DEFINITION:
A resistor is a device used to restrict the flow of electrons (current). Fixed resistors have two connections per resistive element (axial or radial), separated by some type of resistive element (such as a carbon composition, carbon composition film or nichrome film). Variable resistors have three contacts - 2 fixed and 1 moveable and are usually used as voltage dividers. Another type of resistor (Power) has a nichrome wire wrapped around a ceramic core. The current flow follows Ohm's Law \( V = I \times R \) and the current flow generates heat according to \( P = I^2 \times R \). Various forms of resistors are shown in Fig. 1. Standard resistance values are shown in Table 1. Thermistors are temperature sensitive resistors which change resistance (either positively or negatively) with change of temperature.

KEY SPECIFICATIONS (SEE RESISTOR GLOSSARY)

TYPE/MATERIAL: Carbon composition rod, carbon film, nichrome film or nichrome wire
VALUE: Micro ohms (\( \mu \Omega \)), Milliohms (\( m\Omega \)), Ohms (\( \Omega \)), Kilohms (\( k\Omega \)) or Megohms (\( M\Omega \))
VOLTAGE: The voltage values are specified as VDC or VAC
TEMPERATURE COEFFICIENT (TC): The TC is specified as parts per million per oF or oC (ppm/oF or ppm/oC)
VOLTAGE COEFFICIENT (VC): The change of resistance with change of voltage (ppm/oV or ppm/oA)
NOISE: In an RF circuit, spurious noise is induced in a resistor due to charge carriers. It may be significant at high frequencies
FREQUENCY RESPONSE: The change in resistance with change of frequency in an RF circuit.
PACKAGE STYLE: Axial or radial leaded, surface mount (SMT or SMD) or array.
PACKAGE SIZE: Chips: 0201 to 2512, where the first 2 digits are the length and the last 2 digits are the width in mm. Fixed carbon composition, fixed film and power resistors are defined in inches.
RELIABILITY: The mean time between failures (MTBF) of a part.

The determination of which type of resistor is to be used, is primarily determined by the circuit board, if any, on which the resistor will be mounted, the voltage applied to it, and the anticipated power which the resistor will have to dissipate. If the resistor will be mounted as a through-hole element, then an axial leaded (with bent leads, or radial leaded resistor would be used. The size of either of these would be determined by the anticipated power the resistor would have to dissipate. If the resistor is going to be mounted on a printed circuit board, then a chip resistor would be used, and, once again, the size of the chip would be determined by the power to be dissipated.

NOTE: If you purchase a 10% tolerance part, the actual value of the part may be anywhere from 90 ohms to 110 ohms for a part specified as 100 ohms and still comply with the part designated value.

Failure Modes: Most resistor failures occur when either there is too much voltage applied, or current flowing through it, which causes heating which vaporizes the resistive material. Physical damage to chip resistors can happen if the chip is mounted to close to a flexible edge of a circuit board. Micro cracks on larger SMT, (2012 and up) are more common on flexible circuit boards

TYPICAL RESISTOR DESCRIPTION:
Arrays consist of multiple resistive elements on a single substrate. They are either chip type or IC-type packages
Carbon Composition resistors are, generally, not used very much now, so they are not discussed above.
Carbon film and nichrome film resistors have a film of material deposited on an inert material (usually ceramic) then a laser cut is made into the film to arrive at the desired resistance value.
Wire wound resistors are usually wound with nichrome wire, in the lower resistance value ranges. Power resistors are, generally, made from thicker nichrome wire wound on a ceramic core
Surface mount resistors are ceramic chips onto which resistive material has been deposited and are relatively low power. The resistance value is laser trimmed to the specific value desired.
### RESISTOR-TESTING

#### BASIC AND ADVANCED TEST EQUIPMENT

- **(BASIC) Hand Held Ohm or DMM Meter**
- **(ADVANCED) BENCH Digital Multimeter**

#### TEST PROCEDURE – IN AND OUT OF CIRCUIT

Disconnect the resistor from the circuit by lifting one or both leads from the circuit board. Select the appropriate range on the ohmmeter and apply one lead to each end of the resistor. The resistor may be allowed to remain on the circuit board with only one lead removed from the board for testing, but for ease of handling, it is better to completely remove it, since it will probably need to be replaced anyway.

