What Engineers Need to Know About Resistors

WHITEPAPER

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contents

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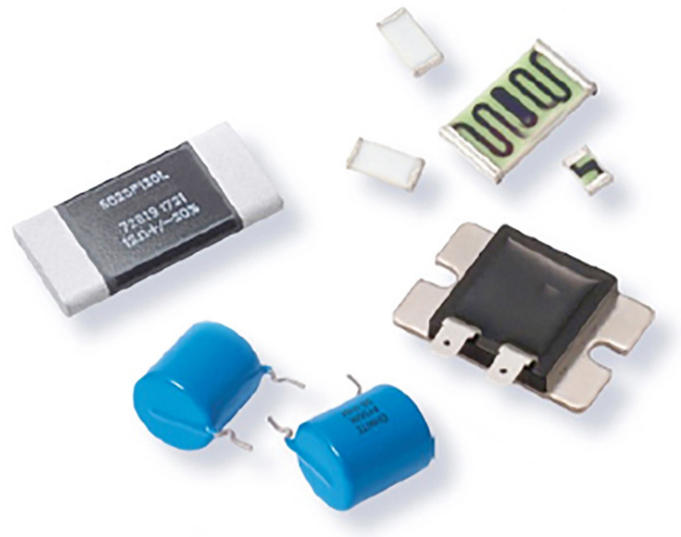


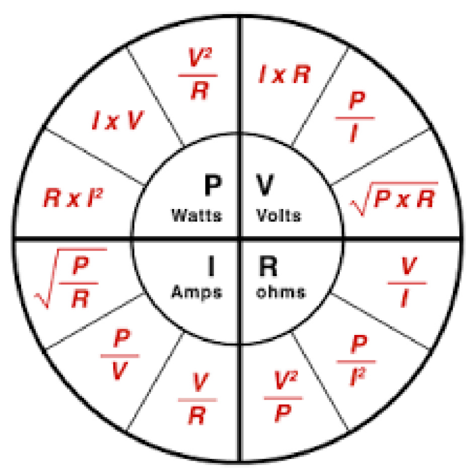
A resistor is a passive electrical device connected into an electrical circuit to introduce a specified resistance in the flow of electric current. A very high resistance allows a small amount of current to flow. A very low resistance allows a large amount of current to flow. The resistance is measured in ohms. An ohm is defined as the resistance that occurs when a current of one ampere passes through a resistor with a one volt drop across its terminals.

In electronic circuits, resistors are used to reduce current flow, divide voltages (turning a large voltage into a smaller one), bias a microcontroller's input pin to a known state, control gain of amplifiers, and terminate transmission lines, among other purposes. They can be used as electric brakes to dissipate kinetic energy from trains, or employed in series with an LED to control the amount of current flowing through it (or else the LED will burn due to it exceeding its current limit).

THE BASICS

Ohm's Law defines the relationships between (P) power, (V) voltage, (I) current, and (R) resistance. Ohm's Law states that the current through the resistor will be directly proportional to the voltage across it and inversely proportional to the resistance:

R = V/I or I = V/R or V = IR



The equation can be rearranged to find any one of the three quantities given the other two. (Source: Ohmite)

An important parameter in resistor specifications is the amount of power it can dissipate. When current passes through a resistor, power is dissipated and manifests itself in the form of heat. This, in turn, causes the temperature of the resistor to rise, and if too much current passes through the resistor, the temperature rise can cause the resistance to change, or in extreme cases results in damage to the resistor.

Power is a measurement of the amount of work that can be done with the circuit, such as turning a motor. Watt's Law states that Power (in Watts) = Voltage (in Volts) x Current (I, in Amps) or P = V I.

This equation can be combined with Ohm's Law to calculate the power dissipated, given knowledge of the resistance and the voltage across it. The actual current must be used in figuring the wattage and the increase in wattage in order to select the proper size resistor. Mathematically, the wattage varies as the square of the current, or voltage.

$P = V^2 / R$ and $P = I^2R$

KEY SPECIFICATIONS

As noted above, when an electrical current passes through a resistor due to the presence of a voltage across it, electrical energy is lost by the resistor in the form of heat; the greater this current flow, the hotter the resistor will get. The resistor's power rating is the amount of energy the resistor can dissipate in a given time at the designated ambient temperature (usually +70°C or below). If the circuit operates at temperatures exceeding the resistor's rated temperature, resistor power handling must be de-rated appropriately.

Resistors are rated to dissipate a given wattage without exceeding a specified temperature, and the physical size is made large enough to accomplish this. Higher power ratings require a larger size and may even require heat sinks. For a surface mount resistor, the power rating generally ranges from less than 100 milliwatts to few watts. A through-hole type has a higher power rating than the SMD type.

