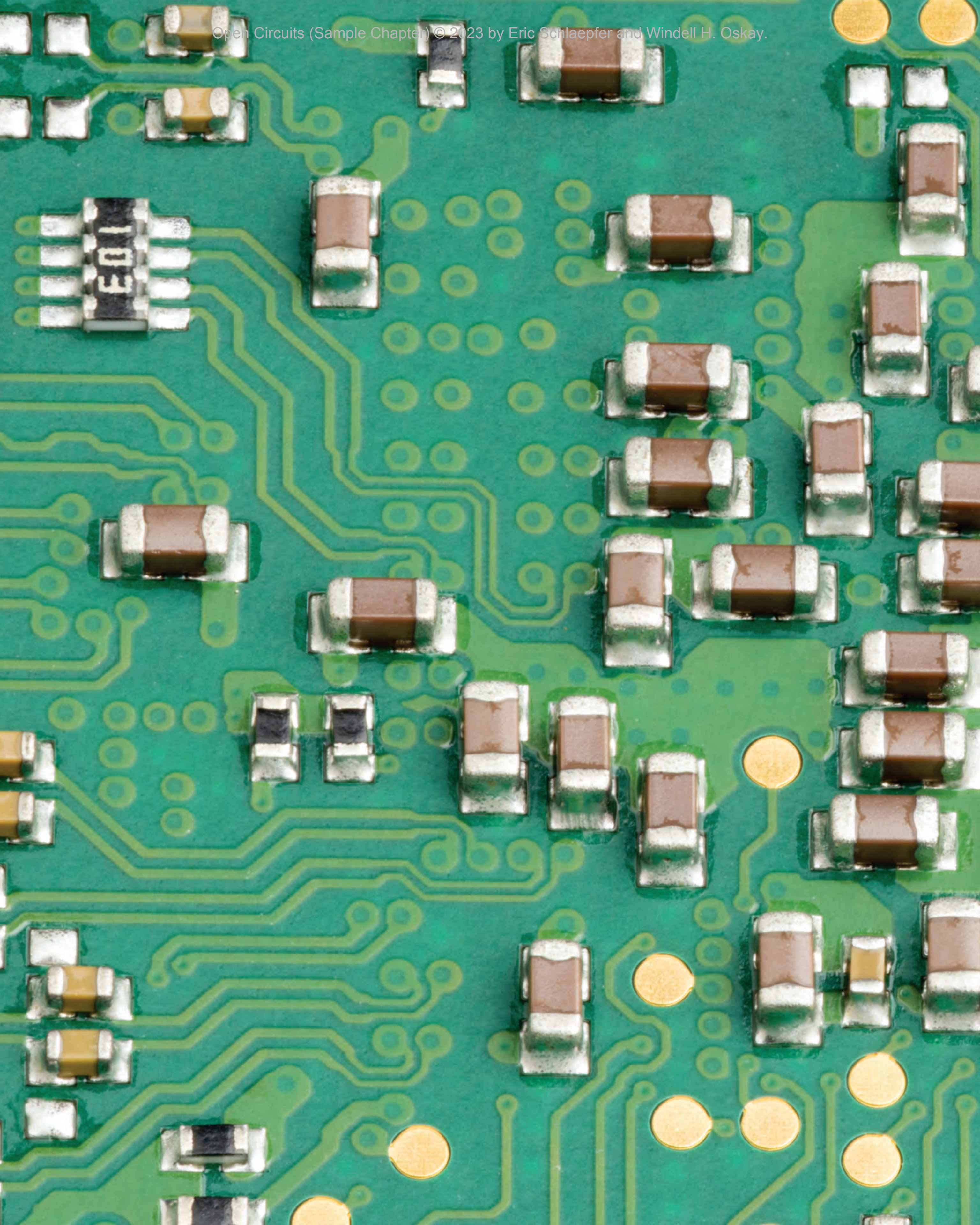
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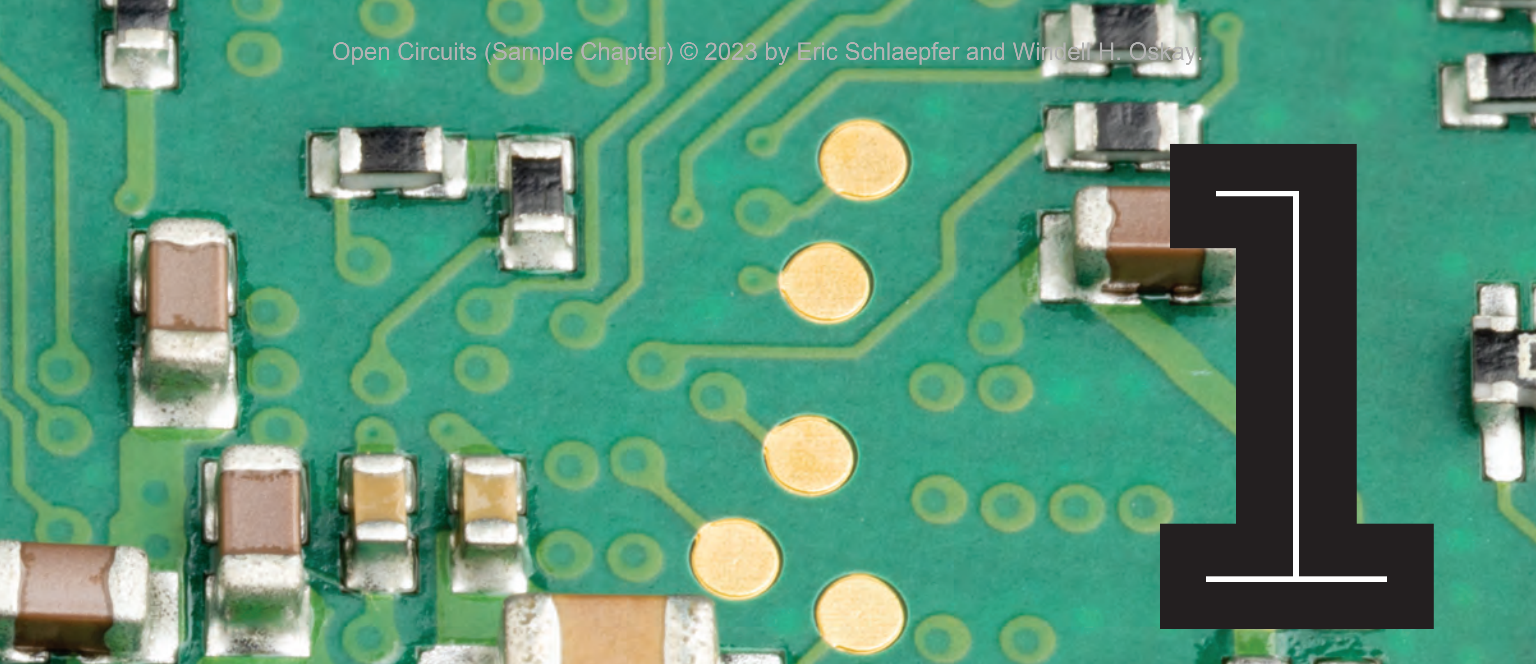

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Passive Components

Resistors, capacitors, and inductors are basic building blocks found in essentially all electronic devices. All three are common examples of **PASSIVE COMPONENTS**, a broad category of components that don't add energy to a circuit. Instead, they dissipate, store, or transform energy in some way. These are some of the most varied and visually striking components, adorned with stripes, dots, glossy coatings, and cryptic labels. Let's take a look.

32 kHz Quartz Crystal

Deep within a quartz wristwatch lies a tiny tuning fork, cut from gleaming quartz crystal, that keeps the watch running on time. The tuning fork is plated with mirror-like electrodes on its surfaces and protected inside a tough metal tube.

A musician's tuning fork might be cut to ring at "A 440," the musical note A at 440 hertz (Hz), or 440 oscillations per second. The resonant frequency of this quartz tuning fork, however, is beyond the range of human hearing, precisely tuned to 32,768 Hz. (Keep dividing 32,768 Hz by 2 and you eventually get 1 Hz.)

Quartz is **PIEZOELECTRIC**: it flexes ever so slightly when a voltage is applied to it and also produces a voltage when flexed. The watch circuitry applies a tiny voltage to the electrodes, causing the quartz to flex and ring at its resonant frequency. As it does so, it produces an oscillating voltage. Every second, a digital circuit counts out 32,768 oscillations, then drives the second hand forward a single tick.

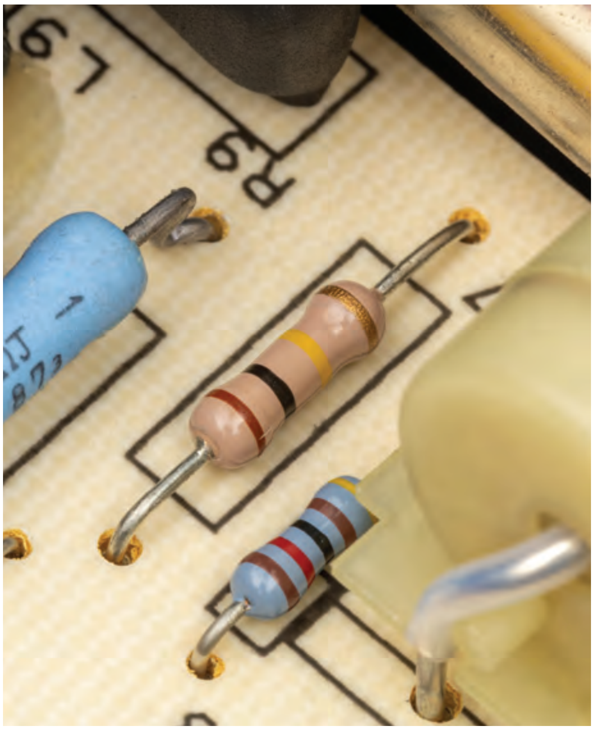
What appear to be scratches on the tips of the tuning fork are actually laser trim marks from a process that fine-tunes the frequency.

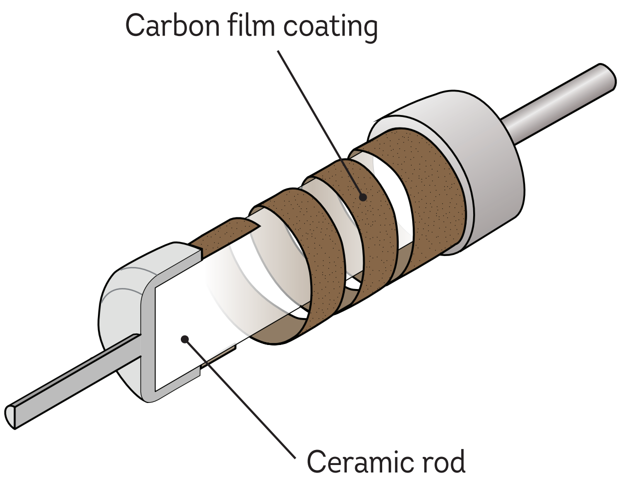
Carbon Film Resistor

RESISTORS are devices that restrict or limit the flow of electricity. They're used wherever a controlled amount of current is needed in a circuit. Everyday **CARBON FILM RESISTORS** like these are used in electronics like appliances and toys, where cost is more important than precision or size.

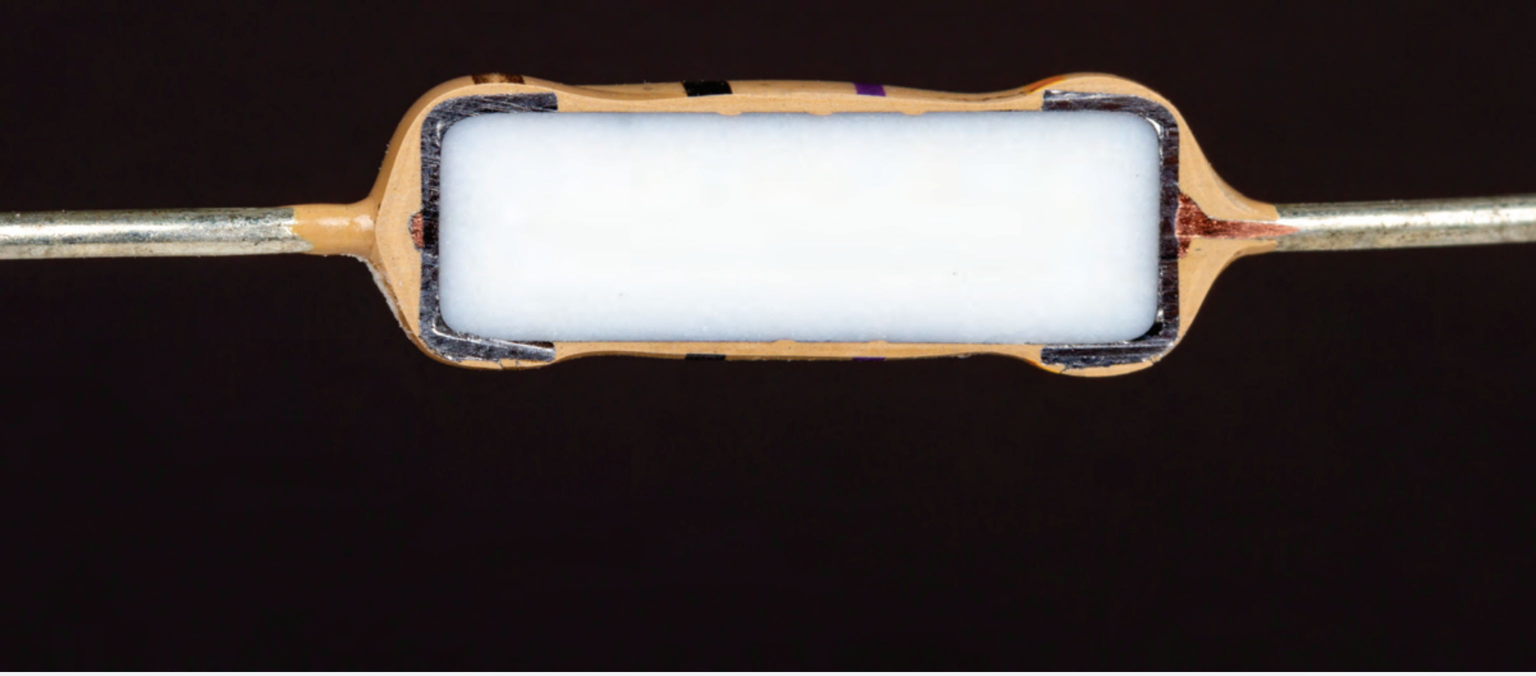
A carbon film resistor is made from a ceramic rod coated with a fine layer of carbon film that conducts electricity with some resistance. A helical groove is cut through the film, leaving a long narrow path of carbon that corkscrews from one end of the rod to the other. Metal caps are crimped onto the two ends, and wire leads are added. The resistor is then dipped in a protective coating and painted with color-coded stripes to indicate its resistance value.

Resistors of this shape are called **AXIAL THROUGH-HOLE RESISTORS**, meaning they have wire leads (intended to go *through holes* in a circuit board) arranged along the resistor's axis of symmetry.





The carbon film is relatively thin. In cross section, the grooves are visible only as indentations in the ceramic rod.



The spiral groove can clearly be seen after the protective coating has been removed.

High-Stability Film Resistor

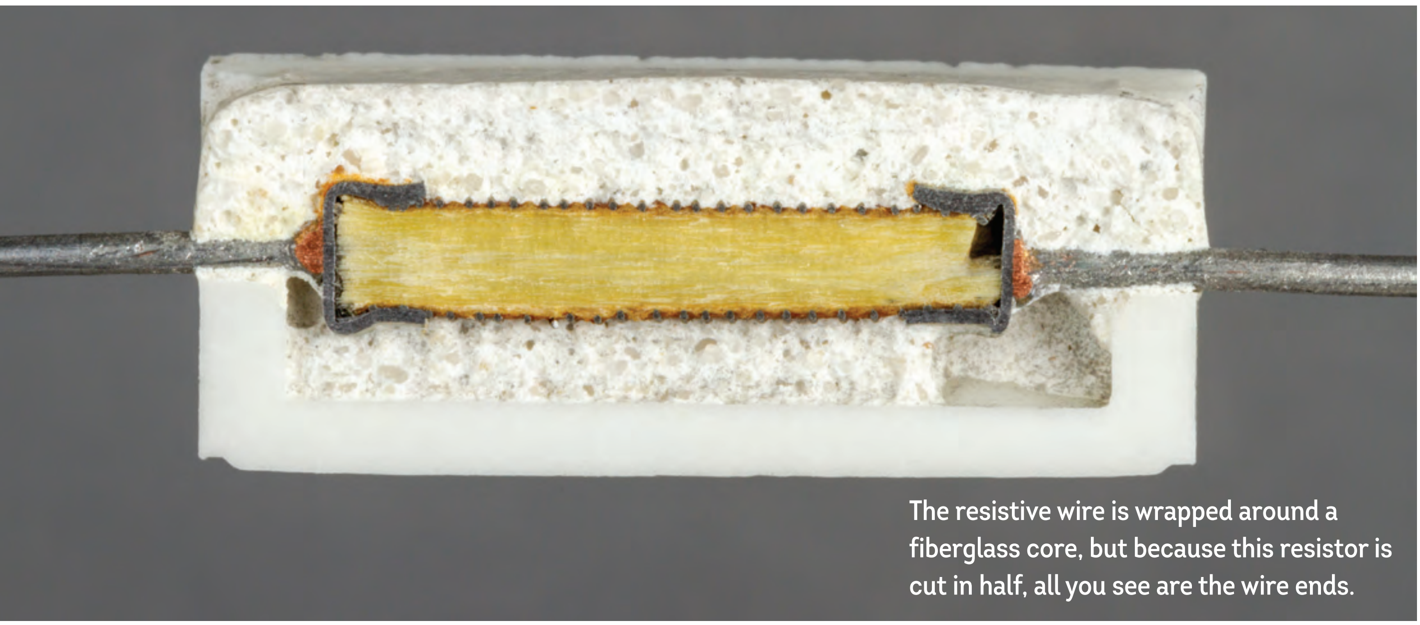
This **HIGH-STABILITY FILM RESISTOR**, about 4 mm in diameter, is made in much the same way as its inexpensive carbon film cousin, but with exacting precision. A ceramic rod is coated with a fine layer of resistive film (thin metal, metal oxide, or carbon) and then a perfectly uniform helical groove is machined into the film.

Instead of coating the resistor with an epoxy, it's hermetically sealed in a lustrous little glass envelope. This makes the resistor more robust, ideal for specialized cases such as precision reference instrumentation, where long-term stability of the resistor is critical. The glass envelope provides better isolation against moisture and other environmental changes than standard coatings like epoxy.

