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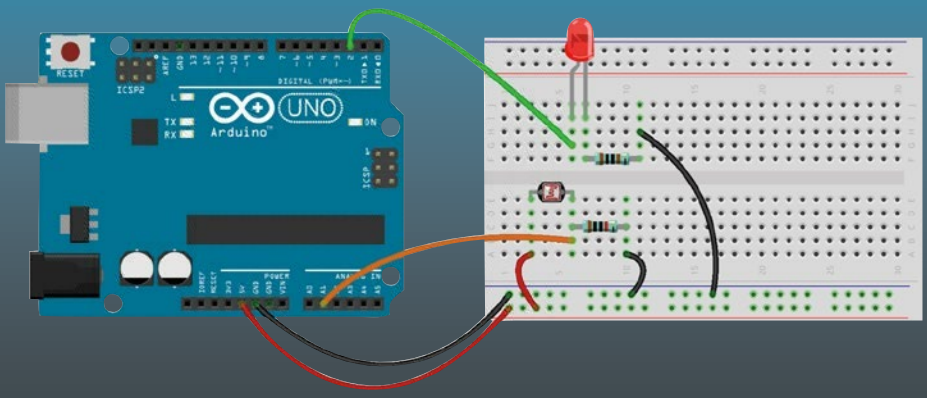

Electronics for Beginners

A Practical Introduction to Schematics, Circuits, and Microcontrollers

Jonathan Bartlett

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Printed on acid-free paper

This book is dedicated to Forrest M. Mims III, whose Engineer's Mini-Notebook series of books I read endlessly as a youth and whose work as a citizen scientist has been an inspiration to me and to many others.

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About the Author

Jonathan Bartlett is a senior software R&D specialist at Specialized Bicycle Components, focusing on creating initial prototypes for a variety of IoT (Internet of Things) projects. Jonathan has been educating the tech community for well over a decade. His first book, *Programming from the Ground Up*, is an Internet classic and was endorsed by Joel Spolsky, co-founder of Stack Exchange. It was one of the first open source books and has been used by a generation of programmers to learn how computers work from the inside out, using assembly language as a starting point. He recently released *Building Scalable PHP Web Applications Using the Cloud* as well as the calculus textbook *Calculus from the Ground Up*. Jonathan also writes a mix of technical and popular articles for a number of websites, including the new MindMatters.ai technology blog. His other articles can be found on IBM's DeveloperWorks website, Linux.com, and Medium.com. He is also the head of Tulsa Open Source Hardware, a local group focusing on do-it-yourself electronics projects.

Jonathan also participates in a variety of academic work. He is an associate fellow of the Walter Bradley Center for Natural and Artificial Intelligence. There, he does research into fundamental mathematics and the mathematics of artificial intelligence. He also serves on the editorial board for the journal *BIO-Complexity*, focusing on reviewing information-theoretic papers for the journal and assisting with LaTeX typesetting.

Additionally, Jonathan has written several books on the interplay of philosophy, math, and science, including *Engineering and the Ultimate* and *Naturalism and Its Alternatives in Scientific Methodologies*. Jonathan served as editor for the book *Controllability of Dynamic Systems: The Green's Function Approach*, which received the RA Presidential Award

of the Republic of Armenia in the area of "Technical Sciences and Information Technologies."

Jonathan serves on the board of Homeschool Oklahoma along with his wife, Christa, of 20 years. They inspire their community in several ways including writing educational material, creating educational videos, tutoring students through Classical Conversations, and sharing their own stories of tragedy and success with others.

About the Technical Reviewer

Mike McRoberts is the author of *Beginning Arduino* by Apress. He is the winner of Pi Wars 2018 and a member of Medway Makers. He is an Arduino and Raspberry Pi enthusiast.

Mike McRoberts has expertise in a variety of languages and environments, including C/C++, Arduino, Python, Processing, JS, Node-RED, NodeJS, Lua.

Acknowledgments

I would like to thank, first and foremost, my homeschool co-op community. This book originally started from a series of classes that I taught in our local co-op, and my students were the guinea pigs for this content. I received a lot of encouragement from that class, with both the students and the parents enjoying the material. I want to thank my wife who put up with me always typing on my computer to put this together. I also want to thank the Tulsa Open Source Hardware community (as well as the larger Tulsa WebDevs community), who gave me a lot of encouragement while putting together this book and who also sat through many presentations based on this material.

CHAPTER 1

Introduction

Welcome to the world of electronics! In the modern world, electronic devices are everywhere, but fewer and fewer people seem to understand how they work or how to put them together. At the same time, it has never been easier to do so as an individual. The availability of training, tools, parts, instructions, videos, and tutorials for the home experimenter has grown enormously, and the costs for equipment have dropped to almost nothing.

