VARIABLE RESISTORS

Adjustable resistors

A resistor may have one or more fixed tapping points so that the resistance can be changed by moving the connecting wires to different terminals. Some wirewound power resistors have a tapping point that can slide along the resistance element, allowing a larger or smaller part of the resistance to be used. Where continuous adjustment of the resistance value during operation of equipment is required, the sliding resistance tap can be connected to a knob accessible to an operator. Such a device is called a rheostat and has two terminals.

Potentiometers

Main article: Potentiometer

A common element in electronic devices is a three-terminal resistor with a continuously adjustable tapping point controlled by rotation of a shaft or knob. These variable resistors are known as potentiometers when all three terminals are present, since they act as a continuously adjustable voltage divider. A common example is a volume control for a radio receiver.
Accurate, high-resolution panel-mounted potentiometers (or "pots") have resistance elements typically wirewound on a helical mandrel, although some include a conductive-plastic resistance coating over the wire to improve resolution. These typically offer ten turns of their shafts to cover their full range. They are usually set with dials that include a simple turns counter and a graduated dial. Electronic analog computers used them in quantity for setting coefficients, and delayed-sweep oscilloscopes of recent decades included one on their panels.

Resistance decade boxes

A resistance decade box or resistor substitution box is a unit containing resistors of many values, with one or more mechanical switches which allow any one of various discrete resistances offered by the box to be dialed in. Usually the resistance is accurate to high precision, ranging from laboratory/calibration grade accuracy of 20 parts per million, to field grade at 1%. Inexpensive boxes with lesser accuracy are also available. All types offer a convenient way of selecting and quickly changing a resistance in laboratory, experimental and development work without needing to attach resistors one by one, or even stock each value. The range of resistance provided, the maximum resolution, and the accuracy characterize the box. For example, one box offers resistances from 0 to 24 megohms, maximum resolution 0.1 ohm, accuracy 0.1%.

Special devices

There are various devices whose resistance changes with various quantities. The resistance of thermistors exhibit a strong negative temperature coefficient, making them useful for measuring temperatures. Since their resistance can be large until they are allowed to heat up due to the passage of current, they are also commonly used to prevent excessive current surges when equipment is powered on. Metal oxide varistors drop to a very low resistance when a high voltage is applied, making them useful for protecting electronic equipment by absorbing dangerous voltage surges. One sort of photodetector, the photoresistor, has a resistance which varies with illumination.
The strain gauge, invented by Edward E. Simmons and Arthur C. Ruge in 1938, is a type of resistor that changes value with applied strain. A single resistor may be used, or a pair (half bridge), or four resistors connected in a Wheatstone bridge configuration. The strain resistor is bonded with adhesive to an object that will be subjected to mechanical strain. With the strain gauge and a filter, amplifier, and analog/digital converter, the strain on an object can be measured.
A related but more recent invention uses a Quantum Tunnelling Composite to sense mechanical stress. It passes a current whose magnitude can vary by a factor of 1012 in response to changes in applied pressure.

Measurement

The value of a resistor can be measured with an ohmmeter, which may be one function of a multimeter. Usually, probes on the ends of test leads connect to the resistor. A simple ohmmeter may apply a voltage from a battery across the unknown resistor (with an internal resistor of a known value in series) producing a current which drives a meter movement. The current flow, in accordance with Ohm's Law, is inversely proportional to the sum of the internal resistance and the resistor being tested, resulting in an analog meter scale which is very non-linear, calibrated from infinity to 0 ohms. A digital multimeter, using active electronics, may instead pass a specified current through the test resistance. The voltage generated across the test resistance in that case is linearly proportional to its resistance, which is measured and displayed. In either case the low-resistance ranges of the meter pass much more current through the test leads than do high-resistance ranges, in order for the voltages present to be at reasonable levels (generally below 10 volts) but still measurable.

Measuring low-value resistors, such as fractional-ohm resistors, with acceptable accuracy requires four-terminal connections. One pair of terminals applies a known, calibrated current to the resistor, while the other pair senses the voltage drop across the resistor. Some laboratory quality ohmmeters, especially milliohmmeters, and even some of the better digital multimeters sense using four input terminals for this purpose, which may be used with special test leads. Each of the two so-called Kelvin clips has a pair of jaws insulated from each other. One side of each clip applies the measuring current, while the other connections are only to sense the voltage drop. The resistance is again calculated using Ohm's Law as the measured voltage divided by the applied current.