Wirewound Power Resistor

As current flows through a resistor, the resistor converts a certain amount of electrical energy into heat. Most general-purpose resistors have little ability to dissipate heat, as they cannot withstand elevated temperatures. This limits the amount of power they can handle.

POWER RESISTORS like this one are made without temperature-limiting materials like solder or epoxy, enabling them to handle more power. Some power supplies use them to limit the rush of current that occurs when you plug them in. The active element is a resistive metal wire wrapped around an insulating core. The resistive assembly is placed in a heat-tolerant ceramic shell and filled with cement grout.



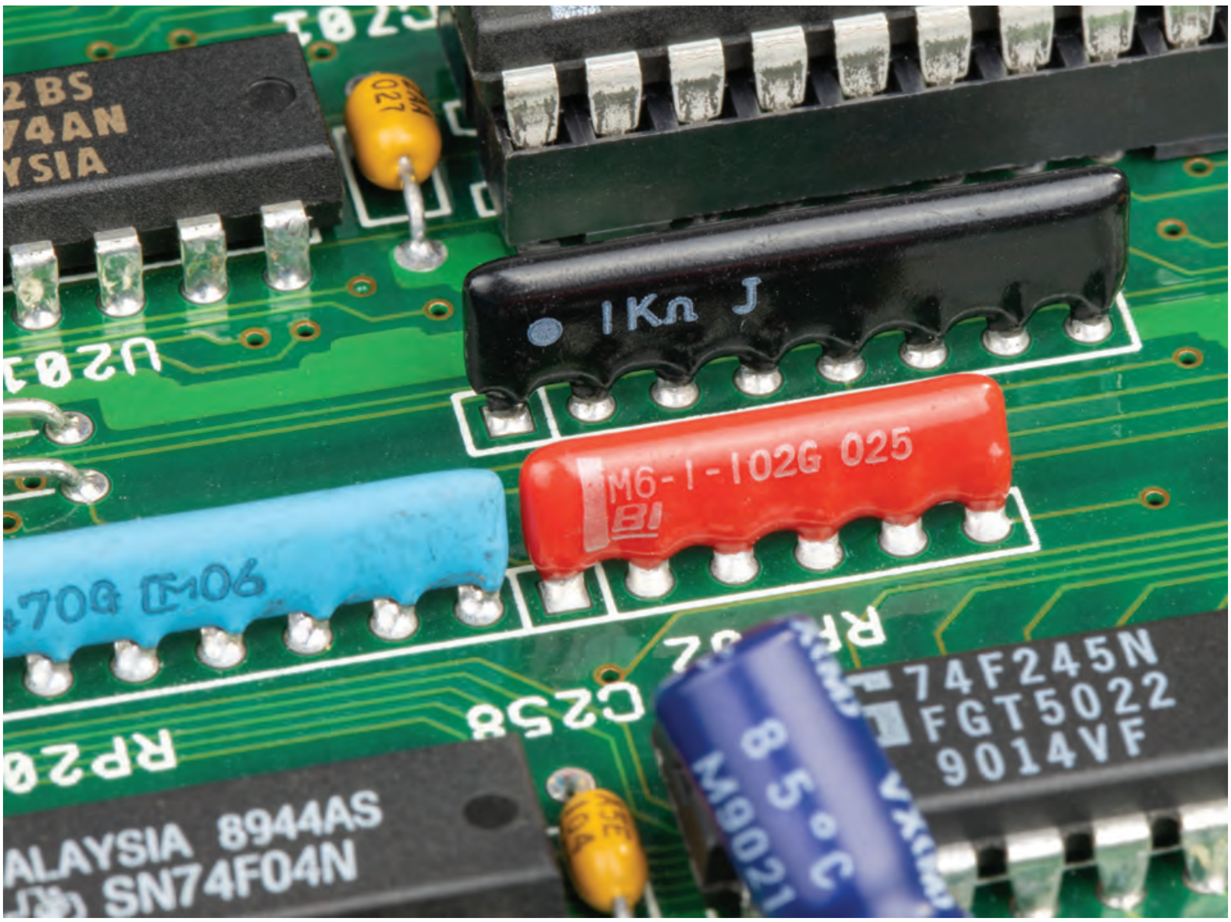
The resistive wire is wrapped around a fiberglass core, but because this resistor is cut in half, all you see are the wire ends.

Thick-Film Resistor Array

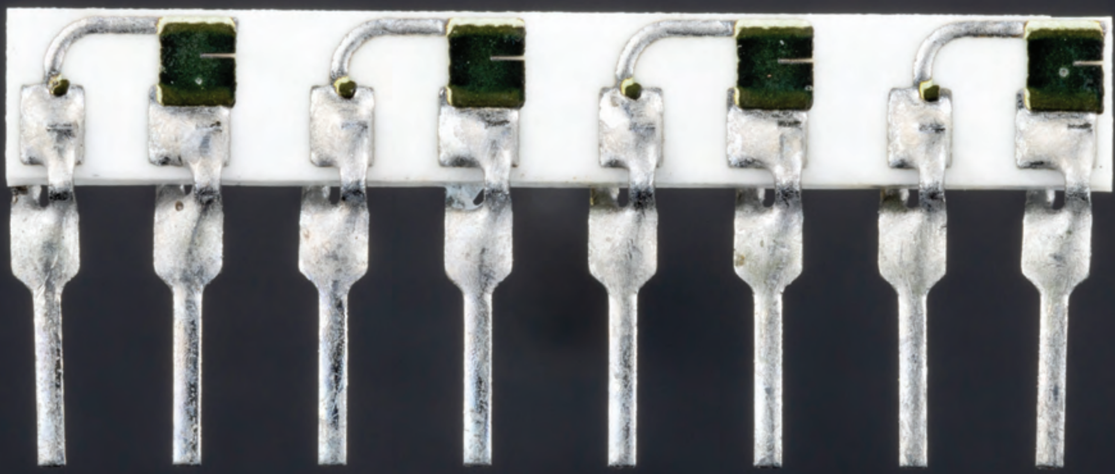
Many circuits require multiple identical resistors. For example, a digital data bus might need a **TERMINATION RESISTOR** connected in series with each data line, or each I/O pin on a microcontroller might need a **PULLDOWN RESISTOR** between the pin and ground. A resistor array eliminates the need for multiple discrete resistors: it consists of several resistors fabricated as a single component.

Shown here are **THICK-FILM ARRAYS**, named for the fabrication technology, which uses silkscreened conductive and resistive films that are fired like pottery glazes onto a ceramic substrate.

After metal terminal pins are fitted and soldered, a laser burns away part of the resistive material to fine-tune each individual resistor to its correct specification. Finally, the array is dipped in an epoxy coating for protection.



This is a *single in-line resistor array*, or *SIL*, where all the terminals are arranged in a straight line. It has four independent resistors that aren't connected to each other.

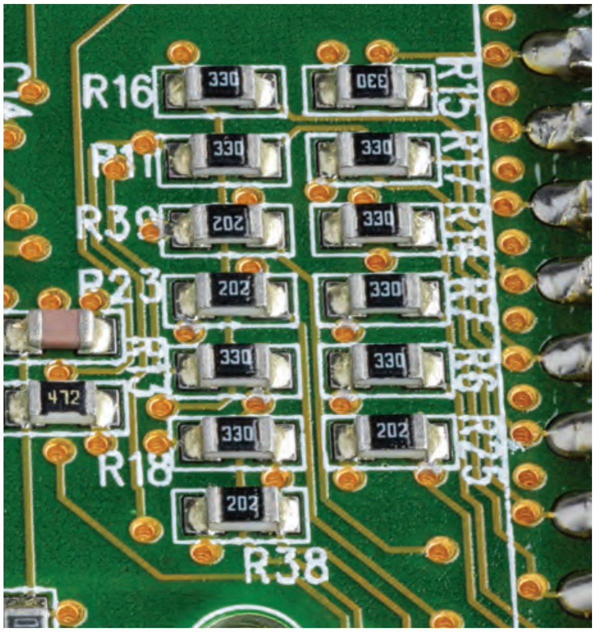


Straight cuts in the greenish resistive material mark the path of the trimming laser.

Surface-Mount Chip Resistor

The most common discrete resistors today are **THICK-FILM SURFACE-MOUNT RESISTORS**, also known as **CHIP RESISTORS** after their tidy rectangular packages, which lack wire leads. Billions of chip resistors are produced annually, and are found in every type of mass-produced consumer electronics.

These are **SURFACE-MOUNT** resistors, designed for soldering directly to the surface of a circuit board, as opposed to soldering wire leads that go through holes in the circuit board. They're constructed much like the resistors on thick-film arrays, right down to the laser trimming.



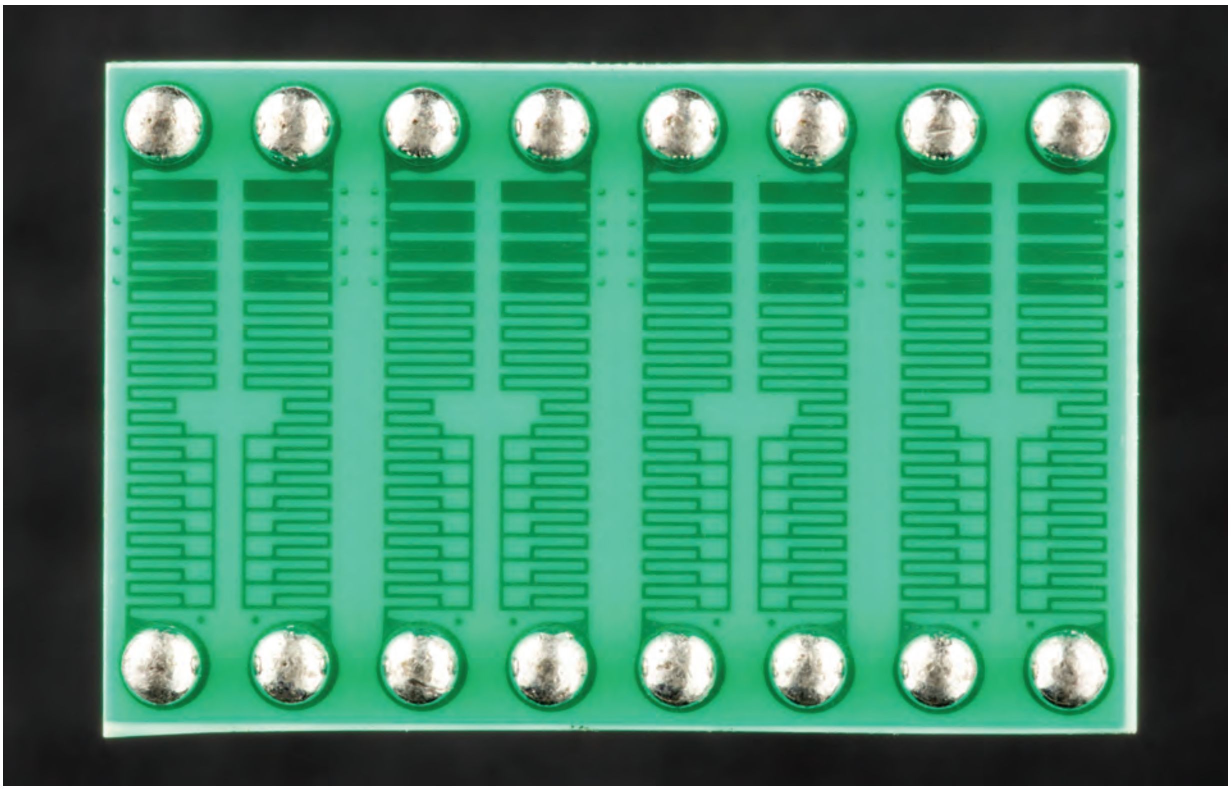
Several surface-mount chip resistors, with the epoxy coating peeled back to show the thick film element below

Thin-Film Resistor Array

THIN-FILM RESISTORS, such as the eight in this array, are precision devices manufactured by etching a pattern into an ultra-thin layer of **SPUTTERED** (vacuum deposited) metal oxide or **CERMET** (ceramic-metal composite). Thin-film arrays are used when a circuit requires precisely matched or calibrated resistors, such as for scientific or medical equipment.

Each serpentine track of resistive material has several areas that can be laser-trimmed to fine-tune the resistance value with increasing exactitude.

The solder ball terminals at the end of each resistor allow this array to be soldered directly to a circuit board.



Wirewound Potentiometer

A **POTENTIOMETER**, or **POT**, is an adjustable resistor. Pots are used as front panel control knobs on everything from laboratory instrumentation to guitar amplifiers—anything where you turn a knob to adjust a setting.

This large pot is made of resistive wire wrapped around a ceramic form, an old design, essentially unchanged since 1925 and still in production today.

There are two terminals connected to either end of the resistive wire and a third terminal connected to a spring-loaded contact called a **WIPER**. The wiper touches the wire windings, making an electrical connection that can be moved around by rotating the shaft.

As the wiper moves away from or toward a terminal, the resistance between the wiper and that terminal increases or decreases because electrical current has to flow through a different amount of resistive wire. An amplifier circuit translates this changing resistance into a louder volume, or a hot plate interprets it as a temperature set point.

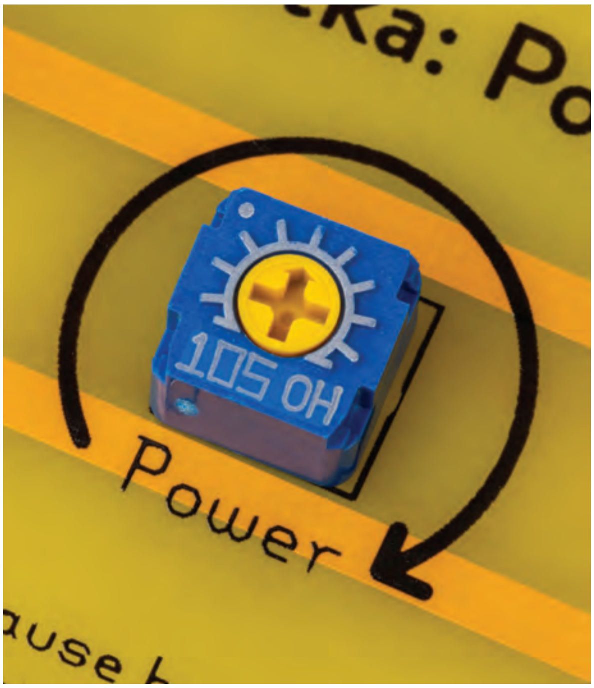
The wiper of a standard pot can be rotated about 2/3 to 3/4 of a turn, between the two fixed terminals.

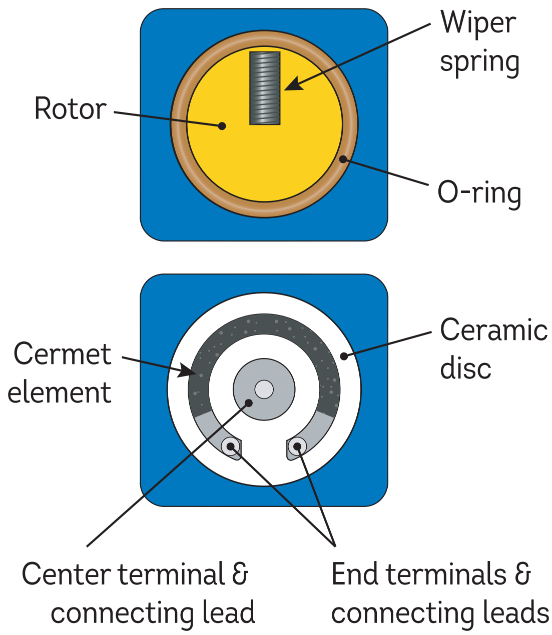
Most of the wrapped wire is covered with vitreous enamel, similar to a pottery glaze. Only the surface that contacts the wiper has exposed wire.

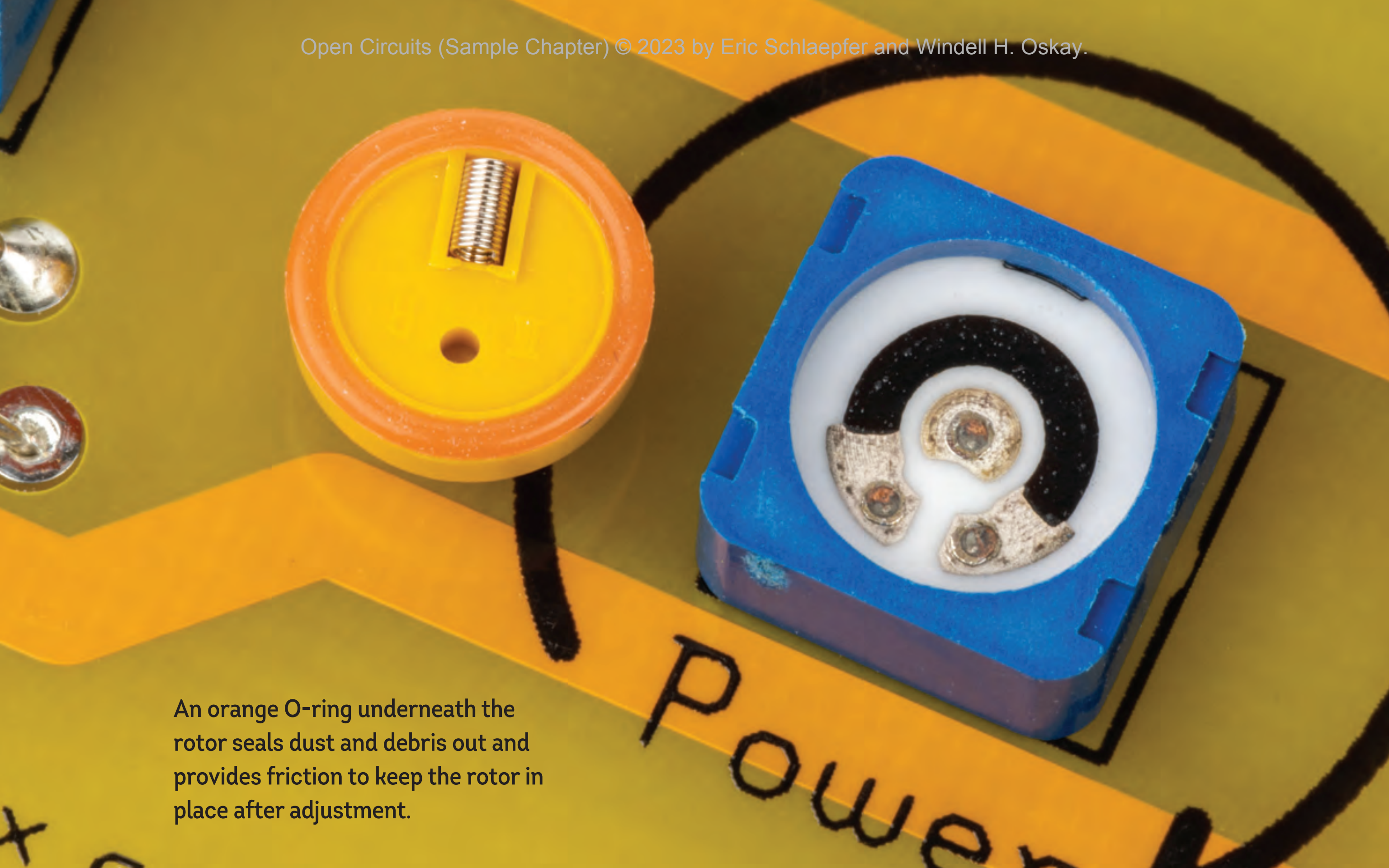
Trimmer Potentiometer

TRIMMER POTENTIOMETERS, often referred to by the trademark name **TRIMPOT**, aren't meant to be manipulated by the end user. Instead, they're designed for initial calibration and rare adjustment. You can find them in precision electronics that require fine-tuning at the factory or by service technicians. The typical service life of a trimmer is only a few hundred adjustments.