However, what has been lacking is a good guide to bring students from *wanting* to know how electronic circuits work to actually understanding them and being able to develop their own. For the hobbyist, there are many guides that show you how to do individual projects, but they often fail to provide enough information for their readers to be able to build projects of their own. There is plenty of information on the physics of electricity in physics books, but they fail to make the information practical. One exception to this is Horowitz and Hill's *The Art of Electronics*. This book is a wonderful reference guide for practical circuit design. However, its target audience is largely electrical engineers or other very advanced circuit designers. Not only that, the book itself is prohibitively expensive.

What has been needed for a long time is a book that takes you from knowing nothing about electronics to being able to build real circuits that you design yourself. This book combines theory, practice, projects, and design patterns in order to enable you to build your own circuits from scratch. Additionally, this book is designed entirely around safe,

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low-current DC (direct current) power. We stay far away from the wall outlet in this book to be sure that you have a fun and largely worry-free experience with electronics.

This book is written with two groups of people in mind. First, this book can be used as a guide for hobbyists (or wannabe hobbyists) to learn on their own. It has lots of projects to work on and experiment with. Second, this book can also be used in electronics classes for high school and college students. It has problems to be worked, activities to do, and reviews at the end of each chapter.

The needs of these groups are not so different from each other. In fact, even if you are a hobbyist and plan on using this book to learn on your own, I suggest that not only do you read the main parts of the chapter but that you also do the activities and homework as well. The goal of the homework is to train your mind to think like a circuit designer. If you work through the example problems, it will make analyzing and designing circuits simply a matter of habit.

1.1 Working the Examples

In this book, all examples should be worked out using decimals, not fractions. This is an engineering course, not a math course, so feel free to use a calculator. However, you will often wind up with very long strings of decimals on some of the answers. Feel free to round your answers, but always include at least a single decimal point. So, for instance, if I divide 5 by 3 on my calculator, it tells me 1.66666667. However, I can just give the final answer as 1.7. This only applies to the final answer. You need to maintain your decimals while you do your computations.

Also, if your answer is a decimal number that *begins* with a zero, then you should round your answer to include the first two to four nonzero digits. So, if I have an answer of 0.0000033333333, I can round that to 0.00000333. If you want to be precise about the proper way to round results, see the section on significant figures in the next chapter.

For beginners and hobbyists, this is less of a concern, and we will generally be in a hobbyist mindset for the book.

In short, as engineers, we wind up being, at minimum, as precise as we *need* to be or, at maximum, as precise as we *can* be. The amount of precision we need will vary from project to project, and the amount of precision that we can be will depend on our tools, our components, and other things we interact with. Therefore, there is not a lot of focus on this book on how many decimals exactly to use. You can get more detailed descriptions in other science books for dealing with significant figures. In the problems in the chapters, if you are off by a single digit due to rounding errors, don't worry about it.

1.2 Initial Tools and Supplies

You can get started in electronics with a minimum set of tools, but you can also be as fancy as you have money to afford. This book will focus on the more modest tools that are within the reach of pretty much every budget.

While the book will walk you through a wide variety of parts for different types of circuits, every electronics hobbyist should start out with the following components:

1. Multimeter: Multimeters will measure voltage, current, resistance, and other important values. For these projects, the cheapest digital multimeter you can find will work just fine. You only need one of these.
2. Solderless Breadboards: Solderless breadboards will hold your projects in place and connect your components together. Breadboards are sold based on the number of holes, known as "tie points," the breadboard contains. If you want to keep your projects around, you should have a separate breadboard for each project. However, the beauty of solderless breadboards is that they are in fact reusable if you want.

3. Jumper Wires: Jumper wires are just like normal insulated wires, except that their ends are solid and strong enough to be pushed into your breadboard. The wires themselves may be flexible or rigid. Jumper wires with female ends (a hole instead of a wire) also exist for plugging into circuits which have metal pins sticking out of them (known as headers) to connect to. Every hobbyist I know has a huge mass of jumper wires. They usually come in bundles of 65 wires, which is plenty to get started.

4. Resistors: Resistors do a lot of the grunt work of the circuit. They resist current flow, which, among other things, prevents damaging other parts of the circuit. Resistors are measured in ohms (Ω). Most hobbyists have a wide variety of resistors. You should have a range of resistors from 200 Ω to 1, 000, 000 Ω. However, if you had to pick one value for your resistors, 1, 000 Ω resistors work in a wide variety of situations. Resistors for this book should be rated for 1/4 watt of power.

