronics for Scientific Application* and *Digital Electronics for Scientific Application* (reissued by Waveland Press, 1989); Horowitz and Hill's comprehensive *The Art of Electronics* (Cambridge University Press, 1989); Diefenderfer and Holton's *Principles of Electronic Instrumentation* (Saunders, 1994);

and Simpson's *Introductory Electronics for Scientists and Engineers* (2nd edition, Prentice-Hall, 1987). There is also a glossary of terms and pinout diagrams for transistors and ICs used within. The reader is presumed to be familiar with the rudiments of differential and integral calculus, as well as with elementary college physics (including electricity, magnetism, and direct- and alternating-current circuits, although these topics are reviewed in the text).

The order we have chosen for our subject matter begins with the basics – resistors, Ohm's law, simple AC circuits – then proceeds towards greater complexity by introducing nonlinear devices (diodes), then active devices (bipolar and field-effect transistors). We have chosen to discuss transistors before devices made from them (operational amplifiers, comparators, digital circuitry) so that the student can understand not only how things work but also why.

There are other texts that put integrated circuits, with their greater ease of use, before discrete devices; or digital circuits, with their simpler rules, before the complexities of analog devices. We have tried these approaches on occasion in our teaching and found them wanting. Only by considering first the discrete devices from which integrated circuits are made can the student understand and appreciate the remarkable properties that make ICs so versatile and powerful. A course based on this book thus builds to a pinnacle of intellectual challenge towards the middle, with the three transistor chapters. After the hard uphill slog, it's smooth sailing from there (hold onto your seatbelts!).

The book includes step-by-step instructions and explanations for the following experiments:

1. Multimeter, breadboard, and oscilloscope;
2. *RC* circuits;
3. Diodes and power supplies;
4. Transistors I;
5. Transistors II: FETs;
6. Transistors III: differential amplifier;
7. Introduction to operational amplifiers;
8. More op-amp applications;
9. Comparators and oscillators;
10. Combinational logic;
11. Flip-flops: saving a logic state;

12. Monostables, counters, multiplexers, and RAM;
13. Digital↔analog conversion.

These thirteen experiments fit comfortably within a sixteen-week semester. If you or your instructor prefers, one or two experiments may easily be omitted to leave a couple of weeks at the semester's end for independent student projects. To this end, Chapter 6, 'Transistors III', has been designed so that no subsequent experiment depends on it; obviously this is also the case for Chapter 13, 'Digital↔analog conversion', which has no subsequent experiment.

As you work through the exercises, you will find focus questions and detailed instructions indicated by the symbol '▹'. Key concepts for each exercise will be denoted by the symbol '•'. Finally, the standard system of units for electronics is the MKS system. Although you may occasionally run across other unit systems, we adhere strictly to the MKS standard.