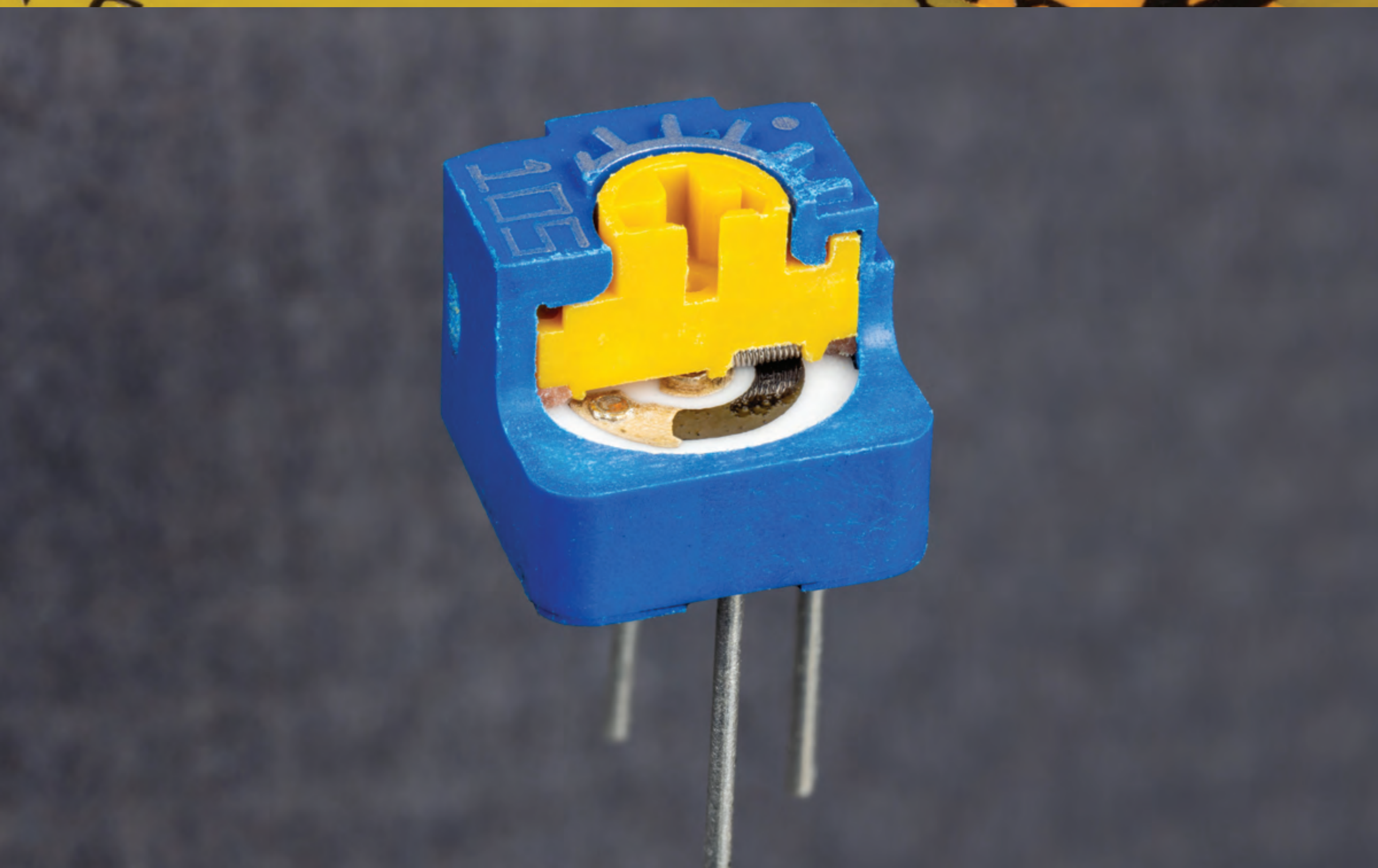
This colorful trimmer has a horseshoe-shaped section of resistive cermet film instead of a coil of wire. From the outside, you use a plastic adjustment tool or a screwdriver to turn the yellow plastic rotor. Inside, the rotor moves a flexible metal spring that acts as the wiper, connecting the center terminal to the resistive cermet film, changing the resistance between that center terminal and the two other terminals.







An orange O-ring underneath the rotor seals dust and debris out and provides friction to keep the rotor in place after adjustment.

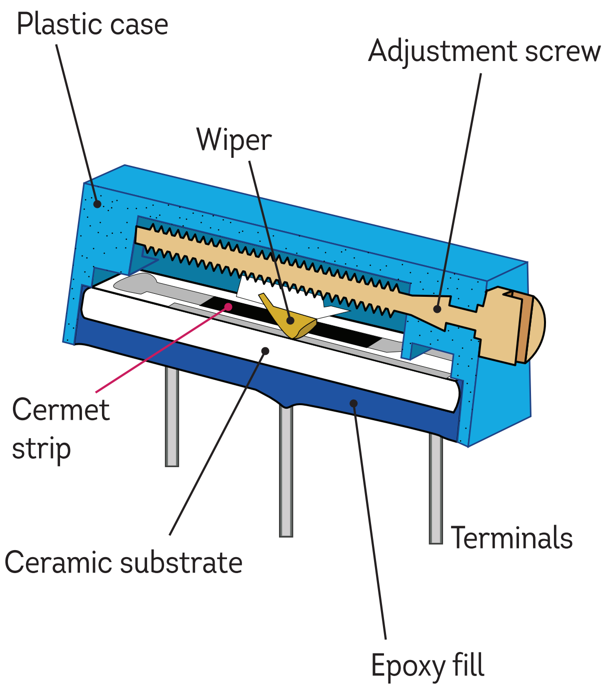


15-Turn Trimmer Potentiometer

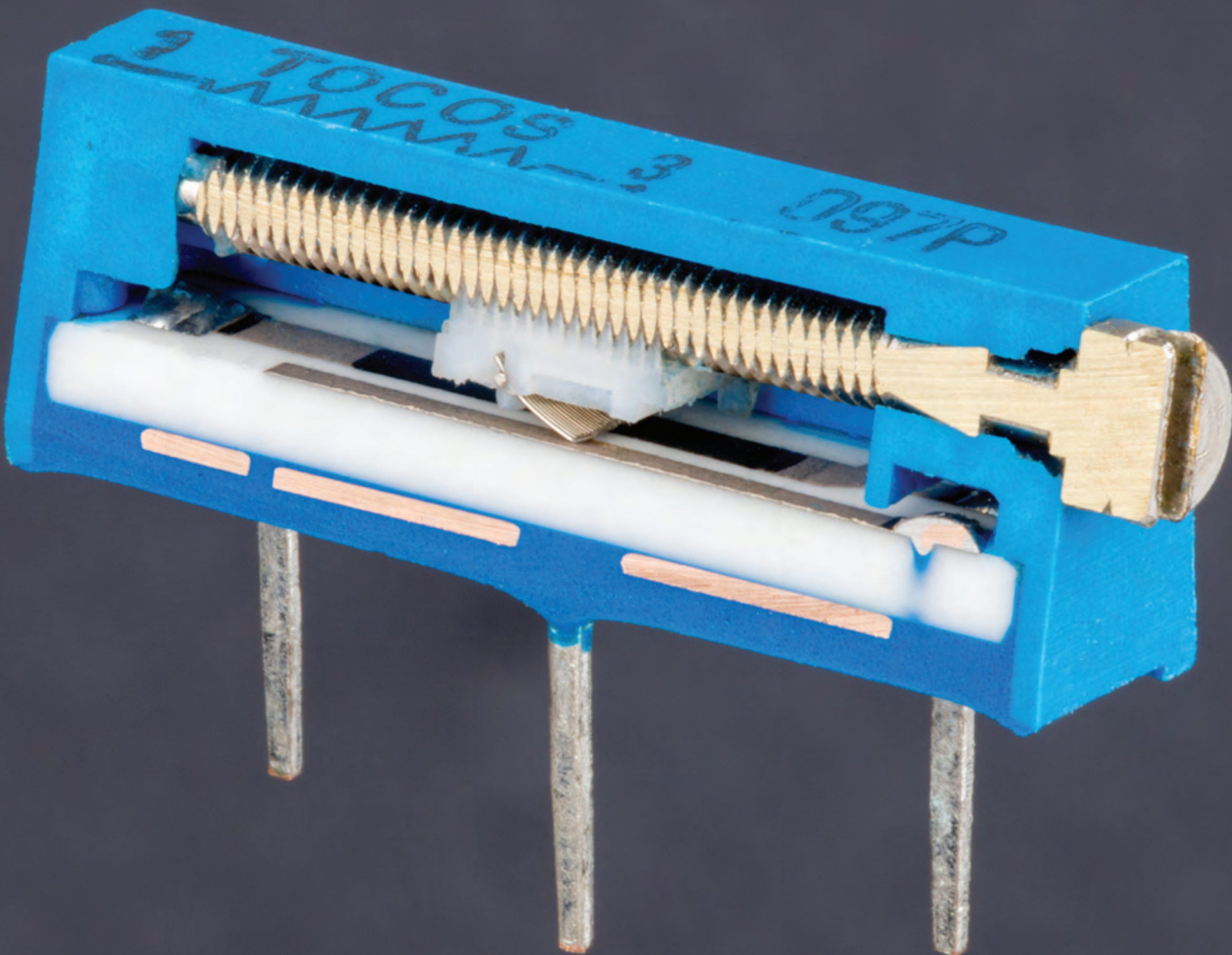
It takes 15 rotations of an adjustment screw to move a 15-turn trimmer potentiometer from one end of its resistive range to the other. Circuits that need to be adjusted with fine resolution control use this type of trimmer pot instead of the single-turn variety.

The resistive element in this trimmer is a strip of cermet silkscreened on a white ceramic substrate. Screen-printed metal links each end of the strip to the connecting wires. It's a flattened, linear version of the horseshoe-shaped resistive element in single-turn trimmers.

Turning the adjustment screw moves a plastic slider along a track. The wiper is a **SPRING FINGER**, a spring-loaded metal contact, attached to the slider. It makes contact between a metal strip and the selected point on the strip of resistive film.



While it isn't obvious from the outside of the device, the adjustment screw is electrically insulated from all three pins of the component.

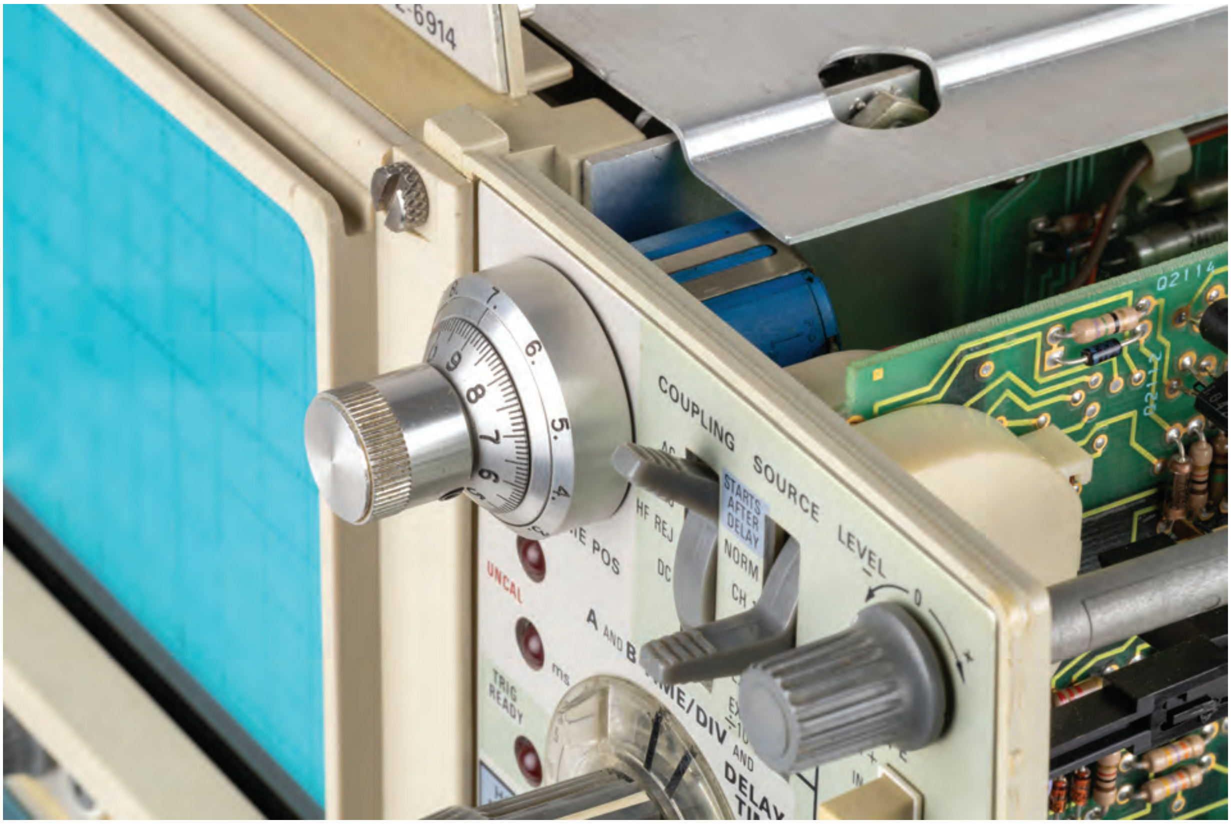


10-Turn Potentiometer

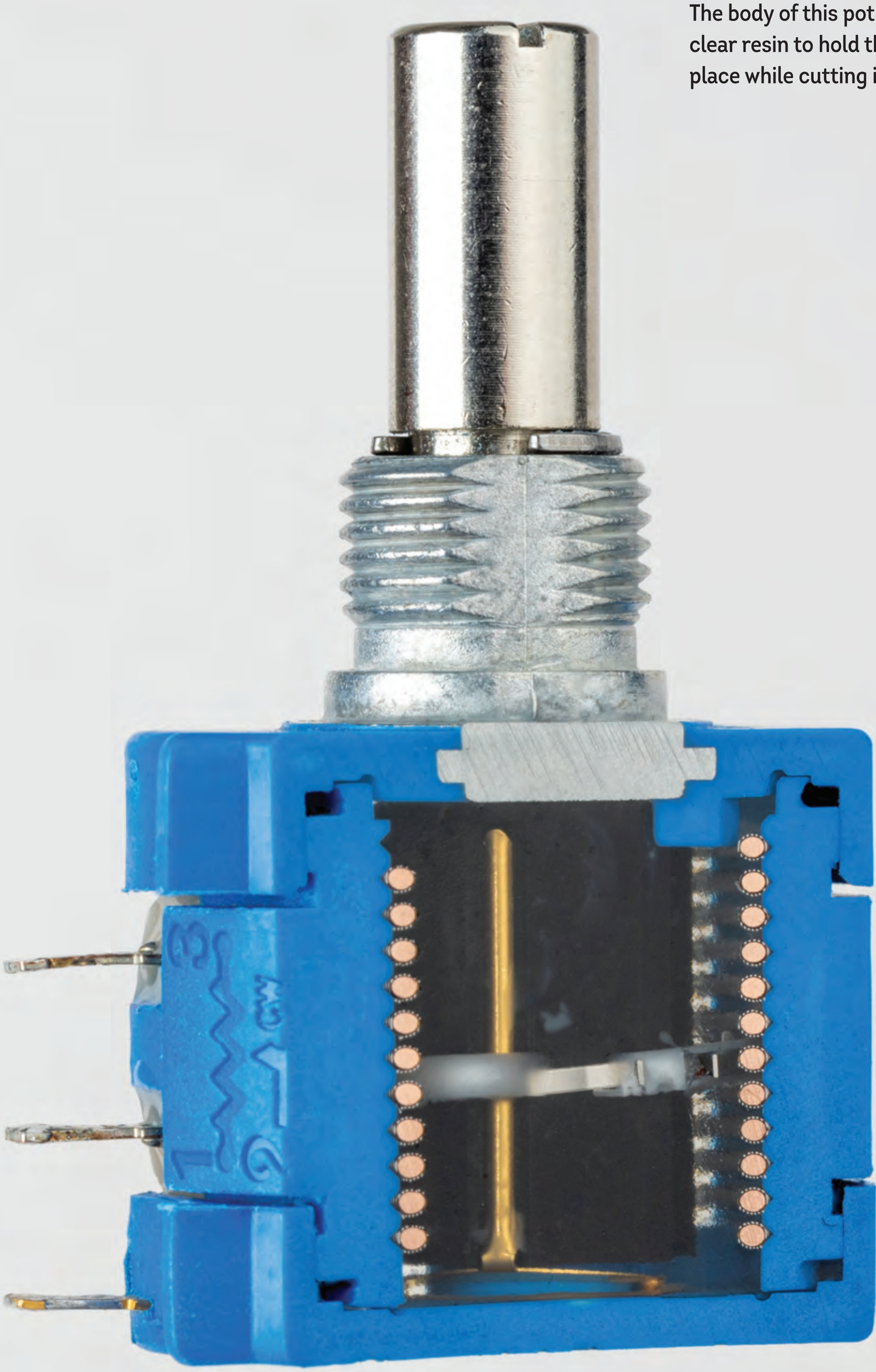
A 10-turn potentiometer is much like a wirewound pot, but its adjustment range is 10 full turns instead of less than one turn. This is a specialized device, occasionally found as an input knob on sensitive instruments where high adjustment resolution is required.