If there is no reading on the ohmmeter, rotate the resistance range switch to see if there is a higher resistance. If there is no reading on the ohmmeter at all, this indicates an “open circuit” and the resistor has been “blown” open. This is usually caused by either a much higher voltage than the resistor is capable of, or by an excess of current which exceeds the resistor’s rating, and fuses the resistor element causing it to open. If the resistor indicated an open circuit, it must be replaced.

Resistors seldom indicate a short, but a low resistance reading on all ranges of the ohmmeter, indicates that the resistor is shorted and must be replaced.

Resistors are seldom intermittent, but this failure mode may occur due to faulty lead attachment which may open up at low temperatures. If an intermittent does occur, the change of resistance should be monitored while temperature is lowered. Mechanical agitation during this test may aggravate the problem connection and make it easier to detect.

Another failure mode of a resistor is if the resistance value of the suspect resistor changes. If the value is outside of the tolerance of the resistor value, it must be replaced in the circuit.

These are the four failure modes of a resistor: open circuit, shorted, intermittent or a resistance value change. In all cases, the failure requires that the resistor be replaced unless the change in resistance is low and stays within the tolerance of the resistor. In all cases, if there is an open or short circuit, the resistance value changes or intermittent, the cause of the change must be investigated and the effect of this change must be evaluated for the circuit.

This investigation of the failure is known as a Failure Mode Effect Analysis (FMEA) and shows both how and why the failure occurred.

Generally, it is not necessary to use an LCR meter to determine if the resistor has failed, but one can be used if an ohmmeter is not available.
Testing of resistors is divided into three basic types:
(A) Environmental - to assure that the device will work adequately within the expected environment
(B) Physical - to determine if the device will withstand the expected physical uses to which it will be subjected
(C) Electrical - to verify that the device will perform its electrical function as required by the circuit into which it will go

Environmental Tests
- These tests may or may not be required for screening the resistor to assure that it will meet the stresses imposed upon it when operated within it's normal or worst case environment.
(a) Salt Atmosphere (Corrosion) (b) Humidity (Steady State)
(c) Immersion (d) Barometric Pressure (Reduced)
(e) Moisture Resistance (f) Thermal Shock
(g) Seal (h) Life (at elevated ambient temperature)

- (a) The corrosion screen is used to simulate the effects of seacoast environments on metals with or without protective coatings, and is designed to test the effectiveness of these coatings to resist corrosion.
- (b) The humidity screen is used to evaluate the properties of the materials used in the resistor as it is influenced by the absorption and diffusion of moisture vapor.
- (c) The Immersion test is performed to detect a defective terminal assembly or a partially closed seam or molded assembly. This test detects such defects as faulty construction or mechanical damage. (usually used after seal testing)
- (d) The reduced pressure (vacuum) screen is used to simulate the low atmosphere pressure experienced by aircraft operating in high altitude flight.
- (e) Moisture resistance test is used to demonstrate the resistance of resistor parts and constituent materials to the deteriorative effects of high humidity and heat conditions typical of tropical environments.
- (f) Thermal shock is used to determine the resistance of the resistor to exposures at extremes of high and low temperatures and to the shock of alternate exposures of the resistor to these extremes. (e.g. moving of the parts to and from heated enclosures in arctic areas or in aircraft going rapidly from low to high altitudes)
- (g) Seal testing is performed to determine the effectiveness of a resistor part which has an internal cavity.
- (h) Life testing is conducted to determine the effects on electrical and mechanical characteristics of a resistor at elevated temperatures while the resistor is performing its operational function.

