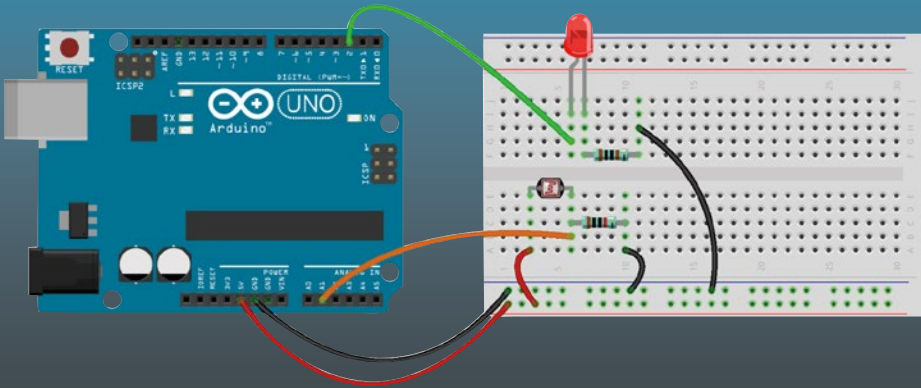


TECHNOLOGY IN ACTION™



# Electronics for Beginners



A Practical Introduction to  
Schematics, Circuits, and  
Microcontrollers

—  
Jonathan Bartlett

Apress®

# **Electronics for Beginners**

**A Practical Introduction  
to Schematics, Circuits,  
and Microcontrollers**

**Jonathan Bartlett**

**Apress®**

# ***Electronics for Beginners: A Practical Introduction to Schematics, Circuits, and Microcontrollers***

Jonathan Bartlett  
Tulsa, OK, USA

ISBN-13 (pbk): 978-1-4842-5978-8

ISBN-13 (electronic): 978-1-4842-5979-5

<https://doi.org/10.1007/978-1-4842-5979-5>

Copyright © 2020 by Jonathan Bartlett

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

Trademarked names, logos, and images may appear in this book. Rather than use a trademark symbol with every occurrence of a trademarked name, logo, or image we use the names, logos, and images only in an editorial fashion and to the benefit of the trademark owner, with no intention of infringement of the trademark.

The use in this publication of trade names, trademarks, service marks, and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Managing Director, Apress Media LLC: Welmoed Spahr  
Acquisitions Editor: Natalie Pao  
Development Editor: James Markham  
Coordinating Editor: Jessica Vakili

Distributed to the book trade worldwide by Springer Science+Business Media New York, 233 Spring Street, 6th Floor, New York, NY 10013. Phone 1-800-SPRINGER, fax (201) 348-4505, e-mail [orders-ny@springer-sbm.com](mailto:orders-ny@springer-sbm.com), or visit [www.springeronline.com](http://www.springeronline.com). Apress Media, LLC is a California LLC and the sole member (owner) is Springer Science + Business Media Finance Inc (SSBM Finance Inc). SSBM Finance Inc is a **Delaware** corporation.

For information on translations, please e-mail [booktranslations@springernature.com](mailto:booktranslations@springernature.com); for reprint, paperback, or audio rights, please e-mail [bookpermissions@springernature.com](mailto:bookpermissions@springernature.com).

Apress titles may be purchased in bulk for academic, corporate, or promotional use. eBook versions and licenses are also available for most titles. For more information, reference our Print and eBook Bulk Sales web page at <http://www.apress.com/bulk-sales>.

Any source code or other supplementary material referenced by the author in this book is available to readers on GitHub via the book's product page, located at [www.apress.com/978-1-4842-5978-8](http://www.apress.com/978-1-4842-5978-8). For more detailed information, please visit <http://www.apress.com/source-code>.

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.*

# Table of Contents

|  |              |
|--|--------------|
| <b>About the Author .....</b>                | <b>xix</b>   |
| <b>About the Technical Reviewer .....</b>    | <b>xxi</b>   |
| <b>Acknowledgments .....</b>                 | <b>xxiii</b> |
| <b>Chapter 1: Introduction.....</b>          | <b>1</b>     |
| 1.1 Working the Examples .....               | 2            |
| 1.2 Initial Tools and Supplies .....         | 3            |
| 1.3 Safety Guidelines .....                  | 5            |
| 1.4 Electrostatic Discharge .....            | 7            |
| 1.5 Using Your Multimeter Correctly .....    | 7            |
| <b>Chapter 2: Dealing with Units .....</b>   | <b>9</b>     |
| 2.1 SI Units.....                            | 9            |
| 2.2 Scaling Units .....                      | 12           |
| 2.3 Using Abbreviations .....                | 14           |
| 2.4 Significant Figures .....                | 15           |
| Apply What You Have Learned.....             | 18           |
| <b>Part I: Basic Concepts .....</b>          | <b>21</b>    |
| <b>Chapter 3: What Is Electricity? .....</b> | <b>23</b>    |
| 3.1 Charge.....                              | 23           |
| 3.2 Measuring Charge and Current.....        | 26           |
| 3.3 AC vs. DC.....                           | 28           |

