Encyclopedia of Electronic Components

Sensors

Want to know how to use an electronic component? This third book of a three-volume set includes key information on electronic sensors for your projects—complete with photographs, schematics, and diagrams. You’ll learn what each one does, how it works, why it’s useful, and what variants exist. No matter how much you know about electronics, you’ll find fascinating details you’ve never come across before.

Convenient, concise, well-organized, and precise

Perfect for teachers, hobbyists, engineers, and students of all ages, this reference puts reliable, fact-checked information right at your fingertips. Beginners will quickly grasp important concepts, and more experienced users will find the specific details their projects require.

- **Unique:** the first and only multivolume encyclopedia of electronic components, distilled into three separate volumes
- **Instructive:** each component description provides details about substitutions, common problems, and workarounds
- **Incredibly detailed:** includes information distilled from hundreds of sources
- **Easy to browse:** parts are clearly organized by component type
- **Authoritative:** fact-checked by experts to ensure current and accurate information
- **Reliable:** a more consistent source of information than online sources, product datasheets, and manufacturer’s tutorials
- **Comprehensive:** Volume 1 covers power, electromagnetism, and discrete semiconductors; Volume 2 includes integrated circuits, and light and sound sources; Volume 3 covers all major types of sensing components

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Ma...
To Brian Jepson
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This third and final volume of the *Encyclopedia of Electronic Components* is devoted entirely to sensors.

Two factors have caused very significant changes in the field of sensors since the 1980s. First, features such as antilock braking, airbags, and emissions controls stimulated the development of low-priced sensors for automotive applications. Many of these sensors were fabricated in silicon as MEMS (microelectromechanical) devices.

The second wave began in 2007 when MEMS sensors were installed in the iPhone. A modern phone may contain almost a dozen different types of sensors, and their size and price have been driven down to a point that would have been unimaginable 20 years previously.

Many MEMS sensors are now as cheap as basic semiconductor components such as a voltage regulator or a logic chip, and they are easy to use in conjunction with microcontrollers. In this Encyclopedia, we have allocated significant space to this segment of the market, hoping that the specific products that we have chosen will remain popular and available for at least the next decade.

In addition, we have devoted space to older components where durability has been proven.

**Purpose**

While much of the information in this volume can be found dispersed among datasheets, introductory texts, Internet sites, and technical briefings published by manufacturers, we believe there is a real need for a durable resource that assembles all the relevant data in one place, properly organized and verified, including details that may be hard to find elsewhere.

This volume may also serve a useful purpose by attempting to categorize and classify components in a field that is remarkably chaotic. For example, is an *object presence sensor* different from a *proximity sensor*? Some manufacturers seem to think so; others disagree. Understanding the distinctions and the underlying principles can be important if you are trying to decide which sensor to use.

Sensor terminology can also be confusing. To take another example, what is the difference between a *reflective interrupter*, a *reflective object sensor*, a *reflective optical sensor*, a *reflective photointerrupter*, and an *opt-pass sensor*? These terms are used in various datasheets to describe components that are all *retroreflective sensors*. Understanding the proliferating variety of terminology can be essential if you simply want to find something in a product index.
As in volumes 1 and 2, this volume is organized by subject. For example, if you want to measure temperature, you’ll find the entries for a thermistor and a thermocouple next to each other, in an entire section devoted to the sensing of heat. This will help you to compare capabilities and choose the component that best suits your application.

The subject path leading to each sensor is shown at the top of the first page of each entry. For gas flow rate, for instance, you would follow this path:

fluid > gas > flow rate

Note that the word “fluid” is properly used to include gases as well as liquids.

Exceptions and Conflicts
Unfortunately, some sensors are not easily categorized. There are four problems in this area.

1. What Does a Sensor Really Sense?
A GPS chip is a radio receiver, picking up transmissions from satellites. Does this mean it should be categorized as a sensor of radio waves? No, its purpose is to tell you your location. Therefore, it is categorized as a location sensor. This leads to the first general rule: sensors are categorized by their primary purpose. Secondary purposes may be found in the index.