Physical Characteristics Tests
- These tests may or may not be required for screening the resistor to assure that it will meet the physical stresses imposed upon it when operated in it's normal and abnormal environment.
(a) Vibration (b) Random Drop
(c) High Frequency Vibration (d) High Impact Shock
(e) Solderability (f) Radiographic (X-ray) Inspection
(g) Resistance to soldering heat (h) Terminal Strength
(i) Acceleration (i) Shock (Specified Pulse)
(k) Random Vibration (l) Resistance to Solvents
(m) Particle Impact Noise Detection (PIND)

SEE PAGE TWO FOR EXPLANATION a-l
Electrical Characteristics Testing - These tests are used to verify the electrical characteristics of the resistors under test to assure that the electrical characteristics are correct, adequate and sufficient for the desired application.

(a) Dielectric Withstanding Voltage  
(b) Insulation Resistance  
(c) DC Resistance  
(d) Resistance - Temperature Characteristic  
(e) Current Noise Test  
(f) Voltage Coefficient of Resistance

(a) Dielectric Withstanding testing is used to prove that the resistor can operate safely at it's rated voltage and withstand momentary over potentials due to switching, surges and other similar phenomena.  
(b) Insulation Resistance testing is used to measure the resistance offered by the insulating members of any component part to an impressed direct voltage tending to produce a leakage current through or on the surface of these members.  
(c) DC Resistance testing measures the direct current (dc) resistance of resistors and conductors.  
(d) Resistance - Temperature Characteristic testing detects the percentage change in dc resistance from the dc resistance at the reference temperature, per unit temperature difference between the test temperature and the reference temperature.  
(e) The Current Noise Test is used to establish the "noisiness" or "noise quality" of a resistor in order to determine it's suitability for use in electronic circuits having critical noise requirements.  
(f) The voltage coefficient of resistance measures the changes in resistance with changes in voltage which occurs in certain types of resistors.

Discussion: Not everyone of these tests are performed on every resistor. Which one to be used, depends upon the anticipated operating requirements of the resistor in question. Because of the diversity of types of resistors, so there is a diversity of tests used to completely characterize each for it's particular application. The amount of testing, frequently, is determined by the specific application of the resistive element. Thus, the testing of a resistor to be used in a home TV set is much different from the testing imposed on a part which will be used for a Mars mission, even though the end result is that we have a specific device which restricts current flow by a measurable amount.
Resistor Glossary

Ambient Operating Temperature
The temperature of the air surrounding an object, neglecting small localized variations.

Bulk Resistor
A resistor made by providing ohmic contacts between two points of a homogenous, uniformly doped material.

Chip Resistor
A small rectangular resistor chip used in hybrid integrated circuits and available in either thick film or thin film construction.

Critical Resistance Value
The maximum nominal resistance value at which the rated power can be loaded without exceeding the maximum working voltage. The rated voltage is equal to the maximum working voltage in the critical resistance value.

Derating
At ambient temperatures higher than the maximum specified for full rated power, a reduced amount of power is allowable in the resistor. The allowable amount is shown in derating curves which normally end at zero power at the maximum surface temperature applicable to the resistor type.

Derating Curve
The curve that expresses the relation between the ambient temperature and the maximum value of continuously loadable power at its temperature, which is generally expressed in percentage.

Dielectric Strength
The maximum voltage of the dielectric or insulation of a resistor or potentiometer applied between the case and all terminals connected to each other, without exceeding a specified leakage current.

Dielectric Withstanding Voltage
A.C. voltage (commercial frequency effective value) that can be applied to a designated spot between the electrode and the outer coating for a minute in the dielectric withstanding voltage test. (JIS C 5201-1 4.7)

Discrete Resistors
Resistors that have a single resistive element per component.

Film Resistor
A fixed resistor relying on film properties of resistance material rather than bulk properties.

Fixed Resistors
Resistors that have a specified resistance value that does not change.

Flip Chip Resistor
An non-encapsulated resistor chip on which bead-type leads terminate on one face to permit “flip” (face down) mounting of the resistor chip by contact of the leads with interconnecting circuitry.

Hot-Spot Temperature
The maximum temperature measured on the resistor due to both internal heating and the ambient operating temperature.

Impedance
The resistance to the flow of current (represented by an electrical network of combined resistance, capacitance, and inductance reaction) in a conductor as seen by an AC source of varying time voltage measured in ohms (Ω).