The resistance tolerance of a power resistor is the extent to which its resistance may be permitted to deviate above or below the specified resistance. Resistance tolerance is usually expressed in percent. The most common values are 1% and 5%. Certain applications require precision values and certain resistor constructions can accommodate tolerances down to 0.01%.

A primary parameter not to be exceeded for a resistor is the continuous power rating, which is the maximum amount of power that can be continuously loaded to a resistor at a rated ambient temperature.

Also essential is the maximum working voltage, particularly on applications involving high voltages such as in the Power Factor Controller (PFC) section of a power supply. For a relatively constant voltage across a resistor of a given resistance value, the maximum allowable voltage can be calculated so that the power dissipation is within that of the resistor package rating. When the voltage is pulsed a higher voltage can be used and the power dissipation is still good. The key is not to exceed this rating to avoid damage. Voltage rating may also be affected by the surrounding temperature, so that also must be considered.

Before establishing the maximum voltage applied to a resistor you have to consider both the maximum continuous- and maximum short-time-overload (STOL) voltage. STOL is a temporary exposure to unexpectedly high current spikes. A component subjected to STOL will be required to dissipate more power than usual causing an extreme temperature rise that can lead to component damage and can be a cause of failure in many applications.

Voltage stress also can make a resistor fail. Voltage stress is the ratio in percent of the actual voltage drop of the resistor to its voltage rating. Resistor voltage stress is not critical in small signal circuits, but in high voltage applications such as the divider feedback of a PFC circuit, it must be limited to avoid wearing out the device.

Designs must not violate either the power rating or the maximum working voltage rating to avoid reliability problems.

Other parameters that affect the resistance value include its long term stability and temperature coefficient. Resistor stability is determined by real-life performance under load and temperature, taking into account both short-term and long-term exposure to electrical and mechanical stresses. Temperature Coefficient of Resistance (TCR), usually considered in high precision applications, is determined by the resistive material as well as the mechanical design. TCR depicts the resistive element's sensitivity to temperature change and is used to specify a resistor's stability.

A quick word on stability and reliability: Users must carefully evaluate data to be sure it does not represent only a few samples (say, ten or twenty units). To be truly significant, the data must come from large lots of continuing tests over long periods of time, from many manufacturing lots, and include the full range of values offered.

OTHER KEY FACTORS

A surge condition for a resistor is the application of a power level that exceeds the continuous power rating of the part for a defined length of time. Most surges last for milliseconds (msec) or microseconds (μsec). If you apply power for only 1 msec or 1 μsec, applying more than a few times the rated power probably is not an issue.

However, putting 10 times the rated power on a resistor for 5 or 10 seconds or more can cause permanent damage and melt the solder joints that hold the part in place. This type of prolonged continuous power application is defined as Overload. Most resistors state a max overload rating that may need consideration.

An unexpected surge condition may occur when a circuit is turned on or when it is rapidly turned on and off. Resistors that tolerate pulse or surge are required for pre-charge resistors (to eliminate the rush current that flows to charge a capacitor having a large value when the power is turned on) ESD protection and lightning protection.

Engineers sometimes overlook the resistive change due to self-heating. When current passes through a resistor it generates heat and the thermal response induces relative mechanical stress due to different thermal expansions in the materials comprising the resistor.

CONSTRUCTION CHOICES

Resistors are produced in multiple constructions such as Wirewound, Composition, Thick Film, and Thin Film. Let's look at these one at a time:

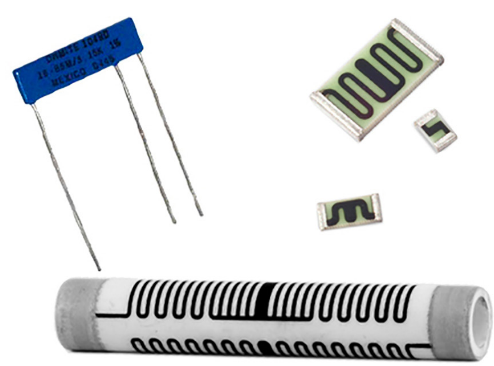
Wirewound resistors are typically used in high power and industrial applications such as circuit breakers and fuses. (Source: Ohmite)

Wirewound: General properties are good stability and high-temperature performance.

Wirewound resistors are constructed using a conductive wire. The conductive wire is then wound around a non-conductive core. The conductive wire can be made of varying alloys and thickness to control the resistance value. Typically used in high power and industrial applications such as circuit breakers and fuses, Wirewound constructed resistors can be chosen based on mounting, application, and resistance range. Different types of Wirewound resistors include Precision, Axial, Tubular, Surface mount, and Adjustable, which all have good stability and resistance range, and are produced in many wattage sizes. Higher wattage Wirewound resistors are used in high current/braking applications in the transportation market.