The wiper on a 10-turn pot keeps continuous contact with a helical track, moving up or down as the shaft is rotated. The track consists of resistive wire tightly wrapped around an insulated copper form. The wire ends connect to two of the terminals.

The connection between the wiper and the third terminal is through a vertical strip of brass that rotates with the shaft. As the wiper moves up and down, it maintains contact with the strip through a spring finger. Another spring finger keeps contact between the brass strip and the third terminal as the strip rotates.



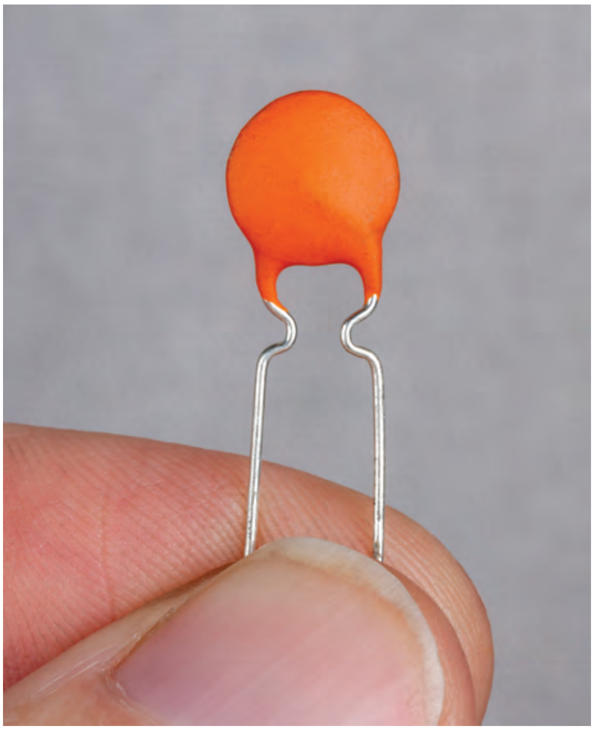
The body of this pot was filled with clear resin to hold the contents in place while cutting it open.

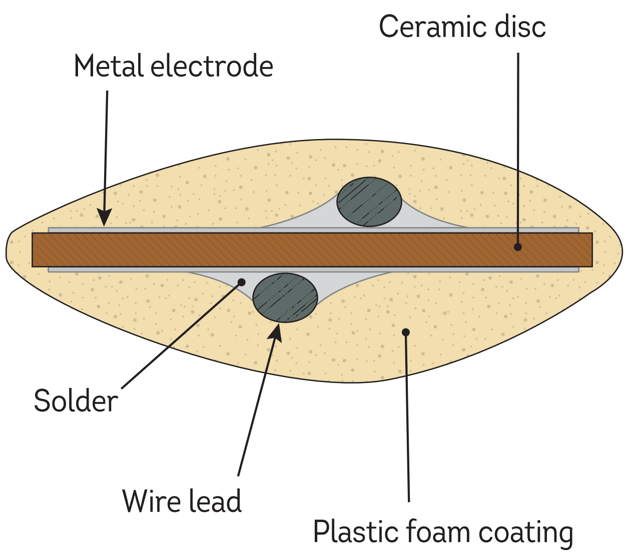


Ceramic Disc Capacitor

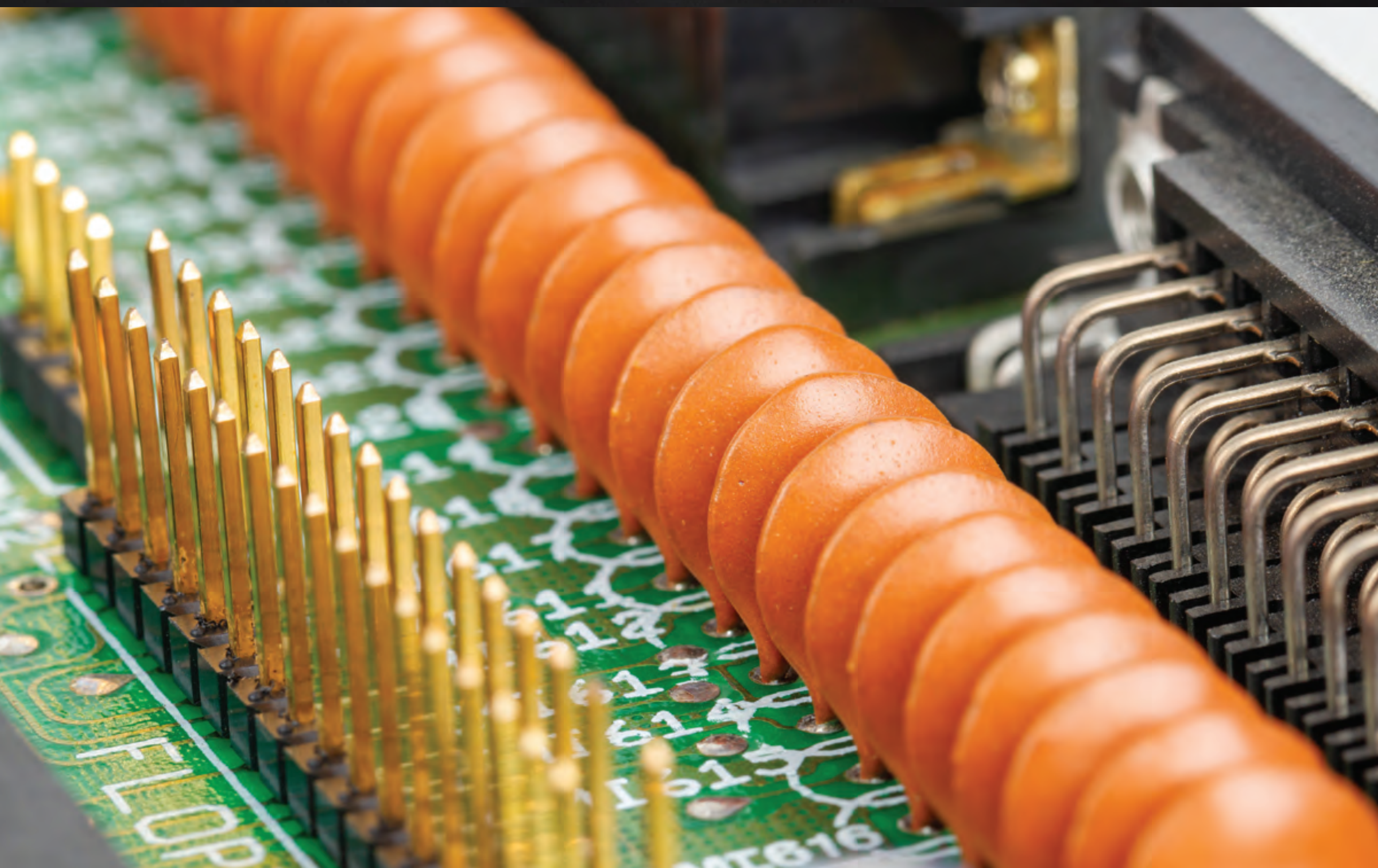
CAPACITORS are fundamental electronic components that store energy in the form of static electricity. They're used in countless ways, including for bulk energy storage, to smooth out electronic signals, and as computer memory cells. The simplest capacitor consists of two parallel metal plates with a gap between them, but capacitors can take many forms so long as there are two conductive surfaces, called **ELECTRODES**, separated by an insulator.

A ceramic disc capacitor is a low-cost capacitor that is frequently found in appliances and toys. Its insulator is a ceramic disc, and its two parallel plates are extremely thin metal coatings that are evaporated or sputtered onto the disc's outer surfaces. Connecting wires are attached using solder, and the whole assembly is dipped into a porous coating material that dries hard and protects the capacitor from damage.





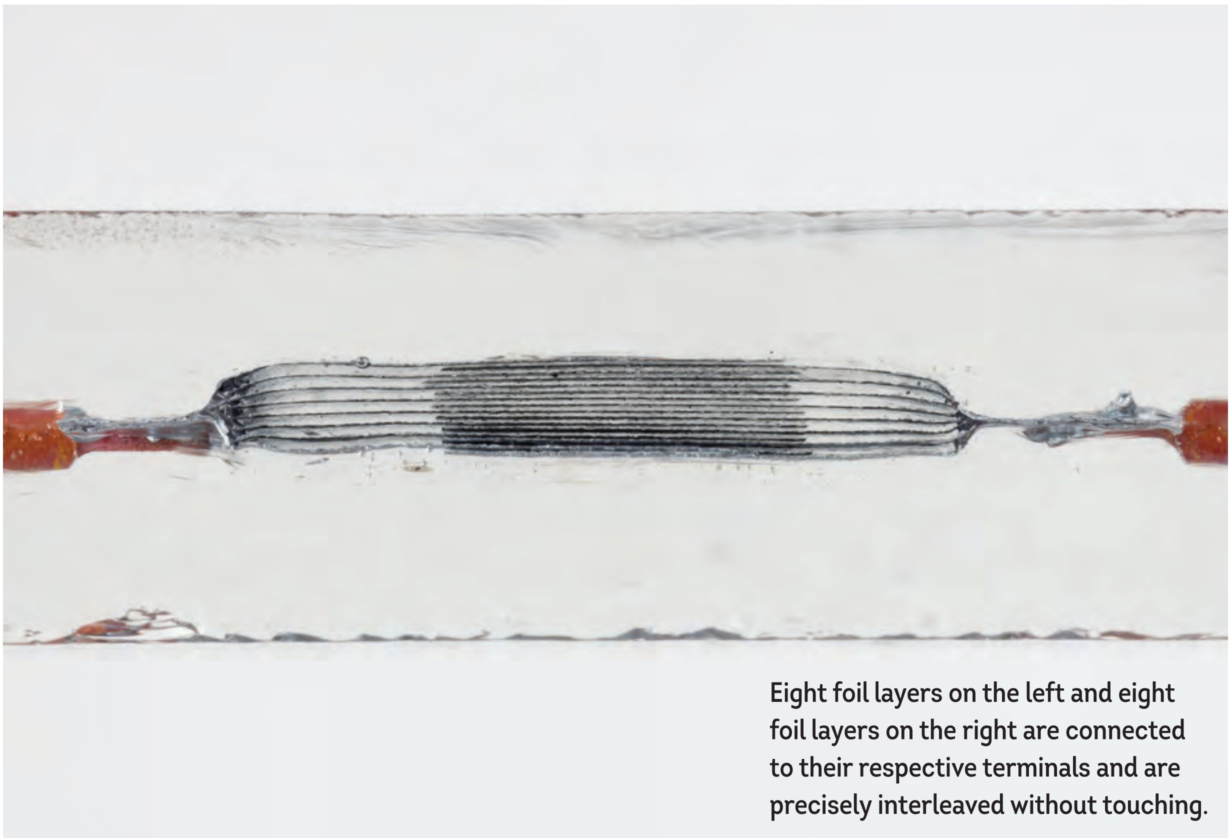
The metal layers on the surfaces of the ceramic disc are so thin that it can be hard to see them in cross section.



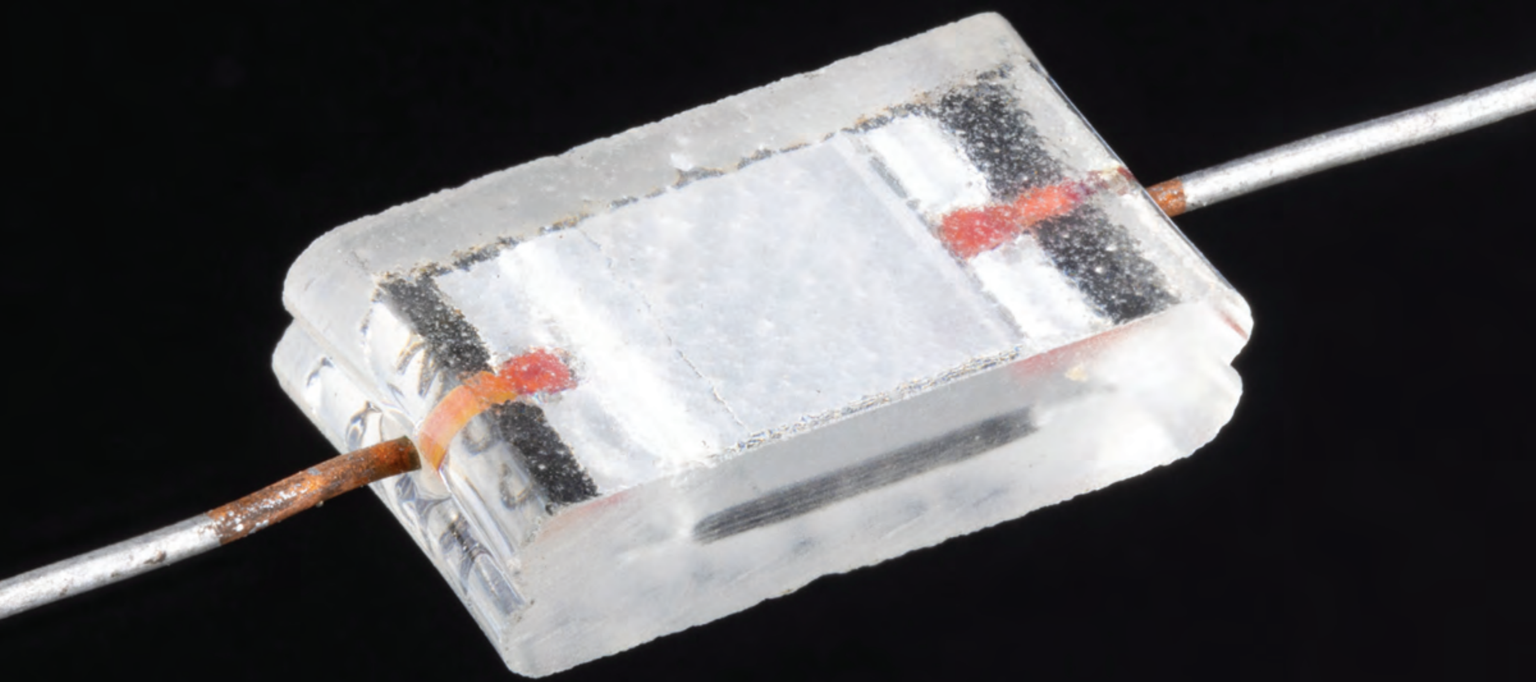
Glass Capacitor

A capacitor's amount of **CAPACITANCE**—the electric charge it can store at a given voltage—depends on the surface area of the conductive plates, how close together they are, and the type of insulator used between them. The insulator is called a **DIELECTRIC**. While almost any insulator—even air—can be used as a dielectric, certain materials provide far more capacitance than an air gap would.

This glass-packaged capacitor has multiple sets of aluminum foil plates interdigitated with each other. This layered arrangement augments the available surface area and increases the capacitance. Thin layers of glass, an excellent insulator, function as the dielectric.



Eight foil layers on the left and eight foil layers on the right are connected to their respective terminals and are precisely interleaved without touching.



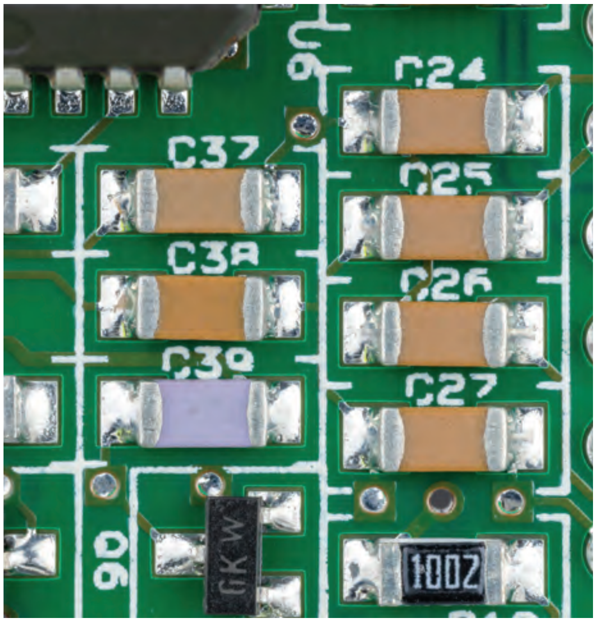
For robustness, the same type of glass used between the foil layers is also used as the outer packaging of the device, about 5 mm thick.

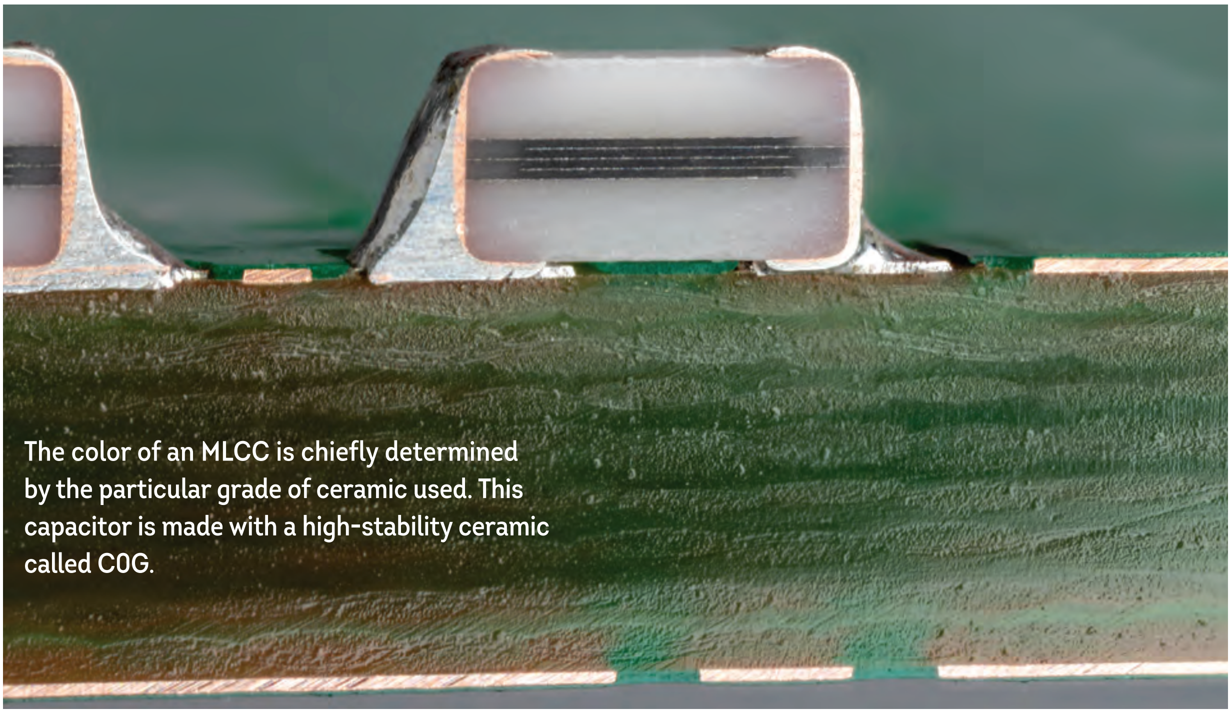
Multilayer Ceramic Capacitor

MULTILAYER CERAMIC CAPACITORS (MLCCs) are the single most common discrete electronic component in production today; a smartphone may contain hundreds, most of which are used to ensure power supply stability at different points in the circuitry.