2. How Many Sensors Are in a Sensor?
Many surface-mount chips perform more than one sensing function. For example, an inertial measurement unit (often identified by its acronym, IMU) can contain three gyroscope sensors and three accelerometers—and may contain three magnetometers, too. How should it be categorized?

The answer is that an IMU will be mentioned in more than one entry in the Encyclopedia, because it performs more than one function; but it will not have its own separate entry, because each entry in the Encyclopedia is for a single primary sensing function.

The names of multisensor chips are, of course, included in the index.

3. How Many Stimuli Can One Sensor Sense?
A single sensing element may be used in multiple different types of sensors. The most notable example is the Hall-effect sensor, which can be found in magnetometers, object presence sensors, speed sensors, current sensors, and dozens more. Modern automobiles can contain Hall-effect sensors everywhere from the ignition system to the trunk-locking mechanism. If you are using a hard drive with rotating platters, it probably contains a Hall-effect sensor to monitor the speed of rotation. If you have a generic computer keyboard, each keypress is probably detected with a Hall-effect sensor.

Bearing this in mind, how should a Hall-effect sensor be classified? And where should you expect to find an explanation of how it works?

The answer is that where different types of components contain the same type of sensing element, the entry for each component will include a cross-reference to one location where the sensing element is explained in detail. This location will be chosen for its relevance. Thus, Hall-effect sensors are explained in the entry for object presence sensors, because this is their primary function. While it is true that a Hall-effect sensor works by detecting a magnetic field, that is not its most common application.

4. Too Many Sensors!
Wikipedia lists more than 100 general types of sensors, and even that list is probably not complete. Consequently, we had to pick and choose. Some of the decisions may seem arbitrary, but all of them were made on the grounds of practicality. There were three principles for deciding what to include and what to leave out.
1. Is it a component? We are more interested in board-mounted components than in packaged products that happen to contain sensors. For instance, a thermocouple is often enclosed in a tubular steel probe, and its wire is often plugged into a specially designed meter that displays temperature. While we do include a photograph of a probe, we are primarily interested in the welded wires of the thermocouple inside it.

2. How much does it cost? An industrial ultrasonic sensor to check items on a factory conveyor belt will be sealed into a module with a waterproof grommet around a shielded cable—which is all very nice, but will not be very affordable. This Encyclopedia is more interested in board-mountable components for one-tenth of the price.

3. How many people are likely to want it? The stock of each type of sensor was checked on component vendor sites. If a sensor wasn’t in the inventory, or if only a couple of variants were stocked, we concluded that the limited demand probably didn’t justify including it here. For example, a Ferraris acceleration sensor responds to eddy currents in a rotating motor shaft, as a way of measuring vibration in the shaft. This is a really interesting device, but is unlikely to be on most people’s shopping lists.

**Volume Contents**

Having explained the organization of this book and our decisions to include or omit various components, we now present a summary of the contents of all three Encyclopedia volumes:

**Volume 1**

Power; electromagnetic devices; discrete semiconductors.

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The **power** category includes sources of electricity and methods to distribute, store, interrupt, convert, and regulate power. The **electromagnetism** category includes devices that exert force linearly, and others that create a turning force. **Discrete semiconductors** include the primary types of diodes and transistors. See Figure P-1 for a contents listing.

![Figure P-1](https://example.com/figureP1.png)
Volume 2
Thyristors (SCRs, diacs, and triacs); integrated circuits; light sources, indicators, and displays; and sound sources.

Integrated circuits are divided into analog and digital components. Light sources, indicators, and displays are divided into reflective displays, single sources of light, and displays that emit light. Sound sources are divided into those that create sound, and those that reproduce sound. A contents listing for Volume 2 appears in Figure P-2.

Volume 3
All the most common types of sensing devices, including those that detect location, presence, proximity, orientation, oscillation, force, load, human input, liquid properties, gas types and concentrations, pressure, flow rate, light, heat, sound, and electricity. A contents listing for Volume 3 appears in Figure P-3.

Method
Reference Versus Tutorial
As its title suggests, this is a reference book, not a tutorial. A tutorial such as Make: Electronics begins with elementary concepts and builds sequentially toward concepts that are more advanced. A reference book assumes that you may dip into the text at any point, learn what you need to know, and then put the book aside. If you choose to read it straight through from beginning to end, you will find some repetition, as each entry is intended to be self-sufficient, requiring minimal reference to other entries.

