Question

There are so many different resistors available: wirewound, film, carbon, and so on. What are the main characteristics of each type of resistor, and where are they commonly used?

Answer

The following explanation is restricted to the major types of *fixed* resistors (no trimmer, potentiometer, thermistors, thick film chip resistors). The discussion below is far from complete but hopefully provides some insight.

In school we most often deal with idealized components, that is, resistors are assumed to obey Ohm's law: $I = V/R$. Additionally, they can dissipate infinite amount of power, their values are totally independent of temperature, and so on. Practical resistors deviate from this idealized model in many ways. Sometimes these deviations may not be all that important. For example, if a resistor has a small inductance, but it is used in a DC or low-frequency circuit, the inductance is irrelevant. However, in high-frequency circuits, the inductive reactance may become significant, and even dominate.

Various manufacturing materials and techniques exist for creating resistors that mitigate the non-ideal behavior of a resistor intended for a particular application. A small difference in the cost of a resistor is not important for pilot projects and small production runs, but cost is in general an important issue. Before describing some of the common resistors, let's examine important characteristics of resistors.

Temperature Coefficient. The resistance of a conductor changes with changes in temperature. This change is in general nonlinear, but for small temperature changes may be approximated as linear, and is commonly expressed as a *temperature coefficient* (TC). The units are ppm/˚C, meaning parts-per-million per degree Celsius. Another specification is ppm/K, meaning parts-per- million per (degrees) Kelvin.

The TCs of carbon composition resistors are in the range ±1500 ppm/˚C, and is often not even listed in manufacturer's specifications. Pure metals generally have TCs that are even higher. As an example, copper's TC is 4000 ppm/K. However, special metal alloys are available with very low TCs: the alloy Constantin has a remarkable low TC of 1–5 ppm/K, and the alloy Kanthal has a TC of 50 ppm/K. Precision wire-wound resistors are made from these alloys, and represent these other end of the TC spectrum.

Temperature Cycling. The concept a TC is relevant for reversible changes in resistance as a function of temperature. Assume a TC of +150 ppm/˚C for a 1K resistor. If the ambient temperature rises from 25 ˚C to 30 ˚C, then the resistor's value will change with

$$\Delta R = 1{,}000 \frac{150}{1{,}000{,}000}(30 - 25) = 0.75\,\Omega\,.$$

When the temperature drops to 25 ˚C the resistor's value returns to 1K.

However, when a resistor is exposed to large, sudden changes in temperature, minute, and irreversible physical changes occur, and the resistance change permanently. This change can be as high as 2% for carbon composition resistors, and as low as 0.1% or smaller for metal film and wire-wound resistors. Temperature cycle tests involve measuring the resistor's initial value, cooling to –55 or –65 ˚C and keeping it there for 0.5 hours. Next, elevate the temperature to at 150 ˚C, and keep it there for 0.5 hours. This cycle is repeated 5 times, and then the value is measured again. It is of course not feasible to do this with every resistor that leaves the manufacturing line, so statistically significant samples are subjected to the test.

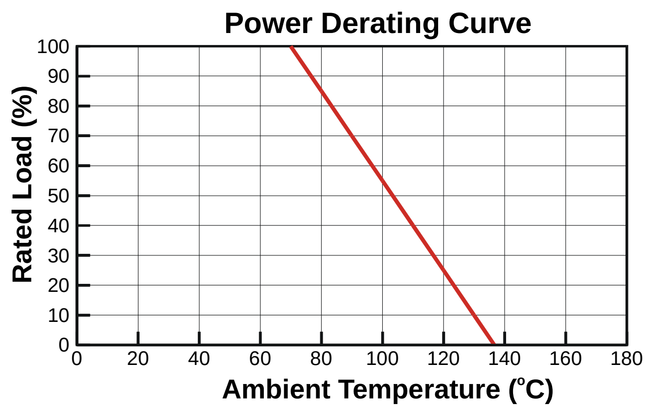
Resistance to Soldering. Soldering (2 s @ 230 ˚C) expose a resistor to a thermal shock that causes minute and irreversible mechanical changes in the body of the resistor, and consequently *permanent* changes in the resistance value. These changes can be as small as 0.05% for some wire-wound resistors, and as high as 2% for carbon composition resistors.

Noise. Any conductor generates what is known as *thermal* or J*ohnson* noise. This is caused by the Brownian motion of carriers in the conductor, and is related to temperature as well as the resistance value. Thermal noise increases with increasing temperature and resistance, and has well-defined statistical properties. The manufacturing process adds another noise component. For example, molded carbon composition resistors are manufactured by mixing small carbon granules with a binder and then molding it and inserting two leads. The *local* resistance inside the resistor varies substantially and the resistor may be viewed as a complicated network of series and parallel resistors, each acting as a noise source. This and other factors make carbon composition resistors very noisy when compared with metal film and wire-wound resistors.