MLCCs are surface-mount **CHIP CAPACITORS**, consisting of interleaved layers of deposited metal between layers of specialized ceramic.

The one shown here in cross section is 1.5 mm long and has five interleaved metal layers, with two layers connected to one terminal and three to the other. Other MLCCs with different properties may have thousands of layers in a device of the same size.



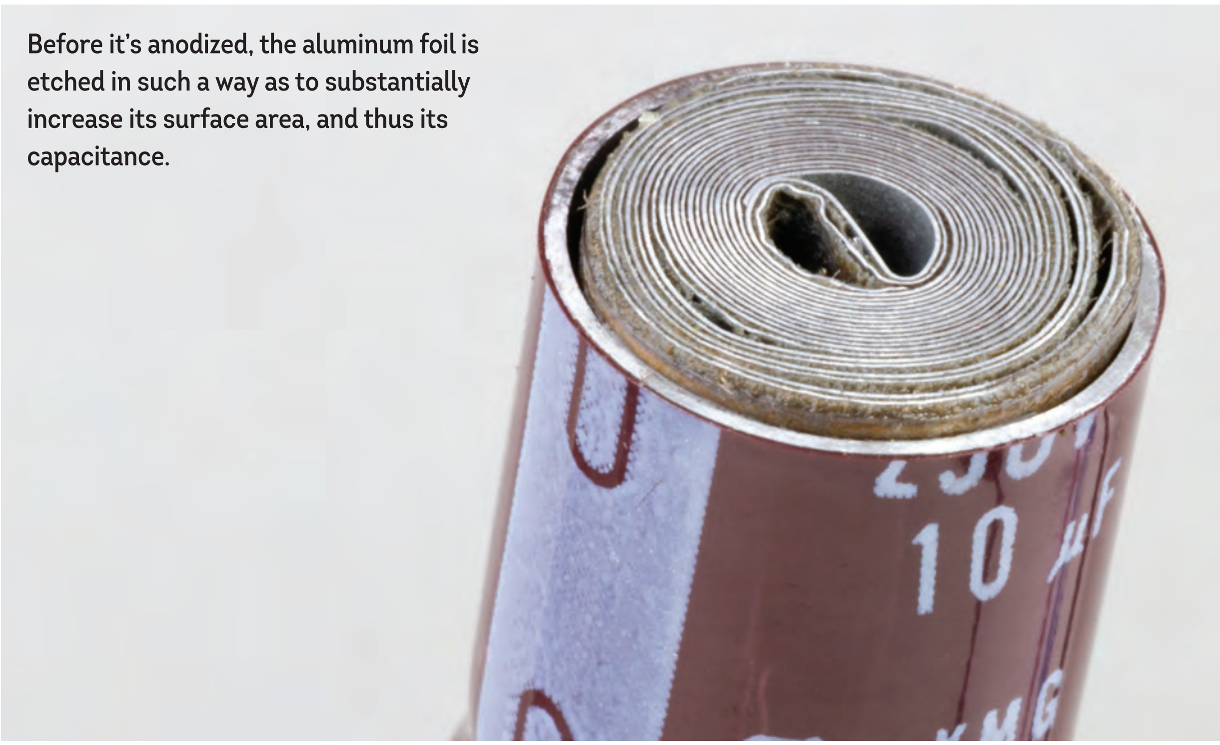


The color of an MLCC is chiefly determined by the particular grade of ceramic used. This capacitor is made with a high-stability ceramic called C0G.

Aluminum Electrolytic Capacitor

ALUMINUM ELECTROLYTIC CAPACITORS pack a large amount of capacitance into a small space, and are very common in power supplies. The outer metal can is filled with an **ELECTROLYTE**—an electrically conductive fluid. The fluid itself serves as one of the capacitor's conductive surfaces. The other is a long, thin, rolled-up strip of aluminum foil submerged in the fluid.

The aluminum foil is **ANODIZED**, producing an aluminum oxide on its surface that acts as the dielectric between the foil and the fluid. A second rolled-up aluminum foil strip, separated from the first by paper insulators, serves as a terminal, connecting the fluid to the wire leads.



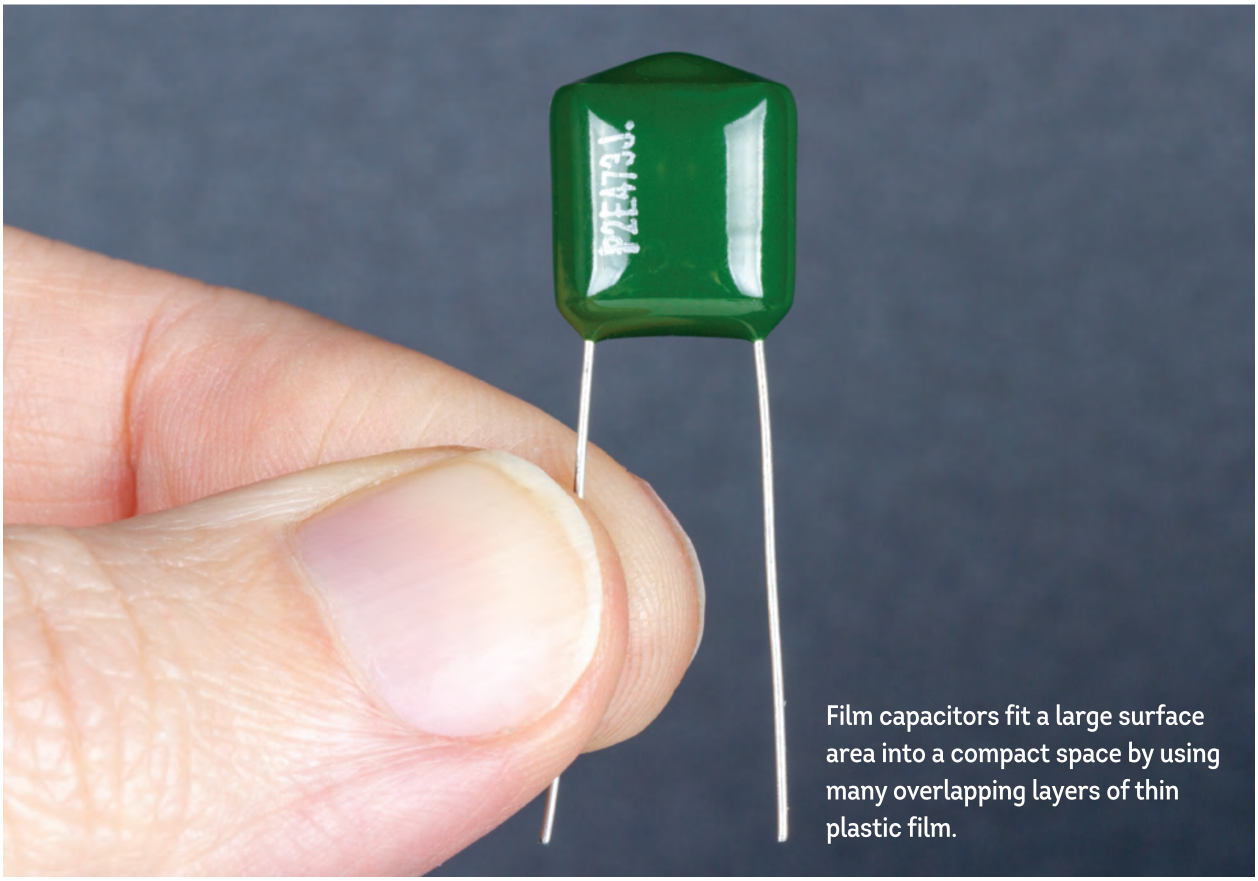
Before it's anodized, the aluminum foil is etched in such a way as to substantially increase its surface area, and thus its capacitance.

Film Capacitor

FILM CAPACITORS are frequently found in high-quality audio equipment, such as headphone amplifiers, record players, graphic equalizers, and radio tuners. Their key feature is that the dielectric material is a plastic film, such as polyester or polypropylene.

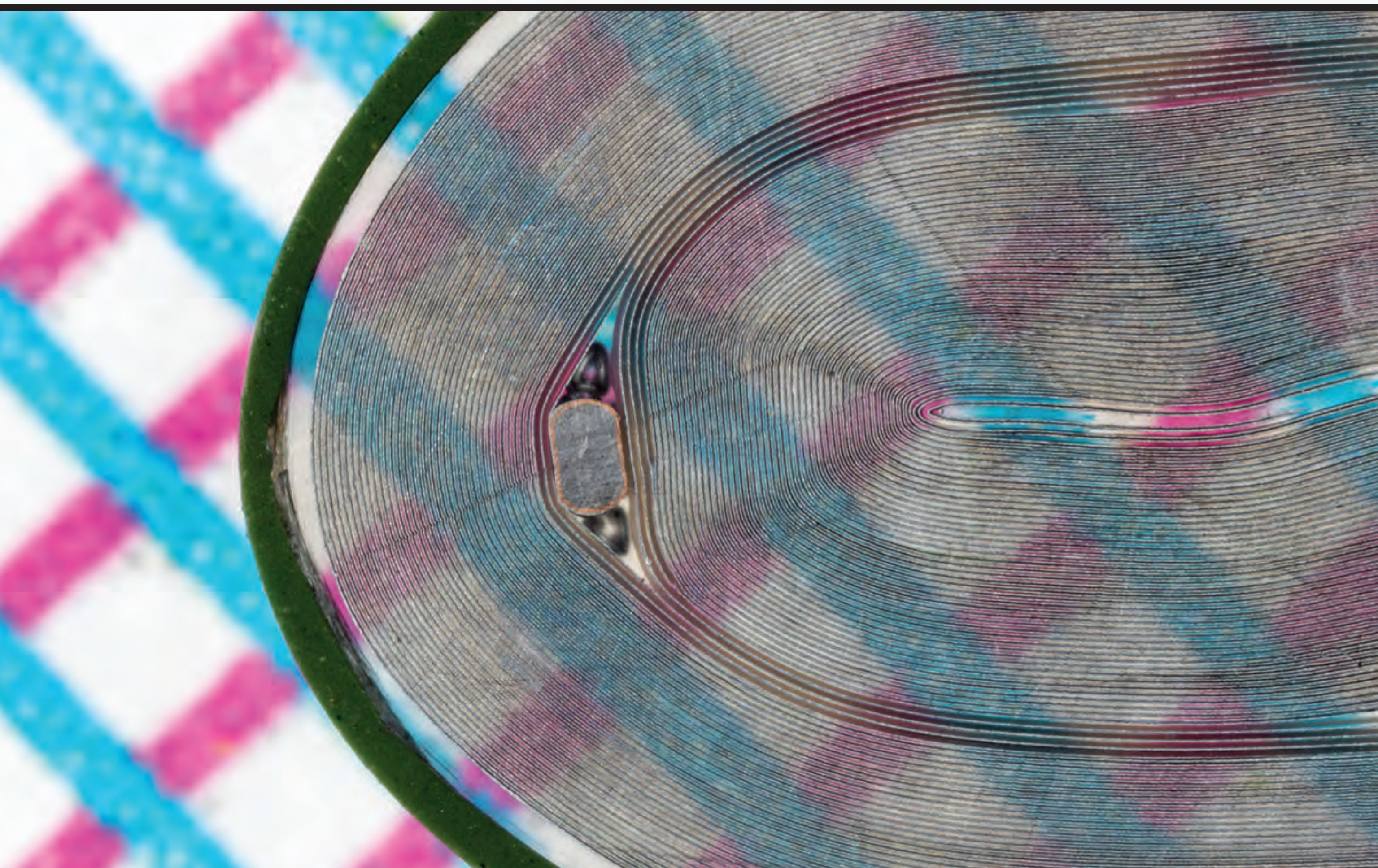
The metal electrodes of this film capacitor are vacuum-deposited on the surfaces of long strips of plastic film. After attaching leads, the films are rolled up and dipped into an epoxy that binds the assembly together. Then the completed assembly is dipped in a tough outer coating and marked with its value.

Other types of film capacitors are made by stacking flat layers of metalized plastic film, rather than rolling up layers of film.



Film capacitors fit a large surface area into a compact space by using many overlapping layers of thin plastic film.

The plastic film is transparent and remarkably thin.

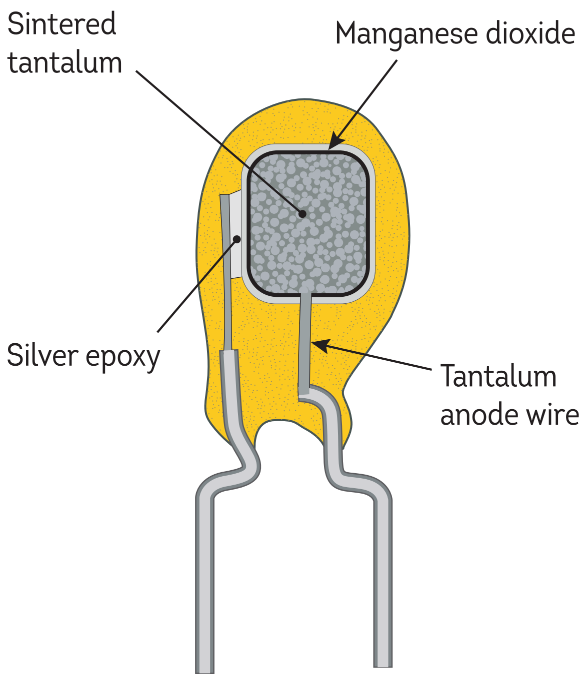


Dipped Tantalum Capacitor

At the core of this capacitor is a porous pellet of tantalum metal. The pellet is made from tantalum powder and sintered, or compressed at a high temperature, into a dense, sponge-like solid.

Just like a kitchen sponge, the resulting pellet has a high surface area per unit volume. The pellet is then anodized, creating an insulating oxide layer with an equally high surface area. This process packs a lot of capacitance into a compact device, using sponge-like geometry rather than the stacked or rolled layers that most other capacitors use.

The device's positive terminal, or **ANODE**, is connected directly to the tantalum metal. The negative terminal, or **CATHODE**, is formed by a thin layer of conductive manganese dioxide coating the pellet.

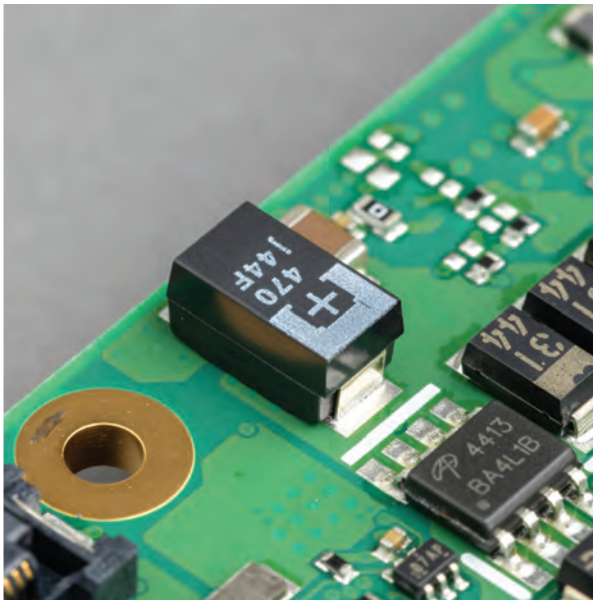


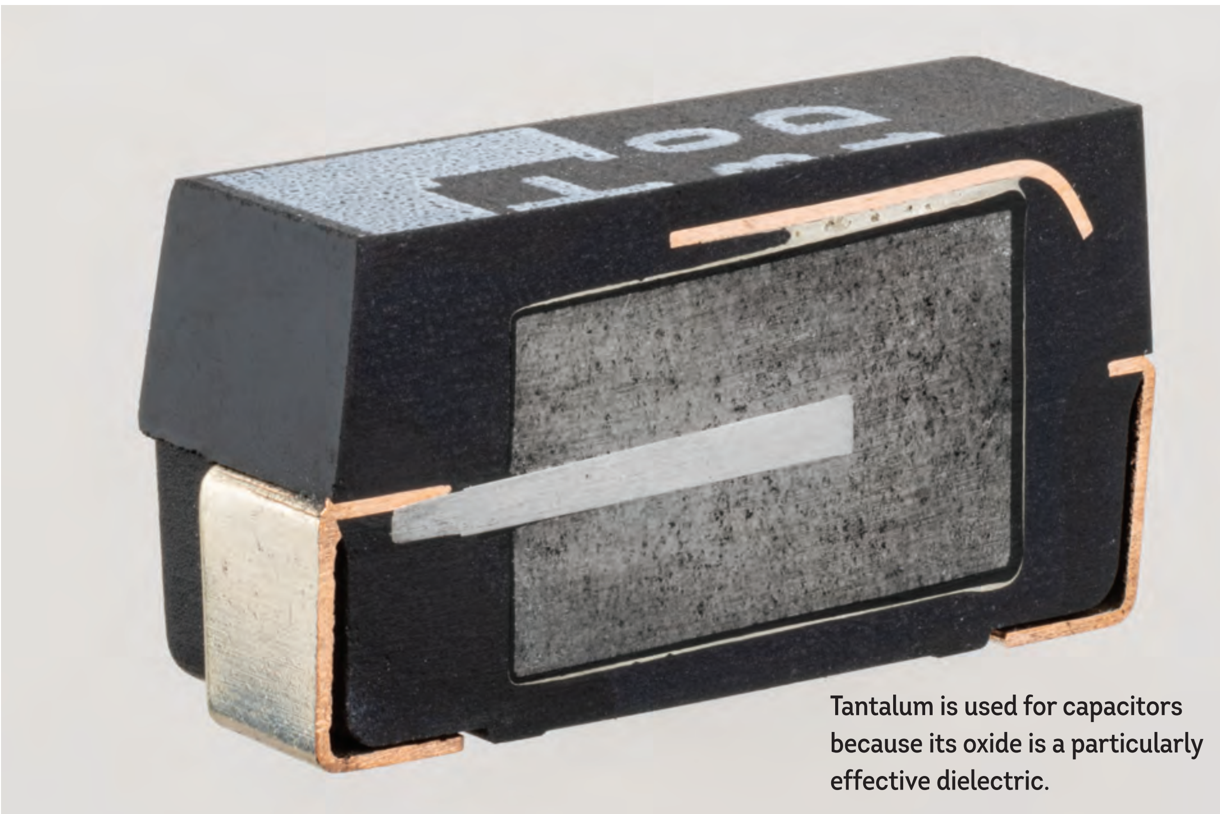
Connecting a tantalum capacitor backward causes chemical changes that damage the thin oxide layer. The label on the dipped plastic coating indicates the anode lead with "++."