TABLE OF CONTENTS

3.4 Which Way Does Current Flow? ..... 30

Review ..... 31

Apply What You Have Learned..... 32

**Chapter 4: Voltage and Resistance ..... 35**

4.1 Picturing Voltage ..... 35

4.2 Volts Are Relative ..... 36

4.3 Relative Voltages and Ground Potential ..... 37

4.4 Resistance ..... 38

Review ..... 41

Apply What You Have Learned..... 42

**Chapter 5: Your First Circuit ..... 45**

5.1 Circuit Requirements ..... 45

5.2 Basic Components ..... 47

5.3 Creating Your First Circuit ..... 49

5.4 Adding Wires ..... 52

5.5 Drawing Circuits..... 53

5.6 Drawing the Ground ..... 56

Review ..... 57

Apply What You Have Learned..... 58

**Chapter 6: Constructing and Testing Circuits ..... 61**

6.1 The Solderless Breadboard ..... 61

6.2 Putting a Circuit onto a Breadboard ..... 64

6.3 Using Fewer Wires ..... 69

6.4 Testing Circuits with a Multimeter ..... 72

6.5 Using a Multimeter with a Breadboard ..... 75

6.6 Measuring Current with a Multimeter ..... 77

6.7 Using a Power Regulator.....78

Review .....80

Apply What You Have Learned.....83

**Chapter 7: Analyzing Series and Parallel Circuits .....85**

7.1 Series Circuits.....85

7.2 Parallel Circuits.....87

    7.2.1 Kirchhoff’s Current Law.....88

    7.2.2 Kirchhoff’s Voltage Law .....90

7.3 Equivalent Parallel Resistance.....93

7.4 Wires in a Circuit.....97

7.5 Wiring Parallel Circuits onto a Breadboard .....99

Review .....100

Apply What You Have Learned.....102

**Chapter 8: Diodes and How to Use Them.....105**

8.1 Basic Diode Behavior .....105

8.2 Circuit Calculations with Diodes in Series .....107

8.3 Circuit Calculations with Diodes in Parallel .....109

8.4 Diode Short Circuits .....113

8.5 Nonconducting Diodes .....115

8.6 Usage of Diodes.....115

8.7 Other Types of Diode Protection.....120

8.8 Zener Diodes.....122

8.9 Schottky Diode.....123

8.10 Diode-Like Behavior in Other Components .....123

Review .....123

Apply What You Have Learned.....126

TABLE OF CONTENTS

**Chapter 9: Basic Resistor Circuit Patterns ..... 129**

- 9.1 Switches and Buttons ..... 129
- 9.2 Current-Limiting Resistor Pattern ..... 131
- 9.3 Voltage Divider Pattern ..... 132
  - 9.3.1 Calculating the Voltages ..... 134
  - 9.3.2 Finding Resistor Ratios..... 135
  - 9.3.3 Finding Resistor Values ..... 136
  - 9.3.4 General Considerations ..... 138
- 9.4 The Pull-Up Resistor..... 138
- 9.5 Pull-Down Resistors..... 141
- Review ..... 141
- Apply What You Have Learned..... 143

**Chapter 10: Understanding Power ..... 145**

- 10.1 Important Terms Related to Power..... 145
- 10.2 Power in Electronics ..... 147
- 10.3 Component Power Limitations ..... 149
- 10.4 Handling Power Dissipation with Heatsinks ..... 150
- 10.5 Transforming Power ..... 151
- 10.6 Amplifying Low-Power Signals ..... 153
- Review ..... 154
- Apply What You Have Learned..... 156