Theory and Practice
This book is oriented toward practicality rather than theory. We assume that the reader mostly wants to know how to use electronic components, rather than why they work the way they do. Consequently we do not include detailed proofs of formulae or definitions rooted in electrical theory.

![Figure P-2](image_url) The subject-oriented organization of categories and entries in Volume 2.
sensor output

In Volumes 1 and 2 of the Encyclopedia, each entry included hints on how to use a component. However, many sensors have identical forms of output, which are processed in a similar way. To avoid repetition, general guidance for using nine principal types of sensor outputs has been placed in Appendix A at the back of this volume.

For example, many sensors provide an analog voltage output that varies with the phenomenon that is being sensed. In Appendix A, you will find suggestions on how to adjust the range of the output, if necessary, or how to digitize it with an analog-to-digital converter.

You will also find a comparison between serial protocols such as I2C and SPI, both of which are commonly used when a microcontroller communicates with a digital sensor via a bus.

Glossary

In the world of sensors, many terms tend to recur. Hysteresis is one; MEMS is another. Rather than define these terms repeatedly, some quick definitions are gathered in a Glossary. Please remember the existence of the glossary if you encounter a term that is unfamiliar. See Glossary.

In many instances, terms that are italicized in the text are defined in the glossary.

Typographical Conventions

Within each entry, bold type is used for the first occurrence in each entry of the name of a component that has its own entry elsewhere. Other important electronics terms or component names may be presented in italics.

The names of components, and the categories to which they belong, are all set in lowercase type, except where a term is normally capitalized because it is an acronym or a trademark, or contains a proper noun. The term Hall effect, for instance, has an initial cap because it is named after a person named Hall. The term GPS is all in caps, because it is an acronym; but psi (meaning pounds per square inch) remains in lowercase, because even though it is an acronym, the lowercase form is more common.

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<th>Type of Sensor</th>
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<td>magnetometer</td>
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<td>presence</td>
<td>object presence</td>
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<td>voltage</td>
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Figure P-3 The subject-oriented organization of categories and entries in Volume 3.
The situation is different when specifying units that are named after electrical pioneers. All of these units should be lowercased when spelled out. Thus, when referring to the SI unit of force, it is “the newton.” However, where a unit named after a person is abbreviated, the abbreviation is capitalized, as in N for newtons, Hz for hertz, Pa for pascals, and A for amperes.

**Mathematical Syntax**

In mathematical formulae, we have used the style that is common in programming languages. The * (asterisk) is used as a multiplication symbol, while the / (forward slash) is used as a division symbol. Where some terms are in parentheses, they must be dealt with first. Where parentheses are inside parentheses, the innermost ones must be dealt with first. Consider this example:

\[ A = \frac{30}{7 + (4 \times 2)} \]

You would begin by multiplying 4 times 2, to get 8; then add 7, to get 15; then divide that into 30, to get the value for A, which is 2.

**Visual Conventions**

*Figure P-4* shows the conventions that are used in the schematics in this book. A black dot always indicates a connection, except that to minimize ambiguity, the configuration at top-right is avoided, and the configuration at top-center is used instead. Conductors that cross each other without a black dot do not make a connection. The styles at bottom right are sometimes seen elsewhere, but are not used here.

All the schematics are formatted with pale blue backgrounds. This enables components such as switches, transistors, and LEDs to be highlighted in white, drawing attention to them and clarifying the boundary of the component. The white areas have no other meaning.

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**Units and Backgrounds**

So long as the United States clings stubbornly to the habit of expressing dimensions in inches, there is a good argument to follow this custom in books intended for an American audience. With this in mind, Volumes 1 and 2 mostly avoided metric units of length. However, as time passed, the books were translated for use in many parts of the world where the inch is regarded as an anachronism.