Polymer Tantalum Chip Capacitor

POLYMER TANTALUM CHIP CAPACITORS are closely related to dipped tantalum capacitors. They're similarly based around an oxidized slug of tantalum metal with a high surface area. The slug is coated with a conductive polymer electrolyte, which flows into all its irregularities. Layers of carbon and silver paste connect the polymer to the cathode terminal.

The component is packaged in a molded epoxy case. It has tin-plated terminals for soldering to a circuit board. As a polarized device, it's labeled with both its value and a mark to indicate the anode.





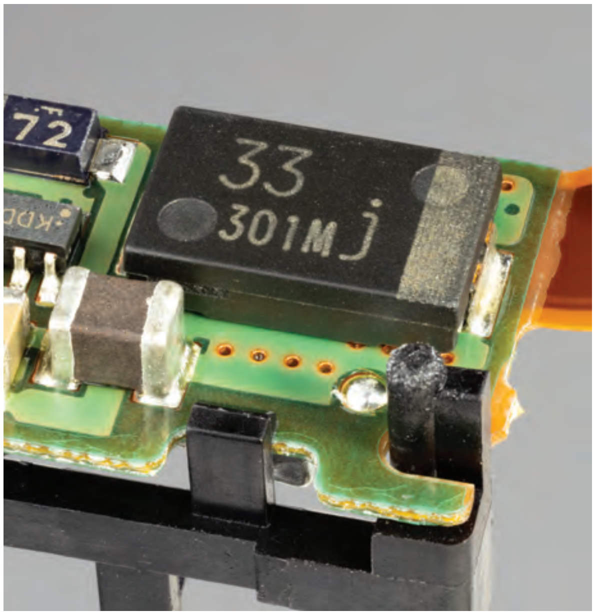
Tantalum is used for capacitors because its oxide is a particularly effective dielectric.

Polymer Aluminum Chip Capacitor

POLYMER ALUMINUM CHIP CAPACITORS are directly descended from standard electrolytic capacitors, despite how different they look both inside and out.

Instead of being rolled up, the etched and oxidized aluminum foils are laid flat and bonded together. And instead of a liquid electrolyte, this capacitor uses a conductive polymer as the cathode.

This newer style of capacitor is commonly found in smartphones, tablets, and laptops. Its popularity comes in part from its low profile, which allows it to fit where taller electrolytic caps cannot.



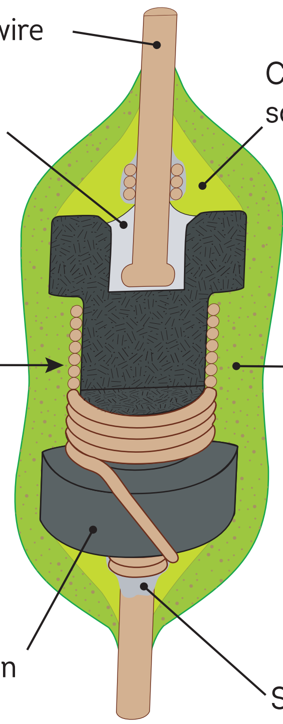
Layers of black conductive carbon paste and silver epoxy provide the electrical connection between the polymer-coated aluminum foils and the cathode terminal.

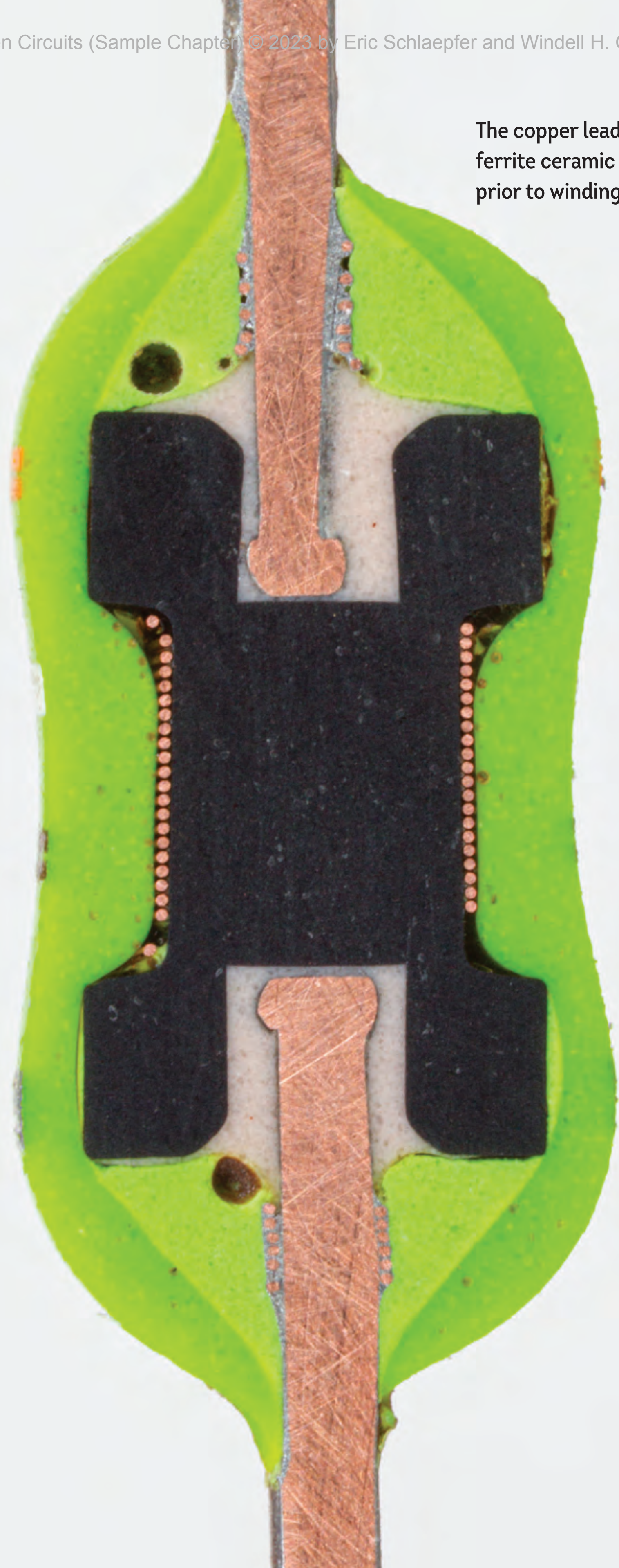
Axial Inductor

INDUCTORS are fundamental electronic components that store energy in the form of a magnetic field. They're used, for example, in some types of power supplies to convert between voltages by alternately storing and releasing energy. This energy-efficient design helps maximize the battery life of cellphones and other portable electronics.

Inductors typically consist of a coil of insulated wire wrapped around a core of magnetic material like iron or **FERRITE**, a ceramic filled with iron oxide. Current flowing around the core produces a magnetic field that acts as a sort of flywheel for current, smoothing out changes in the current as it flows through the inductor.

This axial inductor has a number of turns of varnished copper wire wrapped around a ferrite form and soldered to copper leads on its two ends. It has several layers of protection: a clear varnish over the windings, a light-green coating around the solder joints, and a striking green outer coating to protect the whole component and provide a surface for the colorful stripes that indicate its **INDUCTANCE** value.

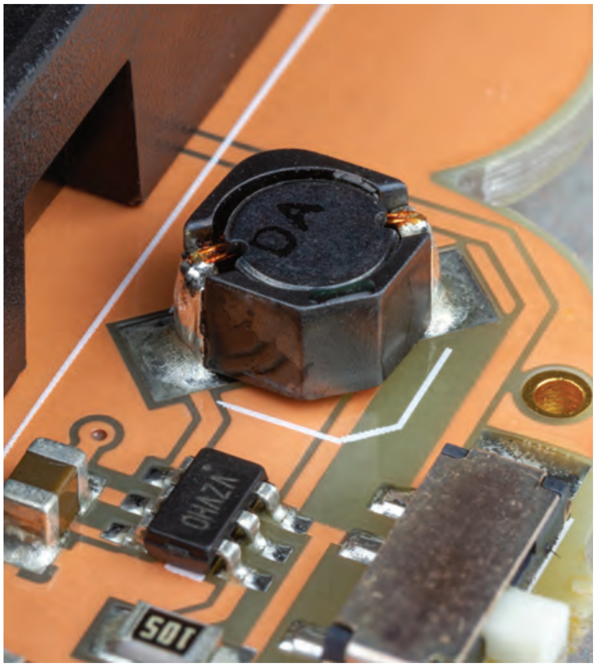




The copper leads are attached to the ferrite ceramic core with beige epoxy prior to winding the copper wire.

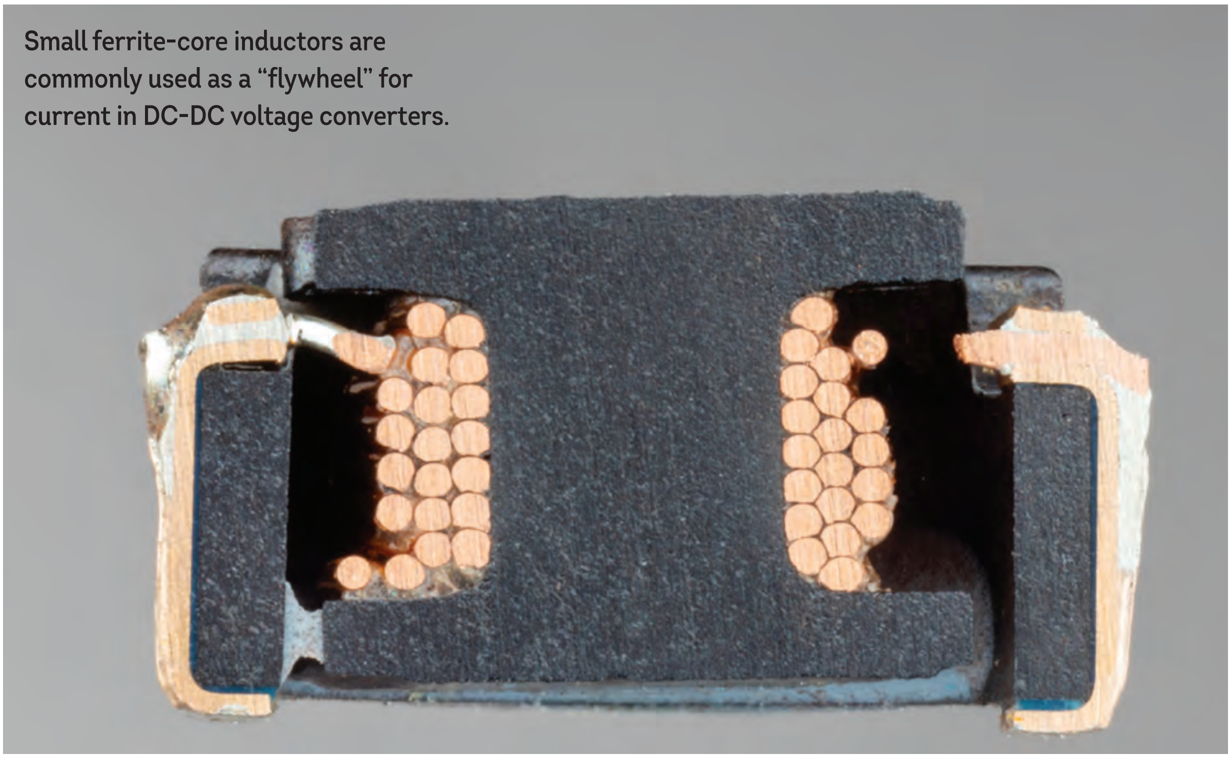
Surface-Mount Inductor

This surface-mount inductor, only 5 mm across, is designed to be compact, inexpensive, and easy for automated equipment to solder. You'd find it in cellphones, tablets, and laptops.



While axial inductors have wire leads that go through the circuit board, this inductor has terminals that sit directly atop the circuit for soldering.

The inductor has fine coils of varnished copper wire called **MAGNET WIRE** wound around a ferrite ceramic bobbin. The assembled core is placed inside another piece of ferrite to shield it from stray magnetic fields.

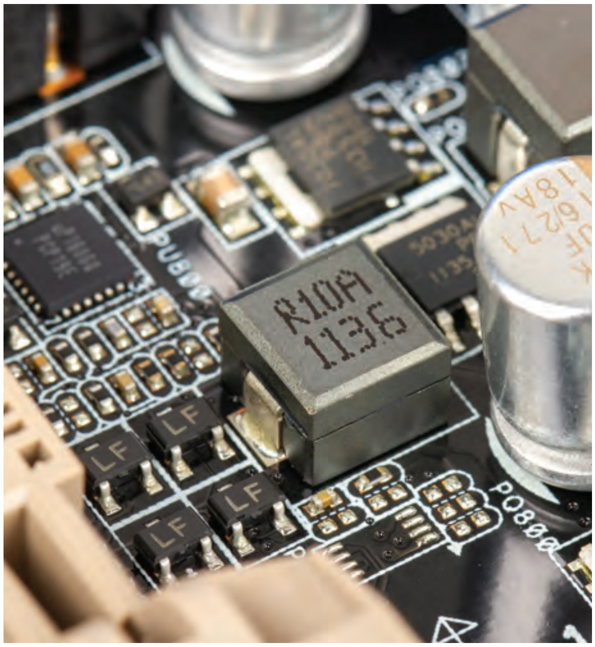


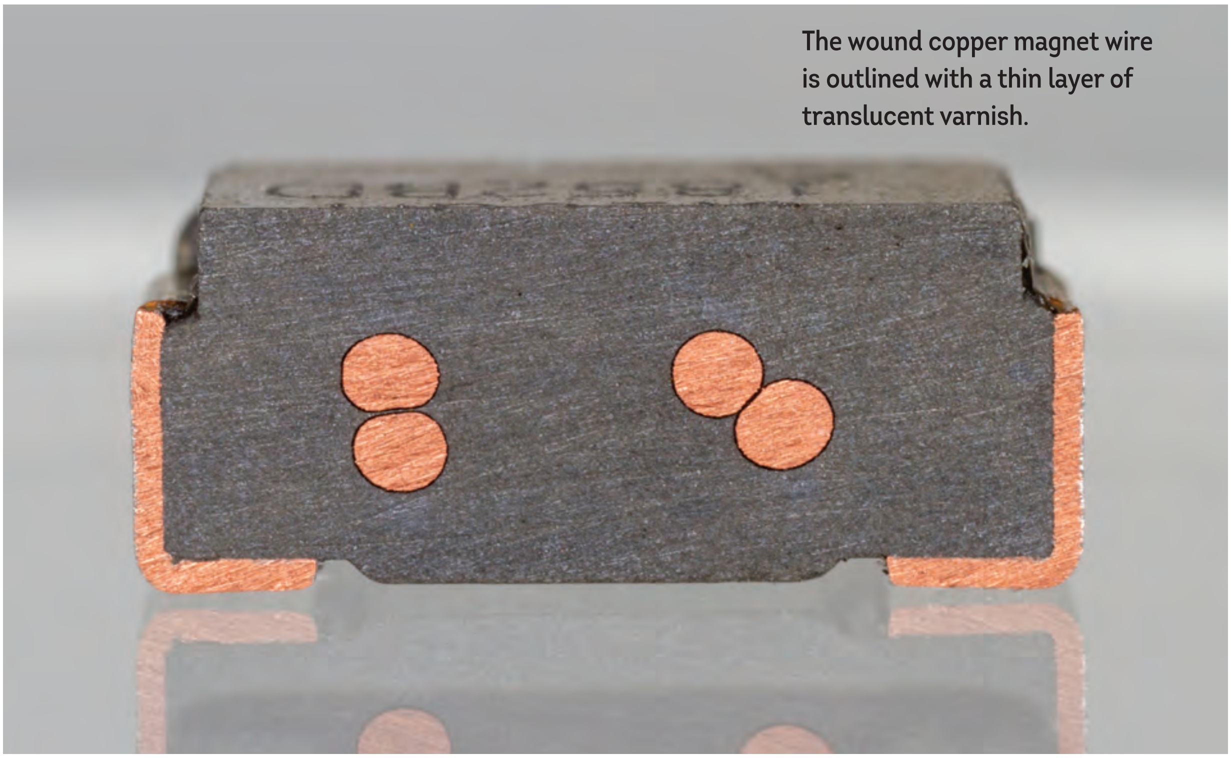
Small ferrite-core inductors are commonly used as a "flywheel" for current in DC-DC voltage converters.

Sintered Ferrite Inductor

This inductor, about 6 mm wide, has only two loops of copper wire. While we can't see it, the two ends of the looped wire are connected to the copper terminals on the left and right.

Unlike the other surface mount inductor, this inductor's copper windings appear suspended inside the solid ferrite as if by magic. It was manufactured in a sintering process: a fine ferrite powder was compressed into its final shape around the windings. Look closely and you'll see the copper windings have been pushed up against each other and deformed slightly as a result of this process.