Standards

Production resistors

Resistor characteristics are quantified and reported using various national standards. In the US, MIL-STD-202 contains the relevant test methods to which other standards refer.
There are various standards specifying properties of resistors for use in equipment:

BS 1852

EIA-RS-279

MIL-PRF-26

MIL-PRF-39007 (Fixed Power, established reliability)

MIL-PRF-55342 (Surface-mount thick and thin film)

MIL-PRF-914

MIL-R-11

MIL-R-39017 (Fixed, General Purpose, Established Reliability)

MIL-PRF-32159 (zero ohm jumpers)

There are other United States military procurement MIL-R- standards.

Resistance standards

The primary standard for resistance, the "mercury ohm" was initially defined in 1884 in as a column of mercury 106 mm long and 1 square millimeter in cross-section, at 0 degrees Celsius. Difficulties in precisely measuring the physical constants to replicate this standard result in variations of as much as 30 ppm. From 1900 the mercury ohm was replaced with a precision machined plate of manganin[12]. Since 1990 the international resistance standard has been based on the quantized Hall effect discovered by Klaus von Klitzing, for which he won the Nobel Prize in Physics in 1985.[13]
Resistors of extremely high precision are manufactured for calibration and laboratory use. They may have four terminals, using one pair to carry an operating current and the other pair to measure the voltage drop; this eliminates errors caused by voltage drops across the lead resistances, because no current flows through voltage sensing leads. It is important in small value resistors (100–0.0001 ohm) where lead resistance is significant or even comparable with respect to resistance standard value.[14]

Resistor marking

Main article: Electronic color code

Most axial resistors use a pattern of colored stripes to indicate resistance. Surface-mount resistors are marked numerically, if they are big enough to permit marking; more-recent small sizes are impractical to mark. Cases are usually tan, brown, blue, or green, though other colors are occasionally found such as dark red or dark gray.

Early 20th century resistors, essentially uninsulated, were dipped in paint to cover their entire body for color coding. A second color of paint was applied to one end of the element, and a color dot (or band) in the middle provided the third digit. The rule was "body, tip, dot", providing two significant digits for value and the decimal multiplier, in that sequence. Default tolerance was ±20%. Closer-tolerance resistors had silver (±10%) or gold-colored (±5%) paint on the other end.

Four-band resistors

Four-band identification is the most commonly used color-coding scheme on resistors. It consists of four colored bands that are painted around the body of the resistor. The first two bands encode the first two significant digits of the resistance value, the third is a power-of-ten multiplier or number-of-zeroes, and the fourth is the tolerance accuracy, or acceptable error, of the value. The first three bands are equally spaced along the resistor; the spacing to the fourth band is wider. Sometimes a fifth band identifies the thermal coefficient, but this must be distinguished from the true 5-color system, with 3 significant digits. For example, green-blue-yellow-red is 56×104 Ω = 560 kΩ ± 2%. An easier description can be as followed: the first band, green, has a value of 5 and the second band, blue, has a value of 6, and is counted as 56. The third band, yellow, has a value of 104, which adds four 0's to the end, creating 560,000 Ω at ±2% tolerance accuracy. 560,000 Ω changes to 560 kΩ ±2% (as a kilo- is 103).
Each color corresponds to a certain digit, progressing from darker to lighter colors, as shown in the chart below.

Color	1st band	2nd band	3rd band (multiplier)	4th band (tolerance)	Temp. Coefficient
Black	0	0	×100		
Brown	1	1	×101	±1% (F)	100 ppm
Red	2	2	×102	±2% (G)	50 ppm
Orange	3	3	×103		15 ppm

Yellow	4	4	×104		25 ppm
Green	5	5	×105	±0.5% (D)	
Blue	6	6	×106	±0.25% (C)	
Violet	7	7	×107	±0.1% (B)	
Gray	8	8	×108	±0.05% (A)	
White	9	9	×109		
Gold			×10−1	±5% (J)	
Silver			×10−2	±10% (K)	
None				±20% (M)	

There are many mnemonics for remembering these colors.

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