Make:

VOL. 3

Charles Platt and Fredrik Jansson

Encyclopedia of Electronic Components

Sensors

Location ▪ Presence ▪ Proximity ▪ Orientation ▪ Oscillation ▪ Force ▪ Load ▪ Human Input ▪ Liquid and Gas Properties ▪ Light ▪ Heat ▪ Sound ▪ Electricity

Encyclopedia of Electronic Components Volume 3

Charles Platt and Fredrik Jansson

MAKER MEDIA
SAN FRANCISCO, CA

Encyclopedia of Electronic Components, Volume 3
by Charles Platt

Printed in Canada.

Published by Maker Media, Inc., 1160 Battery Street East, Suite 125, San Francisco, CA 94111.

Maker Media books may be purchased for educational, business, or sales promotional use. Online editions are also available for most titles (*http://safaribooksonline.com*). For more information, contact O'Reilly Media's institutional sales department: 800-998-9938 or *corporate@oreilly.com*.

Editor: Brian Jepson
Production Editor: Melanie Yarbrough
Copyeditor: Christina Edwards
Proofreader: Charles Roumeliotis
Indexer: Charles Platt
Interior Designer: David Futato
Cover Designer: Karen Montgomery
Illustrator: Charles Platt

April 2016: First Edition

Revision History for the First Edition
2016-04-05: First Release

See *http://oreilly.com/catalog/errata.csp?isbn=9781449334314* for release details.

978-1-449-33431-4

[TI]

To Brian Jepson

Table of Contents

Preface

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.

Organization

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 in to 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.

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.

Primary Category	Secondary Category	Component Type
power	source	battery
	connection	jumper
		fuse
		pushbutton
		switch
		rotary switch
		rotational encoder
	moderation	relay
		resistor
		potentiometer
		capacitor
		variable capacitor
	conversion	inductor
		AC-AC transformer
		AC-DC power supply
		DC-DC converter
		DC-AC inverter
	regulation	voltage regulator
electro-magnetism	linear output	electromagnet
		solenoid
	rotational output	DC motor
		AC motor
		servo motor
		stepper motor
discrete semi-conductor	single junction	diode
		unijunction transistor
	multi-junction	bipolar transistor
		field-effect transistor

Figure P-1 *The subject-oriented organization of categories and entries in Volume 1 of this Encyclopedia.*

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.

Primary Category	Secondary Category	Component Type
discrete semi-conductor	thyristor	SCR
		diac
		triac
integrated circuit	analog	solid-state relay
		optocoupler
		comparator
		op-amp
		digital potentiometer
		timer
	digital	logic gate
		flip-flop
		shift register
		counter
		encoder
		decoder
		multiplexer
light source, indicator or display	reflective	LCD
	single source	incandescent lamp
		neon bulb
		fluorescent light
		laser
		LED indicator
		LED area lighting
	multi-source or panel	LED display
		vacuum-fluorescent
		electroluminescence
sound source	audio alert	transducer
		audio indicator
	reproducer	headphone
		speaker

Figure P-2 *The subject-oriented organization of categories and entries in Volume 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.

Primary Category	Attribute to be Sensed	Type of Sensor
spatial	location	GPS
		magnetometer
	presence	object presence
		passive infrared
	distance	object proximity
		linear position
	orientation	rotary position
		tilt
		gyroscope
		accelerometer
mechanical	oscillation	vibration
	force	force
	human input	single touch
		touch screen
fluid	liquid	liquid level
		liquid flow rate
	gas/liquid	pressure
	gas	gas concentration
		gas flow rate
radiation	light	photoresistor
		photodiode
		phototransistor
	heat	NTC thermistor
		PTC thermistor
		thermocouple
		RTD
		semiconductor
		infrared temperature
	sound	microphone
electricity	metering	current
		voltage

Figure P-3 *The subject-oriented organization of categories and entries in Volume 3.*

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.

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 = 30 / (7 + (4 * 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.