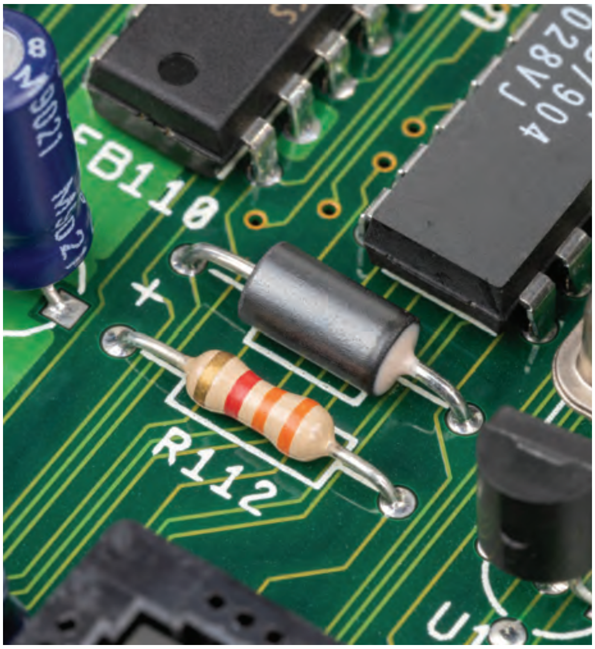


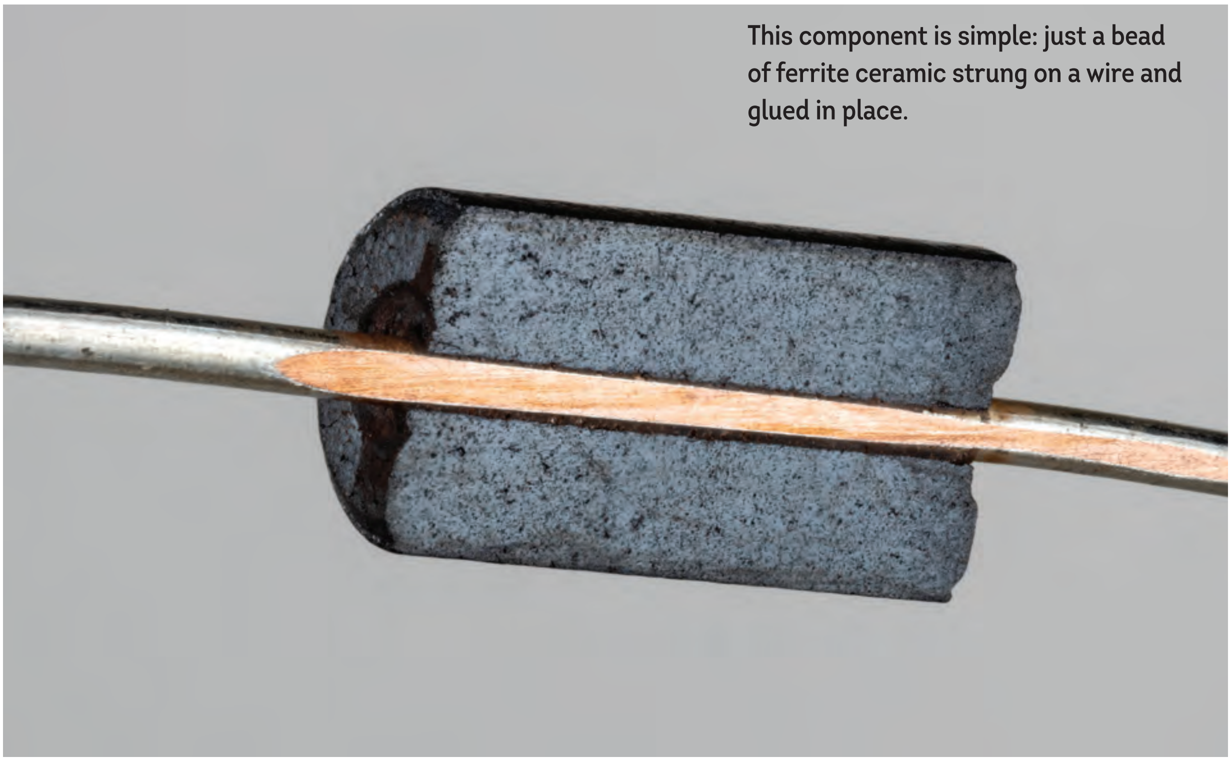
The wound copper magnet wire is outlined with a thin layer of translucent varnish.

Ferrite Bead

At first glance, this component may not look like an inductor at all. Where are the turns of wire? In fact, even a straight piece of wire with current flowing through it produces a magnetic field. The **FERRITE BEAD** surrounding this piece of wire just bumps up the inductance a little bit.

Ferrite beads can be used to stop stray radio waves from sneaking out of one electronic device and causing interference in another. They're also used to filter the power supply connections of sensitive chips, or to prevent electrically noisy chips from interfering with other chips on a circuit board.

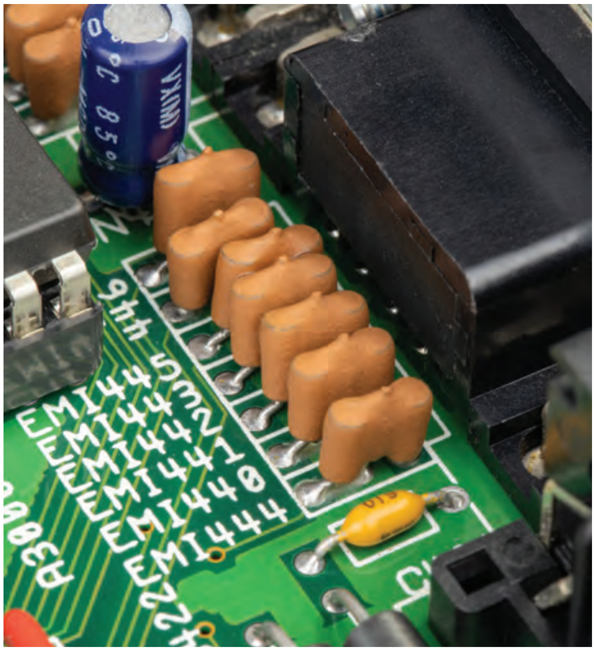




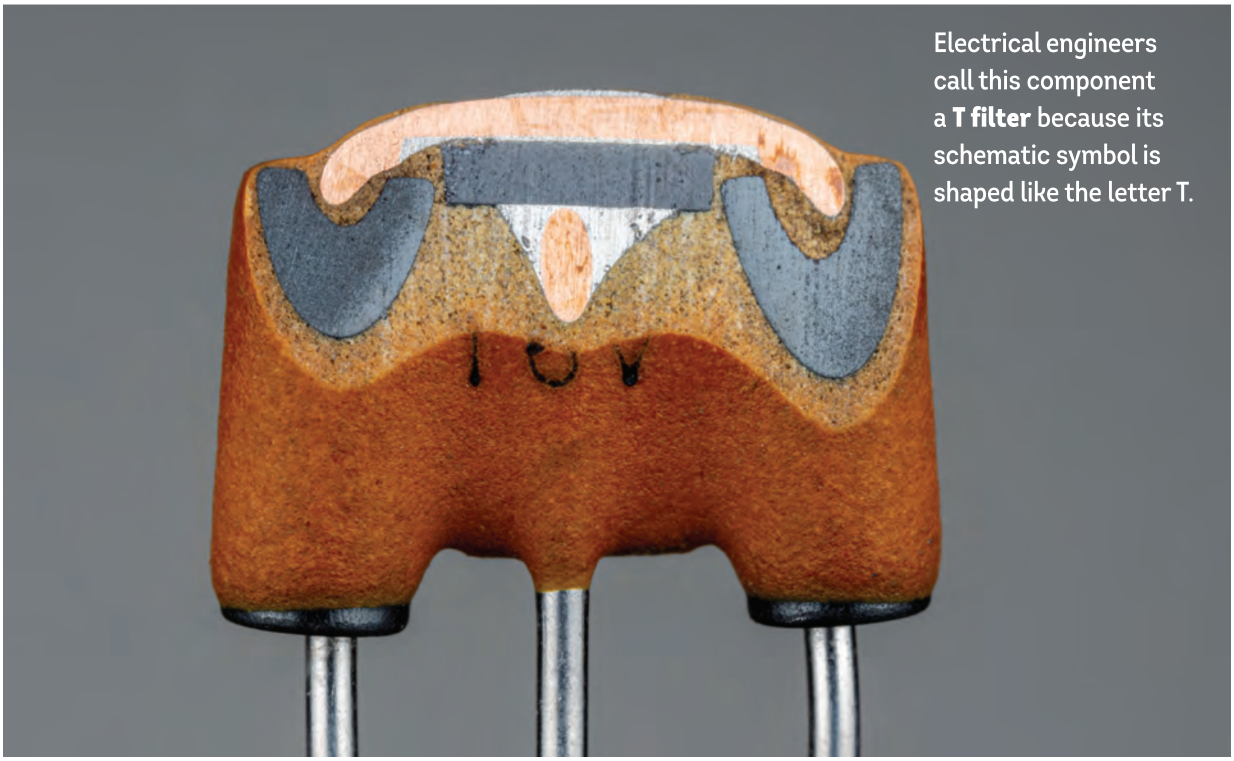
This component is simple: just a bead of ferrite ceramic strung on a wire and glued in place.

Three-Terminal Filter Capacitor

This strange-looking component combines two inductors and a capacitor. A copper wire passes through two ferrite beads. Between the beads, one side of a ceramic capacitor is soldered to the wire. Another wire is soldered to the other side of the capacitor, forming the third terminal of the device.



Together, these parts act as a filter, preventing stray radio waves from wandering outside an electronic device and interfering with TV or Wi-Fi signals. Accordingly, you can find these devices on circuit boards next to connectors that go to the outside world.



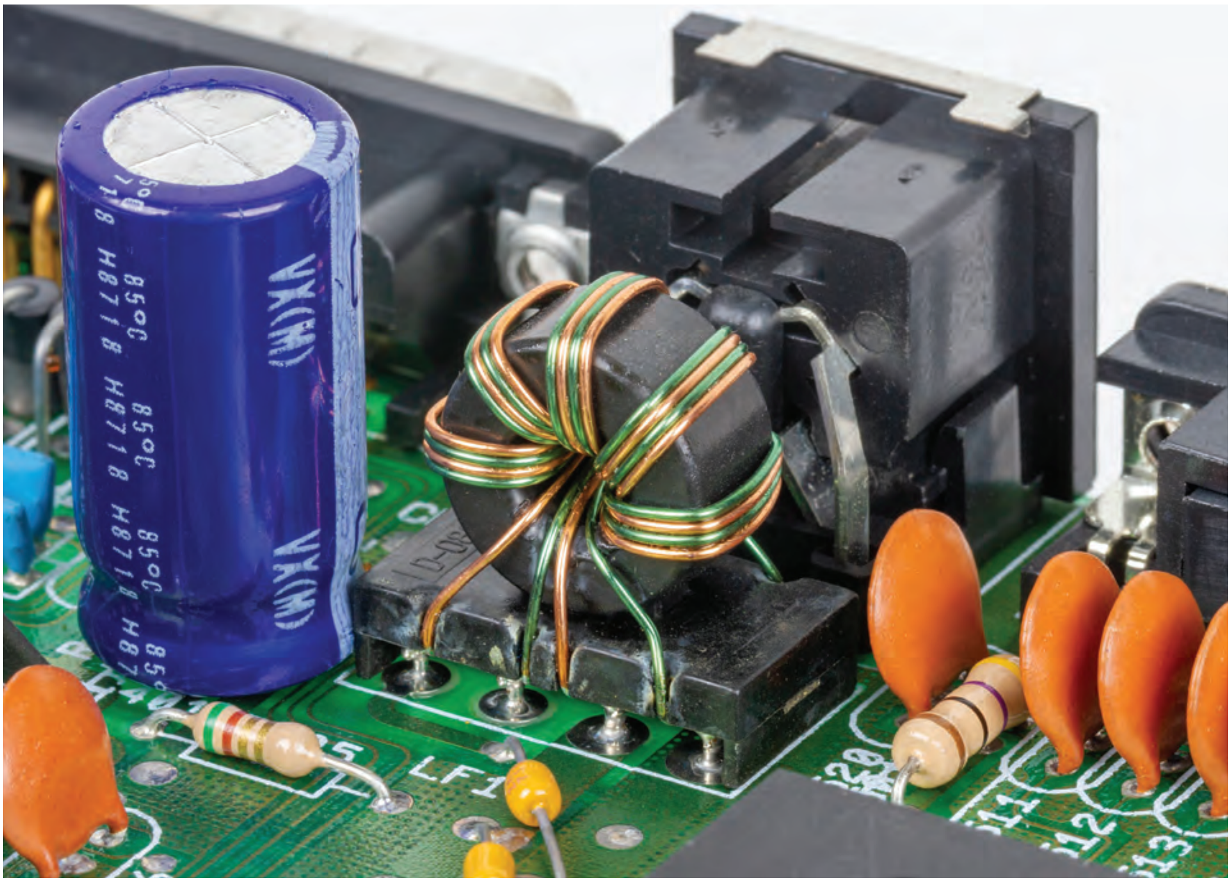
Electrical engineers call this component a **T filter** because its schematic symbol is shaped like the letter T.

Toroidal Transformer

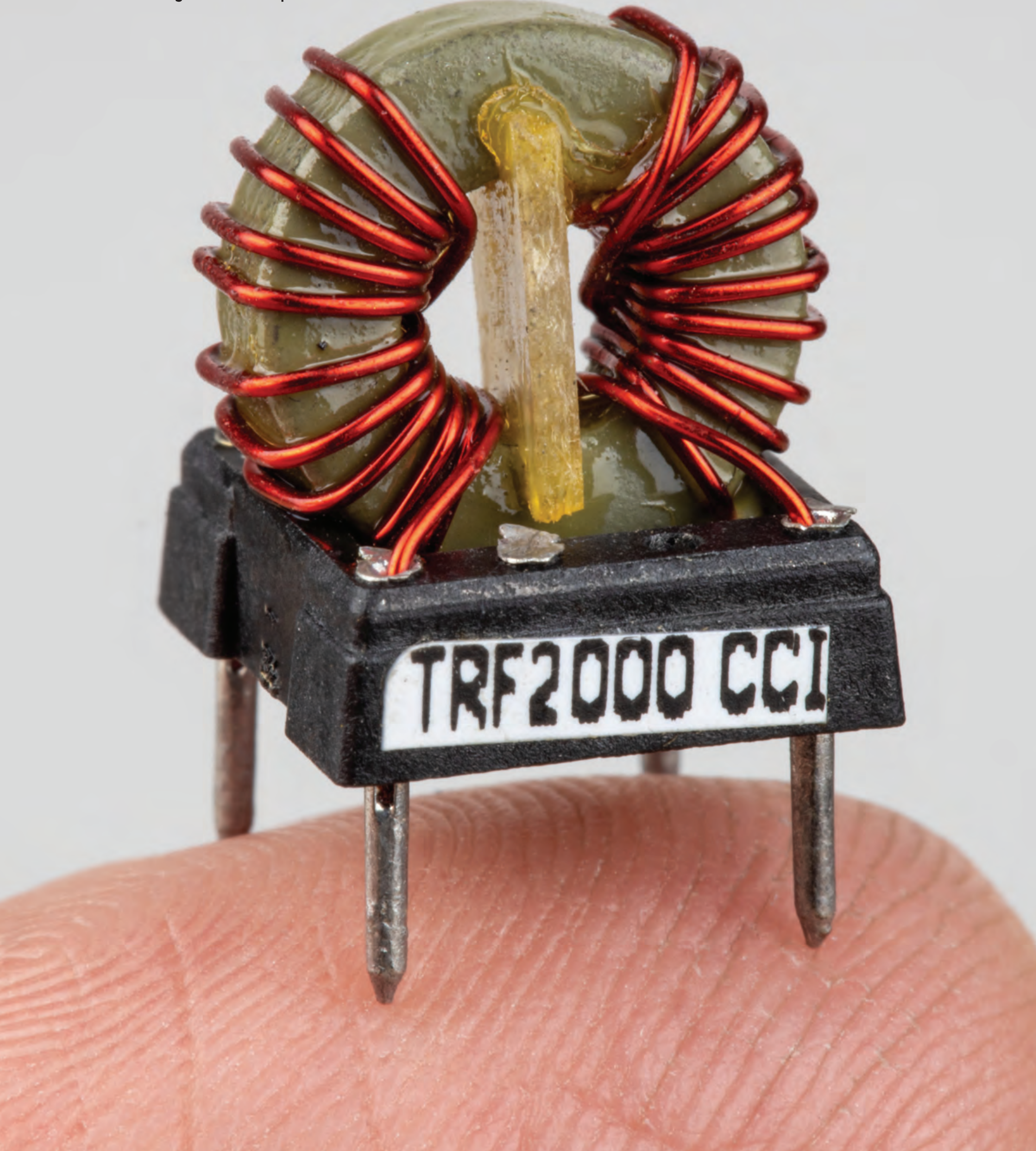
A **TRANSFORMER** is an inductor wound with more than one coil of wire. The coils of these toroidal transformers are wound around donut-shaped ferrite cores.

Electrical current flowing through wire creates a magnetic field. Likewise, a changing magnetic field induces an electrical current in nearby wires. Thus when multiple coils are wound around a single core, changing the current in one wire changes the magnetic field, which creates a changing current in the other wire. This provides a method of **ELECTRICAL ISOLATION**: transmitting power or signals between wires without an electrically conductive path connecting them.

Having a different number of turns on the different windings can *transform* AC voltages from low to high or high to low. This kind of transformer is often used in power supplies for stepping up or stepping down voltages.



This transformer is configured as a choke: a special type of transformer designed to stop stray radio waves from leaking outside of a piece of electronics.



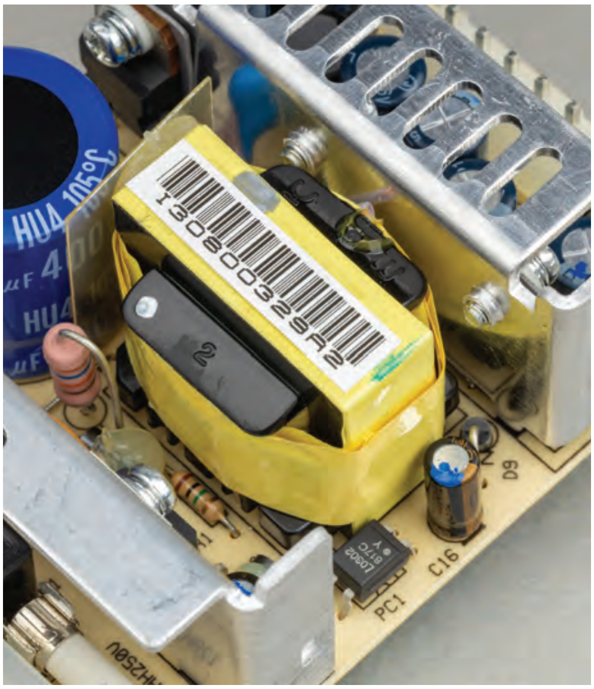
Power Supply Transformer

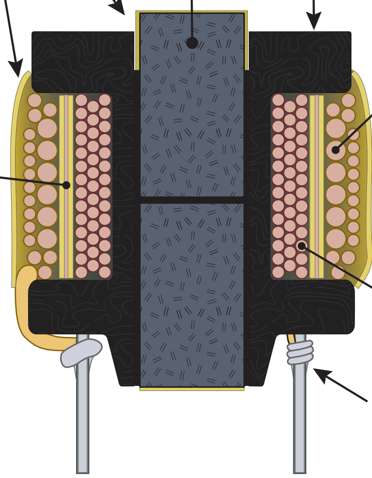
This transformer has multiple sets of windings and is used in a power supply to create multiple output AC voltages from a single AC input such as a wall outlet.

