Bonus Chapter 2

Capacitor Types

Topics Covered in This Chapter

- How a capacitor works
- Building your own capacitor
- Choosing a capacitor type

As you learn how to build circuits, you will undoubtedly work more and more with capacitors. This bonus chapter gives you the rundown on how capacitors work, how to build your own, and what to look for when picking a capacitor.

Meet the Capacitors

A *capacitor* is just a pair of conducting plates (electrodes) separated by an insulator (dielectric). When voltage is applied, electrons are forced onto one plate and removed from the other, charging the capacitor and creating an electric field between the electrodes. The electric field's energy is stored in the capacitor's dielectric. The energy stored in a capacitor is used to reduce changes in voltage, just as an overflow pond will reduce changes in a river's level.

Capacitance measures the amount of energy that a capacitor stores for a given amount of charge and voltage. The area of the electrodes and the material used for the dielectric determine the capacitor's ability to store energy. More area or a thinner dielectric increases capacitance. Like resistors, a capacitor's value comes with a tolerance in percent that allows it to vary around the labeled or *nominal* value.

All capacitor types may be just two separated electrodes, but the way they are manufactured gives them a wide range of electrical characteristics. The length and configuration of the electrodes adds a small amount of unwanted or *parasitic* inductance to every capacitor. The dielectric material between the electrodes also has a small amount of loss that acts like a small resistance or *equivalent series resistance (ESR)* that causes energy to be lost as heat. Parasitic inductance limits a capacitor's ability to work at high-frequencies. The loss from ESR limits the amount of power a capacitor can handle without overheating. Higher ESR means higher loss. Capacitors also allow small amounts of the charge to leak from electrode to electrode, gradually discharging the capacitor. Leakage is specified as a resistance (usually in the megohm or gigaohm range) and can be ignored except in very low power and very high voltage circuits.

Capacitor Construction

There are two common ways of efficiently making capacitors: the roll and the stack. Here's a brief summary:

- **Roll capacitors:** Two strips of very thin aluminum foil are separated by a dielectric. After leads are attached to the foil strips, the sandwich is rolled up and either placed in a metal can or coated with plastic. *Radial* leads both stick out of one end. *Axial* leads stick out from both ends along the roll's axis. Because of the long, rolled strips, the roll capacitor's parasitic inductance is high.
- **Stack capacitors:** In this case, the dielectric is a thin sheet of insulating material. Each piece is coated with a thin metal layer on one side. A stack of coated sheets is then placed under pressure and heated to make a single solid piece of material. Metal end caps with leads are attached to each side of the stack, contacting the metal layers. The whole capacitor is then coated with an epoxy resin. The parasitic inductance of stack capacitors is very low.

The Capacitor Menu

There are many kinds of capacitors out there, and this section gives you a brief rundown of the most common types and what types of circuits they are best used for.

Electrolytic

The most common type of roll capacitor is the aluminum electrolytic. The dielectric is a porous layer of paper-like fiber, impregnated with a chemical gel. Electrolytics have very high capacitance for their volume, but also have high parasitic inductance and ESR and are relatively leaky (meaning they have low leakage resistance). They can be made to withstand substantial voltages. Electrolytics are polarized, meaning that voltage can only be applied in one way due to the chemical electrolyte. They generally have very wide value tolerances of ±20%. Electrolytics are mostly used in power-supply circuits to filter the varying voltage derived from household AC electricity into constant DC voltage suitable for electronic circuits.

WARNING

Electrolytic capacitors are often used in high-voltage circuits. That means they can store a hefty amount of energy and deliver a serious shock! To discharge capacitors in such circuits, high-value resistors (called *bleeder resistors*) are connected across them, dissipating the stored energy over several seconds. Never assume a capacitor in a high-voltage circuit (such as a power supply for vacuum tube equipment) is safe to handle — discharge it with a screwdriver or bleeder resistor first.

Tantalum

The *tantalum capacitor* is a special type: Instead of a roll of foil, an extremely porous cylinder or *slug* of tantalum makes one electrode and an outer metal capsule the other. The dielectric is a chemical solution that forms an oxide coating on the tantalum slug for insulation. The slug has a tremendous amount of area and the oxide layer is very thin, so capacitance is high, but ESR is also high (somewhat lossy). The short leads and small size of the capacitor means that tantalums have low ESL. The maximum applied voltage for tantalum capacitors is under 100 V. Like electrolytics, they are polarized and have wide tolerances of ±20%. Tantalum capacitors are used in low-voltage power supplies and for smoothing out voltage variations at a circuit's power connections.

Film

Film capacitors have a plastic-film dielectric; polyethylene and polycarbonate are the most common materials for the film. Most film capacitors are of roll construction, so the parasitic inductance is moderate. Film capacitors are non-polarized. Leakage resistance is high (low leakage) and ESR is low (low loss). Special types of film are used for highly stable capacitance values or for extremely low leakage. Precision film capacitors of 5% tolerance or better are available. See `www.filmcapacitors.com/specsum.htm` for a good table summarizing the different types of film capacitors. Film capacitors are used in audio and control circuits for their good performance in this frequency range.

Ceramic

By far the most common form of capacitor, *ceramic capacitors* are used in high-frequency applications. Stack construction keeps parasitic inductance extremely low so they are useful at frequencies of hundreds of megahertz. They are low-loss (low ESR) and have good leakage characteristics (moderate leakage resistance). Ceramic capacitors are very rugged. They do not offer the same high values of capacitance as electrolytic and tantalum capacitors, but they do pack a lot of capacitance into a small package. Ceramics are non-polarized and have a wide range of tolerances. Ceramic capacitors are used with high-speed digital circuits to keep the fast signals from contaminating the power supply voltages. They are also used in high-frequency circuits, such as radio and computers.

Mica and glass

You will occasionally find silvered-mica and glass capacitors in RF and transmitting equipment due to their extremely low loss (low ESR and high leakage resistance) and low parasitic inductance. A variation of the ceramic stack, mica and glass dielectric layers is used instead of ceramic. Their layers can not be made as thin as ceramic, so this limits the amount of capacitance that can be obtained. Both types typically have a 5% tolerance.

Adjustable or variable

If you take apart an old radio, behind the tuning knob you'll see a variable capacitor with closely spaced metal plates separated by air. While these are typically small in value (1,000 pF or less), they are adjustable. *Air variables* are stable and low-loss, working very well at RF. An adjustable variation of the mica capacitor in which the stack is squeezed by a screw is called a *compression trimmer*. Ceramic and plastic variables are also available with values of up to several hundred pF.