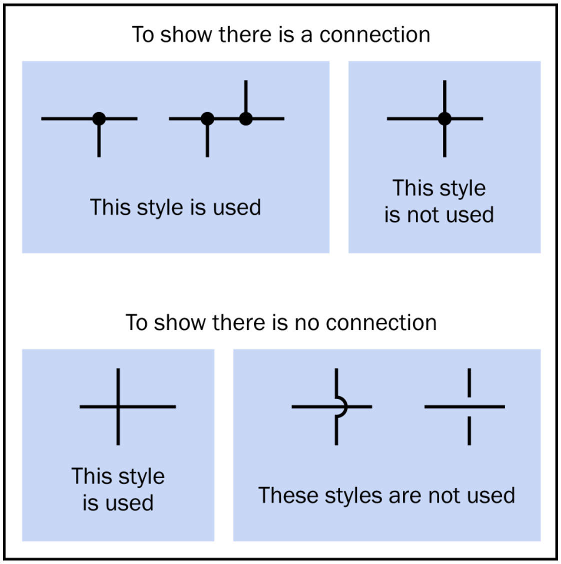

Figure P-4 *Visual conventions that are used in the schematics in this book.*

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:

http://bit.ly/encyclopedia_electronic_components_v3

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*.

Safari® Books Online

Safari

Safari Books Online is an on-demand digital library that delivers expert content in both book and video form from the world's leading authors in technology and business.

Technology professionals, software developers, web designers, and business and creative professionals use Safari Books Online as their primary resource for research, problem solving, learning, and certification training.

Safari Books Online offers a range of plans and pricing for enterprise, government, education, and individuals.

Members have access to thousands of books, training videos, and prepublication manuscripts in one fully searchable database from publishers like O'Reilly Media, Prentice Hall Professional, Addison-Wesley Professional, Microsoft Press, Sams, Que, Peachpit Press, Focal Press, Cisco Press, John Wiley & Sons, Syngress, Morgan Kaufmann, IBM Redbooks, Packt, Adobe Press, FT Press, Apress, Manning, New Riders, McGraw-Hill, Jones & Bartlett, Course Technology, and hundreds more. For more information about Safari Books Online, please visit us online.

You can access the errata page at *http://bit.ly/encyclopedia-electronic-components-v3*.

Make: unites, inspires, informs, and entertains a growing community of resourceful people who undertake amazing projects in their backyards, basements, and garages. Make: celebrates your right to tweak, hack, and bend any technology to your will. The Make: audience continues to be a growing culture and community that believes in bettering ourselves, our environment, our educational system—our entire 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/magazine*
> 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:

Boylestad, Robert L. and Nashelsky, Louis: *Electronic Devices and Circuit Theory*, 9th edition. Pearson Education, 2006.

Braga, Newton C.: *CMOS Sourcebook*. Sams Technical Publishing, 2001.

Hoenig, Stuart A.: *How to Build and Use Electronic Devices Without Frustration, Panic, Mountains of Money, or an Engineering Degree*, 2nd edition. Little, Brown, 1980.

Horn, Delton T.: *Electronic Components*. Tab Books, 1992.

Horn, Delton T.: *Electronics Theory*, 4th edition. Tab Books, 1994.

Horowitz, Paul and Hill, Winfield: *The Art of Electronics*, 2nd edition. Cambridge University Press, 1989.

Ibrahim, Dogan: *Using LEDs, LCDs, and GLCDs in Microcontroller Projects*. John Wiley & Sons, 2012.

Kumar, A. Anand: *Fundamentals of Digital Circuits*, 2nd edition. PHI Learning, 2009.

Lancaster, Don: *TTL Cookbook*. Howard W. Sams & Co, 1974.

Lenk, Ron and Lenk, Carol: *Practical Lighting Design with LEDs*. John Wiley & Sons, 2011.

Lowe, Doug: *Electronics All-in-One for Dummies*. John Wiley & Sons, 2012.

Mims III, Forrest M.: *Getting Started in Electronics*. Master Publishing, 2000.

Mims III, Forrest M.: *Electronic Sensor Circuits & Projects*. Master Publishing, 2007.

Mims III, Forrest M.: *Timer, Op Amp, & Optelectronic Circuits and Projects*. Master Publishing, 2007.

Predko, Mike: *123 Robotics Experiments for the Evil Genius*. McGraw-Hill, 2004.

Scherz, Paul: *Practical Electronics for Inventors*, 2nd edition. McGraw-Hill, 2007.

Williams, Tim: *The Circuit Designer's Companion*, 2nd edition. Newnes, 2005.

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.