5. LEDs: LEDs (light-emitting diodes) are low-power lights often used in electronic devices. I recommend getting a variety of colors of LEDs just because it makes life more fun. Most standard single-color LEDs have about the same specifications, so the main difference is the color.

6. Buttons and Switches: Buttons and switches will be the primary method of input and output in these circuits. You should buy buttons and switches *which are specifically made to go on breadboards*.

7. Power Regulator: While most of these projects can be operated directly from a battery, a power regulator board will make sure that, no matter how well charged or drained the battery is, you get a predictable voltage from your battery. The YwRobot breadboard power supply is extremely cheap (cheaper than most batteries) and also provides your project with an on/off switch. You should buy one of these for each breadboard you have. Other breadboard power supplies are available as well (make sure they output 5 volts), but our drawings will assume the YwRobot one.

8. 9 V Battery and Connector: The easiest way to supply power to the power regulator is with a 9 V battery with a standard barrel plug (2.1 mm × 5.5 mm), which will fit into the YwRobot power supply.

Later projects will require specialized components, but these are the components that are needed for nearly every project you will encounter or design yourself. If you would like to order a kit with all of the components you need for this book, you can find them at www.bplearning.net.

1.3 Safety Guidelines

This book deals almost entirely with direct current from small battery sources. This current is inherently fairly safe, as small batteries are not capable of delivering the amount of current needed to injure or harm. For these projects, you can freely touch wires and work with active circuits without any protection, because the current is incapable of harming you. The main issue that sometimes arises is that, in poorly made circuits, components can overheat and occasionally (but rarely) catch fire.

Additionally, the battery itself may become overheated/compromised, and batteries are often made from potentially toxic chemicals.

Please follow the following safety guidelines when working on projects (both projects from this book and projects you build yourself). They will help keep you safe and help prevent you from accidentally damaging your own equipment:

1. If you have any cuts or other open areas on your skin, please cover them. Your skin is where most of your electric protection exists in your body.
2. Before applying power to your circuit, check to be sure you have not accidentally wired in a short circuit between your positive and negative poles of your battery.
3. If your circuit does not behave as you expect it to when you plug in the battery, unplug it immediately and check for problems.
4. If your battery or any component becomes warm, disconnect power immediately.
5. If you smell any burning or smoky smells, disconnect power immediately.
6. Dispose of all batteries in accordance with local regulations.
7. For rechargeable batteries, follow the instructions on the battery for proper charging procedures.

Please note that if you ever deal with alternating current (AC) or large batteries (such as a car battery), you must exercise many more precautions than described in this book, because those devices generate sufficient power in themselves and within the circuits to harm or kill you if mishandled (sometimes even after the power has been disconnected).

1.4 Electrostatic Discharge

If you have ever touched a doorknob and received a small shock, you have experienced electrostatic discharge (ESD). ESD is not dangerous to you, but it can be dangerous to your equipment. Even shocks that you can't feel may damage your equipment. With modern components, ESD is rarely a problem, but nonetheless it is important to know how to avoid it. You can skip these precautions if you wish, just know that occasionally you might wind up shorting out a chip or transistor because you weren't careful. ESD is also more problematic if you have carpet floors, as those tend to build up static electricity.

Here are some simple rules you can follow to prevent ESD problems:

1. When storing IC components (i.e., electronics chips), store them with the leads enmeshed in conductive foam. This will prevent any voltage differentials from building up in storage.
2. Wear natural 100% cotton fabrics.
3. Use a specialized ESD floor mat and/or wrist strap to keep you and your workspace at ground potential.
4. If you don't use an ESD strap or mat, touch a large metal object before starting work. Do so again any time after moving around.

1.5 Using Your Multimeter Correctly

Even though we haven't covered the details we need to use our multimeter yet, since we are covering proper handling of devices, I am including this section here with the others. Feel free to skip over this until we start using multimeters in the book.

In order to keep your multimeter functioning, it is important to take some basic precautions. Multimeters, especially cheap ones, can be easily broken through mishandling. Use the following steps to keep you from damaging your multimeter or damaging your circuit with your multimeter:

1. Do not try to measure resistance on an active circuit. Take the resistor all the way out of the circuit before trying to measure it.
2. Choose the appropriate setting on your multimeter *before* you hook it up.
3. Always err on the side of choosing high values first, especially for current and voltage. Use the high value settings for current and voltage to give your multimeter the maximum protection. If you set the value too large, it is easy enough to set it lower. If you had it set too low, you might have to buy a new multimeter!