Recognizing that we now have an international audience, we have used the metric system throughout this volume (with very few exceptions, such as a photograph of an American plumbing fixture that is designed to fit 3/4” pipe). For readers who are metrically impaired, here are some units of length, and their abbreviations:

- 1 nanometer (nm)
- 1 micrometer (µm) = 1,000nm
- 1 millimeter (mm) = 1,000µm
- 1 centimeter (cm) = 10mm
- 1 meter (m) = 100cm = 1,000mm
A micrometer is also known as a micron.

The basic conversion factor from meters to inches is 0.0254. Thus:

- 1 inch = 2.54cm = 25.4mm
- 1/1000 inch = 25.4µm

Sometimes 1/1000 inch is called a mil.

In many of the component photographs, a graph-paper background is included. Each square in these backgrounds is 1mm.

To avoid confusion, please remember that a few of these same component photographs appeared in books such as Make: More Electronics, where the background grid was in tenths of an inch. Captions to photographs in this volume will remind you that millimeters are now used.

Background colors in the photographs were chosen for contrast with the colors of the components, or for visual variety. They have no other significance.

**Component Availability**

The world of sensors is changing rapidly, and we have no way of knowing if a component will enjoy a long production run. We recommend checking availability at the following suppliers, which we used frequently during the preparation of the book:

- http://www.mouser.com
- http://www.jameco.com
- http://www.sparkfun.com
- http://www.adafruit.com

For obsolete parts, or those that are nearing the end of their commercial life, eBay can be very useful. Alternatively, new substitutions for old parts are often listed at http://www.mouser.com.

**Issues and Errata**

There are three situations where the reader and the writer may want to communicate with each other.

- We may want to tell you if the book contains a mistake of some significance. This is us-informing-you feedback.

- You may want to tell us if you think you found an error in the book. This is you-informing-us feedback.

- You may be having trouble making something work, and you don’t know whether we made a mistake or you made a mistake. You would like some help. This is you-asking-us feedback.

Here’s how you can deal with each of these situations.

**Us Informing You**

If you already registered your contact information in connection with Make: Electronics (second edition) or Make: More Electronics, you don’t need to register again for updates relating to the Encyclopedia. If you have not already registered, here’s how it works.

The only way you can be notified if there's an error in the book is if you supply your contact information. If we have your email address:

- You will be notified of any significant errors that are found in this book, and you will receive a correction.

- You will be notified if there is a completely new edition of this book, or of Make: Electronics, or any other books by Charles Platt. These notifications will be very rare.

Your contact information will not be used for any other purpose.
Simply send a blank email (or include some comments in it, if you like) to:

make.electronics@gmail.com

Please put REGISTER in the subject line.

**You Informing Us**

If you only want to report an error that you have found, it’s really better to use the “errata” system maintained by our publisher. The publisher uses the “errata” information to fix the error in updates of the book.

If you feel sure that you found an error, please visit:


The web page will tell you how to submit errata.

**You Asking Us**

Our time is obviously limited, but if you have a question, a quick answer may be available. You can send email to make.electronics@gmail.com for this purpose. Please put the word HELP in the subject line.

**Going Public**

There are dozens of forums online where you can discuss this book and mention any problems you are having, but please be aware of the power that you have as a reader, and use it fairly. A single negative review can create a bigger effect than you may realize. It can certainly outweigh half-a-dozen positive reviews.

Responses in the past have been generally positive, but in a couple of cases people have been annoyed over small issues such as being unable to find a part online. Help is available on this kind of topic, if you need it. All you have to do is send a request to make.electronics@gmail.com.
world. This is much more than an audience, it’s a worldwide movement that Make is leading. We call it the Maker Movement.

For more information about Make, visit us online:

Make: magazine: http://makezine.com
Maker Faire: http://makerfaire.com
Makezine.com: http://makezine.com
Maker Shed: http://makershed.com

To comment or ask technical questions about this book, send email to:
bookquestions@oreilly.com.

Acknowledgments

Datasheets and tutorials maintained by component manufacturers were considered the most trustworthy sources of information online. In addition, component retailers, college texts, crowd-sourced reference works, and hobbyist sites were used. The following books provided useful information:


In addition, three individuals provided special assistance. Our editor, Brian Jepson, was immensely helpful in the development of this book. Philipp Marek reviewed the text for errors, and Erico Narita collaborated on the Photoshop work.