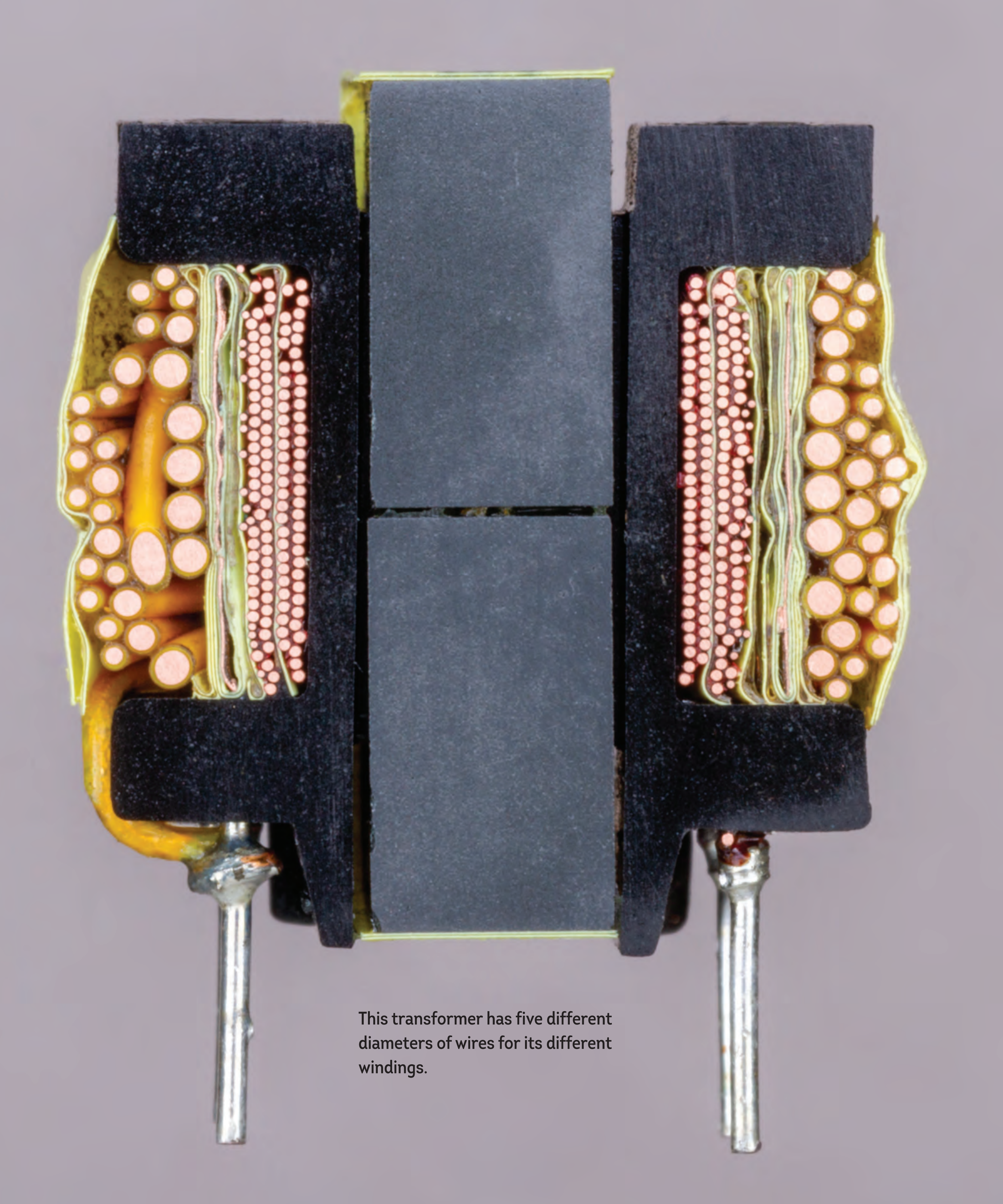
The small wires nearer the center are "high impedance" turns of magnet wire. These windings carry a higher voltage but a lower current. They're protected by several layers of tape, a copper foil electrostatic shield, and more tape.

The outer "low impedance" windings are made with thicker insulated wire and fewer turns. They handle a lower voltage but a higher current.

All of the windings are wrapped around a black plastic bobbin. Two pieces of ferrite ceramic are bonded together to form the magnetic core at the heart of the transformer.







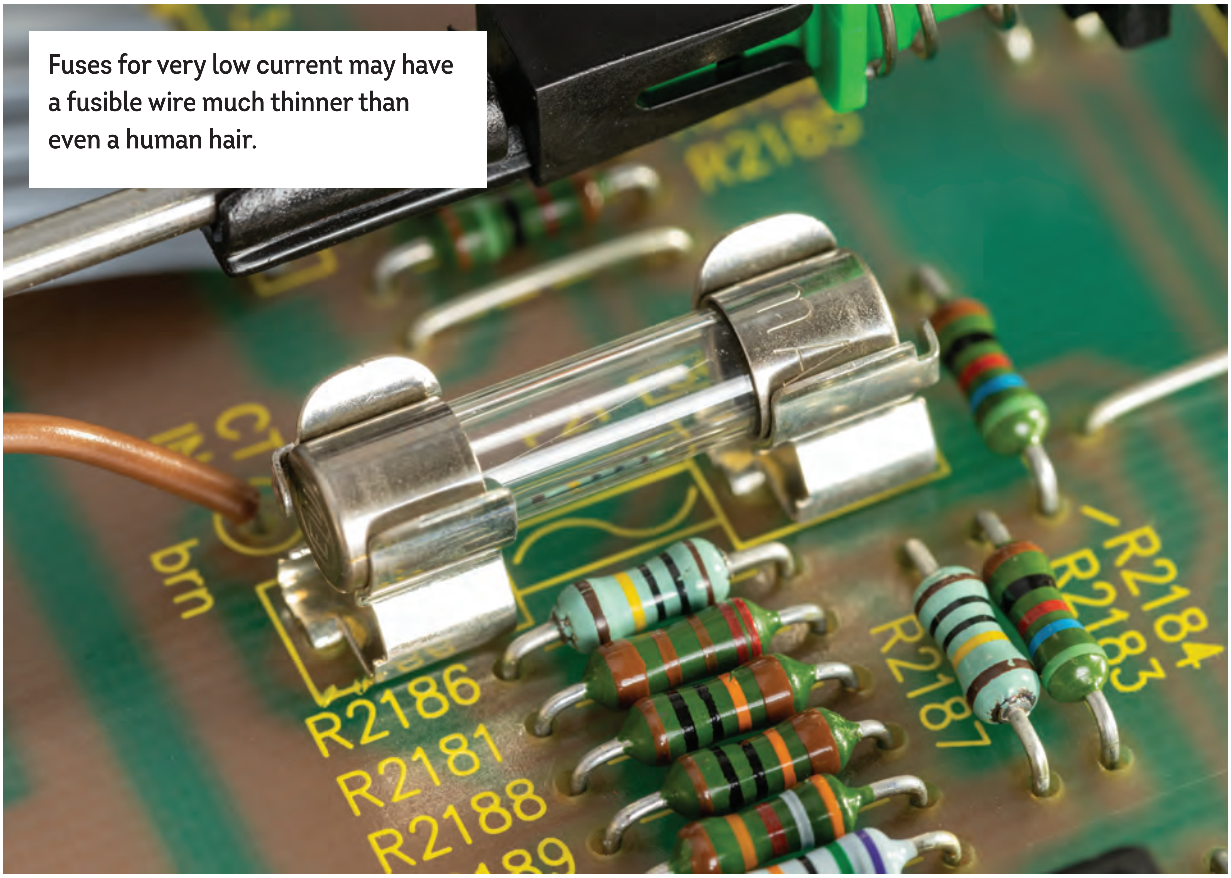
This transformer has five different diameters of wires for its different windings.

Low-Power Cartridge Fuses

FUSES are electrical components that break or "open" a circuit when more than a specified amount of electrical current passes through them, protecting other components from damage.

Here are a few glass cartridge fuses, each 0.25 inch in diameter. The two on the left are **FAST-ACTING** fuses rated for 10 and 15 amperes, respectively. They have round or flat metal wire between their ends. When the current exceeds the fuse's rating, the wire heats up enough to melt and quickly break the circuit.

The two fuses on the right are **TIME-DELAY**, or **SLOW-BLOW**, fuses, both rated for 0.25 A. Time-delay fuses resist spikes beyond their rating, requiring sustained current above that point to blow. One has thin wire wrapped around a fiberglass core that takes a while to heat up. The other has a resistor and spring. If the resistor overheats, it melts a dot of solder, releasing the spring and opening the circuit.



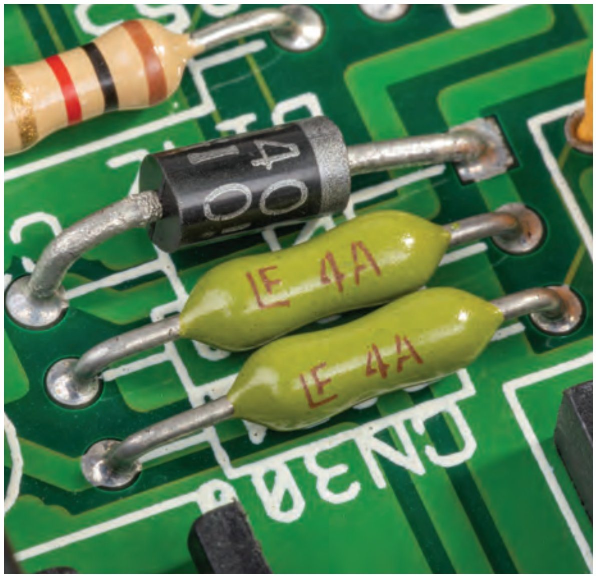
Fuses for very low current may have a fusible wire much thinner than even a human hair.

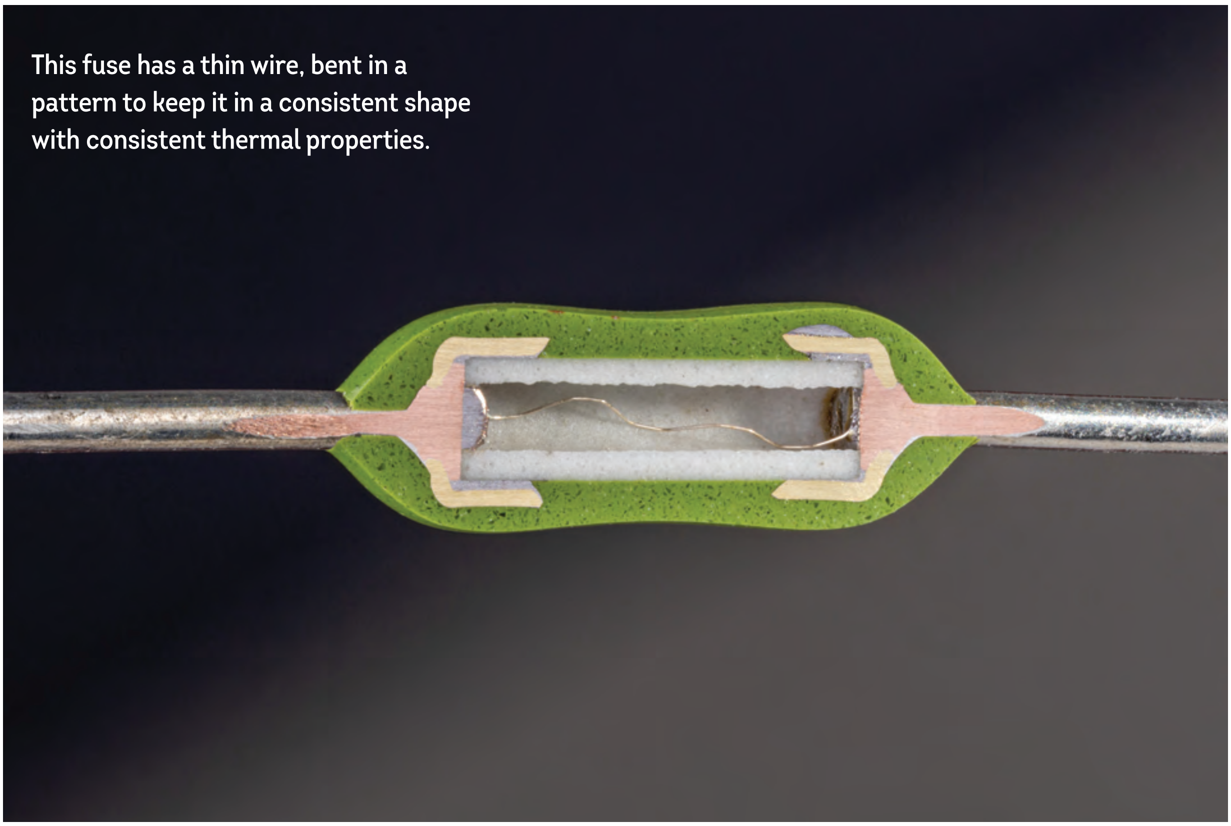
Cartridge fuses like these are found in equipment where the end user will replace the fuse. The glass case makes it easy to see when a fuse has blown.

Axial Lead Fuse

This component might look similar to a resistor, but it's actually a tiny fuse packaged with axial leads. Underneath the outer plastic coating is a ceramic tube containing the fuse wire. The wire is soldered to brass end caps pressed onto the copper lead wires.

This type of fuse is designed to be soldered to the circuit board, so it isn't meant to be replaced by the consumer. They're frequently used to provide additional protection to the circuitry if other protection circuitry fails.





This fuse has a thin wire, bent in a pattern to keep it in a consistent shape with consistent thermal properties.

Liquid Power Fuse

At very high voltages, breaking a circuit gets tricky: long electrical arcs can easily form between pieces of metal as they separate, maintaining the flow of current. This huge, liquid-filled power fuse solves that problem.

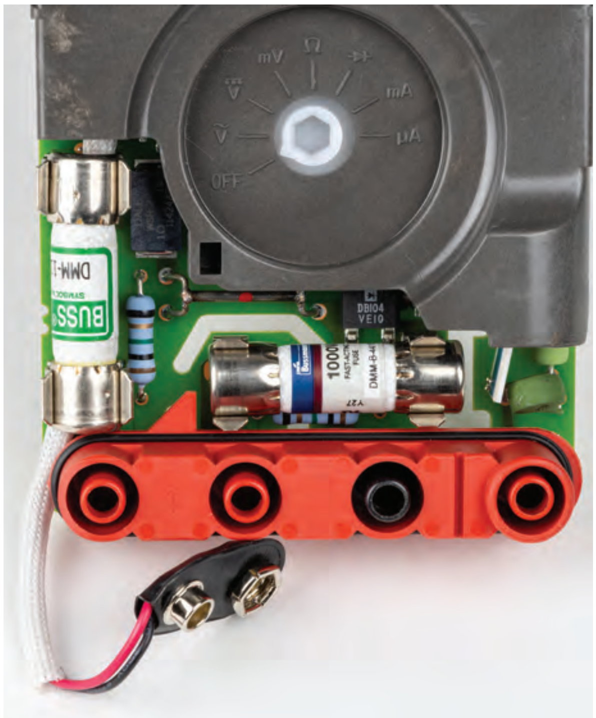
Although the fuse has only a 15 A rating, it's designed to handle up to 23,000 volts. When the fuse is tripped, the long spring retracts below the surface of the liquid, pulling the broken ends of the fuse wire apart. The liquid insulates the end of the wire and quenches the electrical arc.

The liquid inside this vintage fuse is tetrachloroethylene, a chemical widely used as a dry-cleaning fluid.

Compact Power Fuse

Many handheld digital multimeters are protected from over-voltage and over-current conditions by compact power fuses. In fuses like these, an unexpected material surrounds the fusible element: grains of silica sand. The silica absorbs energy and quenches any electrical arc that might form when the fuse breaks, cutting off the current and ensuring that the circuit is fully disconnected.

Instead of a wire, these fuses contain a ribbon of metal, allowing them to handle higher currents. A dot of solder on the ribbon takes time to melt and thus acts as a simple time-delay element. A tough outer fiberglass tube protects the surrounding circuitry from the intense heat that can occur when the fuse blows.



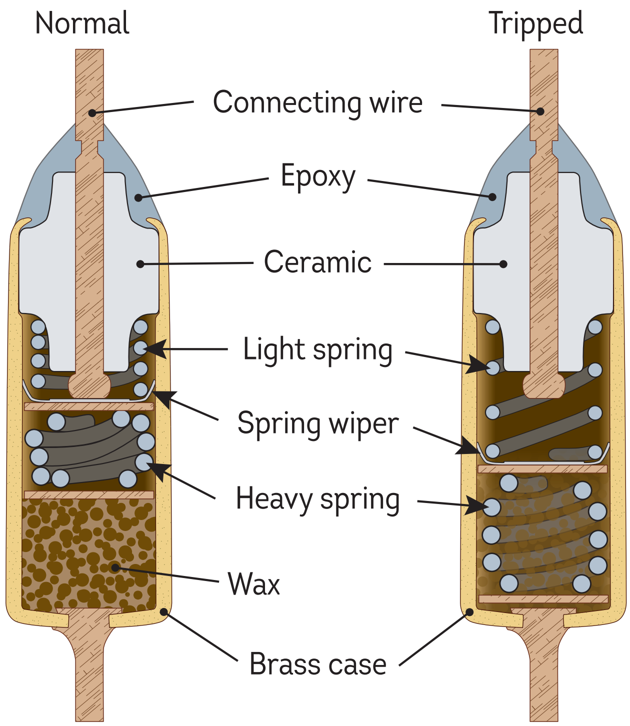
Like the fluid in a liquid power fuse, the sand inside this fuse prevents arcing.

Thermal Fuse

A **THERMAL FUSE**, sometimes called a **THERMAL CUTOFF**, is like a regular fuse, except it opens an electrical circuit when it exceeds a certain temperature, rather than a certain level of current. Thermal fuses function as safety devices in electrical appliances that contain heating elements: coffee makers, hair dryers, rice cookers, and so on. They prevent a fire if some other part of the circuit fails.

The thermal fuse makes an electrical connection from one lead to the other via a spring wiper that contacts the edge of the metal case. The wiper is held in place by two springs braced against a wax pellet that melts at a specific temperature. When the wax melts, the springs expand into it, breaking the electrical connection irreversibly, even after the wax cools down and solidifies again.

As a precaution, thermal fuses are sometimes packaged with wirewound power resistors, which are likely to be one of the hottest points in a circuit.



Thermal fuses are available with a range of different temperature ratings, which simply represent different melting points of the wax.