Manufacturing Tolerance. This is the deviation from the resistor's nominal value, expressed as a percentage. It is measured at 25°C with no load applied. General purpose, axial lead resistors are available in 20%, 10%, 5%, 2%, and 1% values, but 20% and 10% values are becoming uncommon nowadays. Wire-wound resistors are available with ±0.005% tolerances, but these tend to be expensive.

Rated Power. The power dissipated by a resistor R is $P = VR^2$ W. Resistors come in a wide range of rated power dissipation: 1/8–1 W for general-purpose resistors, and up to hundreds of watts for power resistors.

Power Derating. Rated power dissipation values are nominal at some reference point: for example 70˚C. At temperatures above this, the maximum allowable dissipation must be derated. Manufactures often give a simple linear curve, similar to the one below. The area below and to the left of the curve is the valid region of operation.



Voltage Coefficient. This is the change in resistance with applied voltage. It is normally associated with carbon composition and carbon film resistors. High value resistors tend to have high voltage coefficients.

Shelf Stability/Drift. In addition to all the environmental and electrical factors listed above, resistors experience a long-term drift that may be as high as 2% per year for carbon composition resistors. Metal, oxide, metal film, and wire-wound resistor are typically 10 times more stable.

	Metal Film	**Metal Oxide Film**	**Carbon Film**	**Carbon Comp.**	**Wire-wound**
Range	10 Ω–1 MΩ	0.47 Ω–1 MΩ	1 Ω–10 MΩ	1 Ω–100 MΩ	0.1 Ω–1.2 MΩ
Series	E96	E24	E12, E24	E12, E24	Custom
Tol. (%)	1, 2, 5	2, 5	5, 10	5, 10	Power: 1,2, 5 Precision: 0.00
Rated Power (W)	1/4 –1	1/2–9	1/8–2	1/8–1/2	Power: 1–200
TC ppm/°C	±25–±350	±100–±200	-0.0001R-450	±1500	Precision: ±1–10 Power: ±10–400
Temp. Cycling (%)	±0.25	0.5–±1	0.5–±1	±2	±2
Cost	11–50c	27–65c	6–10c	40c	Power: $4–$20
VC ppm/°C	< 1	10	50	350	< 0.5
Stability ppm/year	±1,000	-	±2,500	±2,000	±20–200
Noise (db)	-40 to –5	-	-35 to 0	-25 to +30	-
Moisture Resistance (%)	±5	±1	±3	±5	-

Characteristics of Commonly Available Resistors

Carbon Film Resistors. Their long-term stability is not as good as metal and film wire-wound resistors, but at 0.25%/year very good. These resistors also have low noise, and come in a very wide range of resistance values. Their most important quality, however is price—these are the least expensive resistors available. *The* general purpose resistor.

Carbon Composition Resistors. They are noisy, unstable, have large TCs and exhibit poor long-term stability and poor resistance to soldering heat. They are available in a very wide range of resistors, and have high energy/high voltage surge capabilities. For example, a carbon composition resistor may withstand a voltage pulse that is 3–5 times as high as the maximum rated voltage. They are often used in RC snubber circuits.

Metal Oxide Film Resistors. These resistors have good long-term stability, good TCs. They are excellent replacements for low-power wire-wound resistors.

Metal Film Resistors. The best, general-purpose resistors with high long-term stability, have low to very low TCs, exhibit very low changes in resistance due to soldering, can work at low temperatures, and have low voltage coefficients. Except for carbon film resistors, metal film resistors are the cheapest resistors on the market.

Wire-wound Resistors. There are two broad categories here: power resistors and precision resistors. "Power" generally means 1 Watt and higher, and since $P = V^2/R$, this most often implies low resistance. Their physical construction is designed to dissipate the heat. They have excellent high-energy pulse handling capabilities. Wire-wound resistors are available at values below 1 Ω, where other technologies are often not available. These resistors are bulky when compared to other resistors, and are tend to be expensive. Power wire-wound resistors typically have 1% tolerance, and have good long-term stability. Even power precision wire-wound resistors often have low TCs.

Low tolerances, high stability, and low TCs are the fortes of precision wire-wound resistors. Tolerances as low as ±0.005% are available. Common resistance stability is ±100 ppm/year, and some companies manufacture resistors with stabilities of ±20 ppm/year. The TCs of precision wire-wound resistors are the best available and as low as as ±1 ppm/°C.

Wire-wound resistors are bulkier than other resistors, but the main downside is cost. For example, a 1 K wire-wound resistor can cost 25 times as much as a carbon film resistor (but can dissipate10 Watts versus 0.125 Watts).