Composition: For use in High Energy, High Voltage and Pulse/Surge handling .

Composition resistors are produced using a mixture of a finely ground insulator and conductor. This mixture is then compressed into different shapes. Terminals are attached and the insulation coating is applied to the outside. The resistance is controlled based on the ratio of the insulator and conductor mixture. Composition resistors are chosen based on energy handling and resistance value. Due to its construction, composition resistors typically have a high tolerance. Composition resistors perform well in high energy/surge applications. The large amount of mass contained in the resistor enables high levels of energy absorption. These high levels of energy absorption can be repeated without negative effects to the resistance value.



Ohmite offers over 20 different Thick Film construction series resistors. (Source: Ohmite)

Thick Film and Thin Film: Commonly known for High Voltage and Precision (TCR and Resistive Toelrance) devices

Thin and thick film resistors are characterized by a resistive layer on a ceramic substrate. Although their appearance might be similar, their properties and manufacturing process are very different. The main difference is the method in which the resistive film is applied onto the substrate. Thin film resistors have a metallic film that is vacuum deposited on an insulating substrate. This creates a uniform metallic film of around 0.1 micrometer thick.

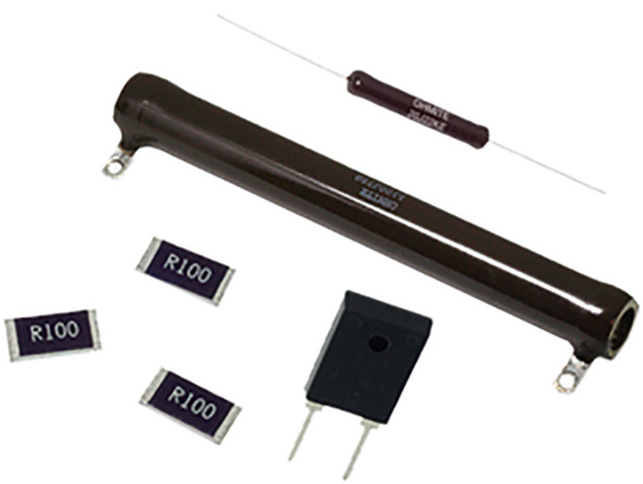
Generally speaking, thin film is more accurate than thick film, has a better temperature coefficient, and is more stable. It therefore competes with other technologies that feature high precision, such as Wirewound resistors. On the other hand, thin film resistors have relatively limited surge capabilities such as ESD and short time overload due to the low mass of resistive material.

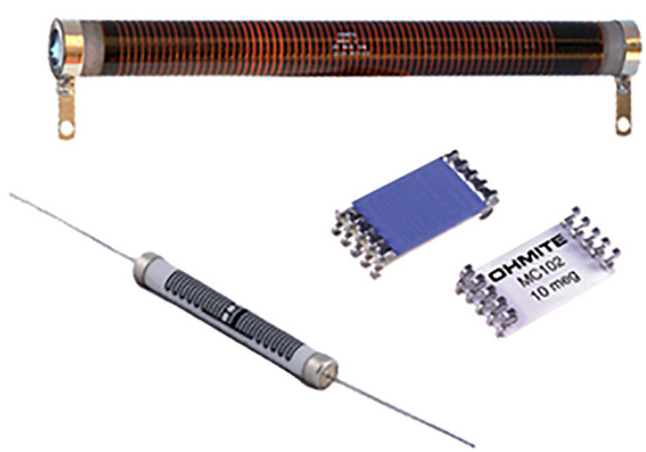
Thick film resistors are produced by firing a special paste--a mixture of glass and metal oxides--onto the substrate. Once applied, the resistance is adjusted using a laser or abrasive trimmer. Thick film parts can be chosen based on mounting, application, and voltage range. They are easily integrated into a heat sinkable package for high wattage applications. High voltage can be applied to thick film products with little change in resistance value.

MOUNTING OPTIONS

Suppliers such as Ohmite offer several mounting options. As the power or application requirements rise the type of mounting will change. Lower wattage parts, typically below 3 watts, come in SMD form. Using SMD improves manufacturing efficiency by enabling high levels of automation, and boosts reliability. As power rises, axial through-hole mounting is used up to 10 watts. Through-hole mounting is the process by which component leads are placed into drilled holes on a bare PCB. Heat-sinkable designs and tubular parts are used for higher wattages (above 20 watts). These larger parts may be securely mounted to a manufactured chassis. Each mounting style has its own advantages depending on the application.

For more information go to: https://www.ohmite.com/.





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