**Chapter 11: Integrated Circuits and Resistive Sensors ..... 159**

- 11.1 The Parts of an Integrated Circuit ..... 159
- 11.2 The LM393 Voltage Comparator ..... 163
- 11.3 The Importance and Problems of Datasheets ..... 164
- 11.4 A Simple Circuit with the LM393..... 167



|  |            |
|--|------------|
| 11.5 Resistive Sensors and Voltages .....                      | 169        |
| 11.6 Sensing and Reacting to Darkness .....                    | 170        |
| Sources and Sinks .....  | 172        |
| Review .....   | 173        |
| Apply What You Have Learned.....                               | 175        |
| <b>Part II: Digital Electronics and Microcontrollers .....</b> | <b>177</b> |
| <b>Chapter 12: Using Logic ICs.....</b>                        | <b>179</b> |
| 12.1 Logic ICs.....  | 179        |
| 12.2 Getting a 5 V Source.....                                 | 185        |
| 12.3 Pull-Down Resistors.....                                  | 187        |
| 12.4 Combining Logic Circuits .....                            | 190        |
| 12.5 Understanding Chip Names .....                            | 193        |
| Review .....   | 196        |
| Apply What You Have Learned.....                               | 197        |
| <b>Chapter 13: Introduction to Microcontrollers.....</b>       | <b>201</b> |
| 13.1 The ATmega328/P Chip .....                                | 203        |
| 13.2 The Arduino Environment.....                              | 204        |
| 13.3 The Arduino Uno.....                                      | 206        |
| 13.4 Programming the Arduino .....                             | 207        |
| Review .....   | 210        |
| Apply What You Have Learned.....                               | 211        |
| <b>Chapter 14: Building Projects with Arduino .....</b>        | <b>213</b> |
| 14.1 Powering Your Breadboard from an Arduino Uno.....         | 213        |
| 14.2 Wiring Inputs and Outputs to an Arduino Uno .....         | 214        |
| 14.3 A Simple Arduino Project with LEDs.....                   | 216        |

