Bonus Chapter 1

Resistor Types

Topics Covered in This Chapter

- The various kinds of resistors
- Power dissipation and voltage ratings
- Choosing the right resistor

Resistors are the most common *passive* electronic component (one that does not require power to operate). They are used to control voltages and currents. While a resistor is a very basic component, there are many ways to manufacture them. Each style has its own characteristics that make it desirable in certain types of applications. Choosing the right type of resistor is important to making high-performance or precision circuits work well. This bonus chapter covers the resistor types and helps with picking the right one for your project.

Meet the Resistors

All resistors are basically just a piece of conducting material with a specific value of resistance. For that piece of conducting material to be made into a practical resistor, a pair of electrodes and leads are attached so current can flow. The resistor is then coated with an insulating material to protect the conducting material from the surrounding environment and vice versa. There are several different resistor-construction methods and body styles (or *packages*) that are designed for a certain range of applied voltage, power dissipation, or other considerations. The construction of the resistor can affect its performance at high frequencies where it may act like a small inductor or capacitor has been added, called *parasitic* inductance or capacitance.

Carbon-composition resistors

These are also known as *carbon-comp* resistors. “Composition” means that the resistive material is a mix of carbon and stabilizing compounds. The amount of carbon in the mix determines the resistance of the material. A small cylinder, like a pencil lead, is held between the two electrodes and coated with resin or phenolic, making a *non-inductive* resistor (one with very low parasitic inductance) that is often used in RF circuits.

Carbon-comp resistors are available with power ratings of ¼- to 2 watts. They can also handle temporary overloads much better than film resistors (more about those in a moment) because the heat is distributed evenly throughout the cylinder of resistive material. That makes this type of resistor a good choice for circuits that protect against and absorb pulses and transients (short bursts of excess voltage or current), for example. Unfortunately, these resistors are also strongly influenced by temperature and humidity and so are not good for circuits that depend on precise, stable resistance values.

Film resistors

In a *film resistor,* the resistive material is a very thin coating of carbon or metal on an insulating substrate, such as ceramic or glass. The value of the resistance is determined by the thickness of the film and the amount of carbon or metal in it. These resistors are available with very accurate and stable values.

A drawback of film resistors is that they are unable to handle large amounts of power because the film is so thin. Overloads can also damage the film by creating "hot spots" inside the resistor, changing its value permanently. The value of film resistors is sometimes adjusted before sealing by cutting away some of the film with a laser, a process called *trimming*.

Surface-mount resistors are almost always film resistors; the film is deposited on a ceramic sheet. Because of their extremely small size, surface-mount resistors have very low power ratings — from 1⁄10 to ¼ watt.

Wirewound resistors

Common in power supplies and other equipment that dissipates lots of power, wirewound resistors are made just as you might expect: A high-resistance wire is wound around an insulating form — usually a ceramic tube — and attached to electrodes at each end. These are made to dissipate a lot of power in sizes from 1-watt to hundreds of watts! Wirewound resistors are usually intended to be air cooled, but some styles have a metal case that can be attached to a heat sink or metal chassis to get rid of undesired heat.

Because the resistive material in these resistors is wound on a form, they also act like small inductors. For this reason, wirewound resistors are not used in audio and RF circuits. Be careful when using a resistor from your junk box or a grab bag in such a circuit! Small wirewound resistors look an awful lot like film or carbon-comp resistors. There is usually a wide color band on wirewound resistors, but not always. If you're in doubt, test the resistor at the frequencies you expect to encounter.

Ceramic and metal oxide

If you need a high-power *non-inductive* resistor, you can use *cermet* (ceramic-metal mix) or metal oxide resistors. These are constructed much like carbon-comp resistors, substituting the cermet or metal oxide for the carbon-composition material.

Adjustable resistors

There are many different types of adjustable resistors. The simplest are wirewound resistors with some of the wire exposed so a movable electrode can be attached. The most common are adjusted with a rotary shaft. The *element* provides a fixed resistance between two terminals. The *wiper* moves to contact the element at different positions, changing the resistance between the end of the element and the wiper terminal.

If an adjustable resistor has only two terminals — one end of the element and the wiper — then it's called a *rheostat* and provides an adjustable value of resistance. Most rheostats are intended for use in high-power circuits with power ratings from several watts to several tens of watts.

If the adjustable resistor has three terminals, it is called a *potentiometer* (or "pot" for short). Most pots are intended to act as voltage dividers; they can be made into rheostats by leaving one of the element terminals unconnected. Miniature versions called *trimmers,* mounted on a circuit board, are used to make small adjustments or calibrate a circuit. They are available in single-turn or multi-turn versions. Larger pots (with shafts ⅛" or ¼" in diameter) are intended as user controls — for example, the volume and tone pots on an electric guitar or a radio. Pots are available with resistance values from a few ohms to several megohms and with power ratings up to 5 watts.

As with fixed-value resistors, the construction of the pot is important. Higher-power pots may have a wirewound element that has enough inductance to be unsuitable for audio or RF signals. Smaller pots, particularly trimpots, are not designed to be strong enough mechanically for use as a frequently adjusted control.

Pots are also available with elements that have a non-linear *taper* or change of resistance with wiper position. For example, a *log taper* pot has a resistance that changes logarithmically with shaft rotation. This is useful in attenuator circuits. An *audio taper* pot is used to create a voltage divider that mimics the loudness response of the human ear so volume appears to change linearly with control rotation.

Resistor networks

Often resistor networks are used to save space on printed circuit boards. These networks are miniature printed circuits themselves, placing several resistors on one substrate — where they may be isolated from each other, share one common terminal, or be connected in series. You can find various configurations of these resistors in any component supplier's catalog.

Power Dissipation and Voltage Ratings

After value, power dissipation is the next most important characteristic of a resistor. An overloaded resistor often changes in value over time and can often get hot enough to burn its self and surrounding components. Every circuit designer learns the smell of burnt resistor sooner or later!

How to read a resistor

Learning the resistor color code is a rite of passage for electronics techs the world over. A handy Web guide is available at `www.proaxis.com/~iguanalabs/resistors.htm` (along with other handy tutorials), or you can just type "resistor color code" into an Internet search engine. Surface-mount and power resistors may have the value printed on their body as a three- or four-digit code with the final digit acting as an exponent. For example, 513 mean 51×10^3 or 510 kΩ. (The resistor color code is also reprinted on the Cheat Sheet that comes with *Circuitbuilding Do-It-Yourself For Dummies*.)

The common rule is to calculate how much power the resistor will have to dissipate — and then use the next largest size or a factor-of-two higher dissipation ratings, whichever is larger. The power rating is based on unobstructed air circulation around the resistor. For resistors dissipating more than a watt, arrange nearby components so air can circulate freely. If possible, mount power resistors horizontally so convection cools all parts of the resistor equally.

Another important rating is *maximum applied voltage*. Voltages above this value may cause an arc between the resistor terminals! At high voltages, *leakage resistance* from current across the resistor's body surfaces can also become significant — allowing current to leak around the internal resistance. High-voltage resistors must be kept clean. Fingerprints, oil, dirt and dust all create unwanted current paths, increasing leakage or even arcing. This is why resistors for use in high-voltage circuits are long and thin, with their terminals far apart — to minimize leakage and maximize their ability to withstand high voltage.

Choosing Resistors

Here's a short list of special applications that require special types of resistors. These aren't hard and fast rules, but they can guide your initial selection. For most circuits, plain old carbon-film or carbon-comp resistors work just fine.

- **ESD and transient protection:** Carbon composition and metal oxide (they withstand short pulse overloads and have low values of parasitic inductance).
- **Audio and instrumentation circuits:** Metal film (low noise).
- **High voltage:** Wirewound and metal oxide in high-voltage body styles.
- **RF:** Carbon composition and metal oxide (low inductance).
- **Precision circuits:** Carbon or metal film (fixed-value) and cermet (trimmers or controls).

Consider what's most important for your particular circuit — value, power, voltage, stability, cost — and then look for the resistor type that meets those requirements.

Tolerance and temperature coefficient

Resistors have a *nominal* value and a *tolerance* (the amount of acceptable variation above or below the nominal value). Most resistors have a 1%, 5%, or 10% tolerance, and you can find smaller (that is, *tighter*) tolerances. The *tolerance series* determines which values of resistors are available. For example, in the 5% series, values are selected so each is approximately twice the tolerance or 10% from the next highest or lowest value.

Resistors also change value with temperature. The relative change of resistance with temperature is called the *temperature coefficient* or *tempco* — specified as *parts per million* (ppm) or as percentage-change-per-degree-Celsius of temperature change. A positive tempco means resistor value increases with temperature. When designing and constructing sensitive circuits that use precision (1% or tighter tolerance) resistors, it's important to keep them at an even temperature.

Further Reading

To learn more about resistors, definitions are available from the Resistor Term Glossary at `www.prpinc.com/pdf/GlossaryofTerms.pdf`. Download the article on choosing resistors "Ask the Applications Engineer #24" from Analog Devices' Web site at `www.analog.com/library/analogDialogue/archives/31-1/Ask_Engineer.html`. Serious designers will want to find a copy of *The Resistor Handbook* by Kaiser (CJ Publishing) which is a good reference.