TABLE OF CONTENTS

14.4 Changing Functionality Without Rewiring ..... 219

Review ..... 220

Apply What You Have Learned..... 221

**Chapter 15: Analog Input and Output on an Arduino .....223**

15.1 Reading Analog Inputs ..... 223

15.2 Analog Output with PWM ..... 226

Review ..... 229

Apply What You Have Learned..... 231

**Part III: Capacitors and Inductors..... 233**

**Chapter 16: Capacitors .....235**

16.1 What Is a Capacitor? ..... 235

16.2 How Capacitors Work..... 237

16.3 Types of Capacitors ..... 241

16.4 Charging and Discharging a Capacitor..... 243

16.5 Series and Parallel Capacitances..... 245

16.6 Capacitors and AC and DC ..... 248

16.7 Using Capacitors in a Circuit..... 249

Review ..... 251

Exercises..... 253

**Chapter 17: Capacitors as Timers .....255**

17.1 Time Constants ..... 255

17.2 Constructing a Simple Timer Circuit ..... 258

17.3 Resetting Our Timer ..... 263

Review ..... 265

Apply What You Have Learned..... 267

**Chapter 18: Introduction to Oscillator Circuits.....269**

    18.1 Oscillation Basics..... 269

    18.2 The Importance of Oscillating Circuits ..... 271

    18.3 Building an Oscillator ..... 273

    18.4 Calculating On and Off Times with the 555..... 279

    18.5 Choosing the Capacitor ..... 283

    Review ..... 284

    Apply What You Have Learned..... 287

**Chapter 19: Producing Sound with Oscillations .....289**

    19.1 How Sound Is Produced by Speakers ..... 289

    19.2 Graphing Electricity..... 290

    19.3 Outputting a Tone to Headphones ..... 292

    19.4 AC vs. DC..... 294

    19.5 Using Capacitors to Separate AC and DC Components ..... 295

    19.6 Speaker Wattage..... 297

    19.7 Sound Control ..... 298

    Review ..... 300

    Apply What You Have Learned..... 302

**Chapter 20: Inductors.....303**

    20.1 Inductors, Coils, and Magnetic Flux ..... 303

        20.1.1 What Is an Inductor?..... 303

        20.1.2 What Is Magnetic Flux? ..... 304

        20.1.3 What Is the Difference Between Electric and Magnetic Fields..... 304

    20.2 Induced Voltages..... 306

    20.3 Resisting Changes in Current..... 307

    20.4 Analogy from Mechanics..... 308

TABLE OF CONTENTS

20.5 Uses of Inductors ..... 308

20.6 Inductive Kick..... 309

Review ..... 311

Apply What You Have Learned..... 312

**Chapter 21: Inductors and Capacitors in Circuits..... 315**

21.1 RL Circuits and Time Constants ..... 315

21.2 Inductors and Capacitors as Filters ..... 317

21.3 Parallel and Series Capacitors and Inductors ..... 318

Review ..... 319

Apply What You Have Learned..... 320

**Chapter 22: Reactance and Impedance ..... 323**

22.1 Reactance ..... 323

22.2 Impedance ..... 326

22.3 RLC Circuits..... 329

22.4 Ohm’s Law for AC Circuits..... 331

22.5 Resonant Frequencies of RLC Circuits ..... 334

22.6 Low-Pass Filters ..... 335

22.7 Converting a PWM Signal into a Voltage ..... 336

Review ..... 337

Exercises..... 339

**Chapter 23: DC Motors..... 343**

23.1 Theory of Operation..... 343

23.2 Important Facts About Motors..... 344

23.3 Using a Motor in a Circuit..... 345

23.4 Attaching Things to Motors ..... 347

23.5 Bidirectional Motors..... 348

23.6 Servo Motors..... 349

23.7 Stepper Motors ..... 350

Review ..... 350

Apply What You Have Learned..... 352

**Part IV: Amplification Circuits ..... 353**

**Chapter 24: Amplifying Power with Transistors ..... 355**

24.1 An Amplification Parable ..... 356

24.2 Amplifying with Transistors ..... 357

24.3 Parts of the BJT ..... 358

24.4 NPN Transistor Operation Basics..... 361

    Rule 1: The Transistor Is Off by Default..... 361

    Rule 2:  $V_{BE}$  Needs to Be 0.6 V to Turn the Transistor On ..... 361

    Rule 3:  $V_{BE}$  Will Always Be Exactly 0.6 V When the Transistor Is On ..... 361

    Rule 4: The Collector Should Always Be More Positive Than the Emitter .... 362

    Rule 5: When the Transistor Is On,  $I_{CE}$  Is a Linear Amplification of  $I_{BE}$ ..... 362

    Rule 6: The Transistor Cannot Amplify More Than the Collector  
    Can Supply ..... 362

    Rule 7: If the Base Voltage Is Greater Than the Collector Voltage,  
    the Transistor Is Saturated..... 363

24.5 The Transistor as a Switch ..... 364

24.6 Connecting a Transistor to an Arduino Output..... 367

24.7 Stabilizing Transistor Beta With a Feedback Resistor ..... 368

24.8 A Word of Caution..... 370

Review ..... 370

Apply What You Have Learned..... 372

TABLE OF CONTENTS

**Chapter 25: Transistor Voltage Amplifiers.....375**

- 25.1 Converting Current into Voltage with Ohm’s Law..... 375
- 25.2 Reading the Amplified Signal ..... 378
- 25.3 Amplifying an Audio Signal ..... 380
- 25.4 Adding a Second Stage ..... 385
- 25.5 Using an Oscilloscope ..... 387
- Review ..... 388
- Apply What You Have Learned..... 390

**Chapter 26: Examining Partial Circuits.....391**

- 26.1 The Need for a Model..... 391
- 26.2 Calculating Thévenin Equivalent Values ..... 393
- 26.3 Another Way of Calculating Thévenin Resistance ..... 396
- 26.4 Finding the Thévenin Equivalent of an AC Circuit with  
Reactive Elements ..... 397
- 26.5 Using Thévenin Equivalent Descriptions ..... 398
- 26.6 Finding Thévenin Equivalent Circuits Experimentally ..... 399
- Review ..... 403
- Apply What You Have Learned..... 404

**Chapter 27: Using Field Effect Transistors for Switching and  
Logic Applications .....407**

- 27.1 Operation of a FET..... 408
- 27.2 The N-Channel Enhancement Mode MOSFET ..... 410
- 27.3 Using a MOSFET..... 410
- 27.4 MOSFETs in Logic Circuits ..... 414
- Review ..... 415
- Apply What You Have Learned..... 416

|   |            |
|---|------------|
| <b>Chapter 28: Going Further .....</b>                                | <b>417</b> |
| <b>Appendix A: Glossary.....</b>                                      | <b>419</b> |
| <b>Appendix B: Electronics Symbols.....</b>                           | <b>435</b> |
| <b>Appendix C: Integrated Circuit Naming Conventions.....</b>         | <b>439</b> |
| C.1 Logic Chip Basic Conventions.....                                 | 439        |
| <b>Appendix D: More Math Than You Wanted to Know.....</b>             | <b>443</b> |
| D.1 Basic Formulas .....  | 443        |
| D.1.1 Charge and Current Quantities .....                             | 443        |
| D.1.2 Volt Quantities .....   | 444        |
| D.1.3 Resistance and Conductance Quantities.....                      | 444        |
| D.1.4 Ohm's Law.....  | 445        |
| D.1.5 Power .....   | 445        |
| D.1.6 Capacitance.....  | 445        |
| D.1.7 Inductance.....   | 446        |
| D.2 Semiconductors.....   | 447        |
| D.2.1 Diodes .....  | 447        |
| D.2.2 NPN BJT .....   | 448        |
| D.3 DC Motor Calculations .....                                       | 448        |
| D.4 555 Timer Oscillator Frequency Equation .....                     | 450        |
| D.5 Output Gain Calculations in BJT Common Emitter Applications ..... | 452        |
| D.6 The Thévenin Formula.....   | 461        |
| D.7 Electronics and Calculus.....                                     | 463        |
| D.7.1 Current and Voltage.....  | 463        |
| D.7.2 Capacitors and Inductors .....                                  | 464        |
| D.7.3 Time Constants.....   | 465        |

TABLE OF CONTENTS

**Appendix E: Simplified Datasheets for Common Devices .....467**

- E.1 Batteries..... 468
  - E.1.1 Overview..... 468
  - E.1.2 Variations..... 468
  - E.1.3 Notes ..... 469
- E.2 Resistors ..... 469
  - E.2.1 Overview..... 469
  - E.2.2 Finding a Resistor Value ..... 470
- E.3 Diodes ..... 471
  - E.3.1 Overview..... 471
  - E.3.1 Variations..... 472
  - E.3.3 Forward Voltage Drop ..... 472
  - E.3.4 Usages..... 473
- E.4 Capacitors..... 473
  - E.4.1 Overview..... 473
  - E.4.2 Variations..... 474
  - E.4.3 Finding Capacitance Values..... 475
- E.5 Inductors ..... 475
  - E.5.1 Overview..... 475
  - E.5.2 Uses..... 476
  - E.5.3 Inductive Kick ..... 476
  - E.5.4 Inductor Color Codes ..... 477
- E.6 NPN BJTs ..... 477
  - E.6.1 Overview..... 477
  - E.6.2 Variations..... 478
  - E.6.3 Pin Configuration ..... 478
  - E.6.4 Design Considerations..... 479



E.7 YwRobot Power Module ..... 479

    E.7.1 Overview..... 479

    E.7.2 Variations..... 480

    E.7.3 Pin Configuration ..... 480

    E.7.4 Limitations..... 480

E.8 555 Timer ..... 481

    E.8.1 Overview..... 481

    E.8.2 Variations..... 482

    E.8.3 Pin Configuration ..... 482

    E.8.4 Specifications ..... 483

    E.8.5 Implementation Example..... 483

E.9 LM393 and LM339 Voltage Comparator ..... 483

    E.9.1 Overview..... 483

    E.9.2 Variations..... 484

    E.9.3 Specifications ..... 484

E.10 CD4081 and 7408 Quad-AND Gate..... 485

    E.10.1 Overview..... 485

    E.10.2 Variations..... 485

    E.10.3 Specifications (CD4081) ..... 486

    E.10.4 Specifications (7408)..... 486

E.11 CD4071 and 7432 Quad-OR Gate ..... 487

    E.11.1 Overview..... 487

    E.11.2 Variations..... 487

    E.11.3 Specifications (CD4071) ..... 488

    E.11.4 Specifications (7432)..... 488

TABLE OF CONTENTS

E.12 CD4001 and 7402 Quad-NOR Gate..... 489

    E.12.1 Overview..... 489

    E.12.2 Variations..... 489

    E.12.3 Specifications (CD4001) ..... 490

    E.12.4 Specifications (7402)..... 490

E.13 CD4011 and 7400 Quad-NAND Gate ..... 491

    E.13.1 Overview..... 491

    E.13.2 Variations..... 491

    E.13.3 Specifications (CD4011) ..... 492

    E.13.4 Specifications (7400)..... 492

E.14 CD4070 and 7486 Quad-XOR Gate ..... 493

    E.14.1 Overview..... 493

    E.14.2 Variations..... 493

    E.14.3 Specifications (CD4070) ..... 494

    E.14.4 Specifications (7486)..... 494

E.15 LM78xx Voltage Regulator ..... 495

    E.15.1 Overview..... 495

    E.15.2 Variations..... 495

    E.15.3 Specifications ..... 496

    E.15.4 Usage Notes ..... 497

**Index..... 499**