Inductance
The property of a wirewound resistor that causes voltage to be set up because of a change in current through the device.

Insulation Resistance
The DC resistance measured between all terminals connected together and the case, exterior insulation, or external hardware.

Insulator
A material along which an electrical charge (current flow) cannot readily pass. Used to keep conductors apart or to prevent the escape of electricity.
**Linearity** —
The relationship of actual electrical output to the theoretical output when the theoretical output is a straight-line function.

**Low Profile** —
Components designed with “lower than standard heights,” to save space and allow clearance when mounted on PCBs.

**Maximum Overload Voltage** —
Specifications given herein may be changed at any time without prior notice. Please confirm technical specifications before you order and/or use. The maximum value of voltage capable of being applied to resistors for five seconds in the overload test (JIS C 5201-1 4.13). Typically the applied voltage in the short time overload test shall be 2.5 times larger than the rated voltage. However, it shall not exceed the maximum overload voltage.

**Maximum Working Voltage** —
The maximum value of D.C. voltage or A.C. voltage (commercial frequency effective value) capable of being applied continuously to resistors or element. However, the maximum value of the applicable voltage is the rated voltage at the critical resistance value or lower.

**Megohm (MΩ)** —
One million ohms.

**Metallization** —
A film pattern (single or multilayer) of conductive material deposited on a substrate to interconnect electronic components, or the metal film on the bonding area of a substrate which becomes a part of the bond and performs both an electrical and a mechanical function.

**Ohm’s Law** —
The formula used to determine the three basic building blocks of a circuit:
volts (V), current in amps (I), resistance in ohms (R); \( V = I \times R \).

**Output** —
The voltage, current, or power developed by a circuit in response to an input.

**PPM** —
Parts per million. The terminology used when describing the temperature coefficient.

**Passive Components** —
Components such as capacitors and resistors, which have no gain characteristics.

**Paste/Ink** —
Screenable, thick film material composed of metals, oxides, and glasses in an organic vehicle which when fired, produces a circuit element such as a resistor or conductor.

**Rated Ambient Temperature** —
The maximum ambient temperature at which resistors are capable of being used continuously with the prescribed rated load (power). The rated ambient temperature refers to the temperature around the resistors inside the equipment, not to the air- temperature outside the equipment.

**Rated Power** —
The maximum value of power, which can be continuously loaded to a resistor at a rated ambient temperature. Please confirm beforehand that there is such a case in a network that rated power per package as well as per element is specified.

**Rated Voltage** —
The maximum value of D.C. voltage or A.C. voltage (commercial frequency effective value) capable of being applied continuously to resistors at the rated ambient temperature. Rated voltage shall be calculated from the following formula. However, it shall not exceed the maximum working voltage.
Rated Voltage \( V \) = \sqrt{\text{Rated Power} (W) \times \text{Nominal Resistance Value}(Ω)}

**Reactance** —
Opposition to the flow of alternating current offered by capacitance, inductance or both. Both reactances are measured in ohms, and symbolized by the variable \( x \).
Resistance (unit Ohm, Ω) —
A specific property of a material depends on its molecular structure, size and temperature and in a circuit, acts to oppose an applied voltage and limit the current flowing into the circuit. Resistance is measured in ohms.

Resistive Products —
A broader term that describes components whose primary function is to introduce resistance into the circuit.

Resistor Element —
A continuous, unbroken length of resistive material without joints, bonds or welds except at the junction of the element and the electrical terminals connected to each end of the element, or at an intermediate point.

Resistor —
A basic component that introduces resistance in electrical and electronic circuits.

Resistor Tolerance —
The permissible deviation of the manufactured resistance value (expressed in percent) from the specified nominal resistance value at standard (or stated) environmental conditions.

Screen Print —
The process of printing a network pattern of thick-film ink or paste onto a substrate by means of a squeegee applied to a photo-etched wire-mesh “silk screen” or metal mask.

SMT/SMD —
Surface-mount technology/surface-mount device.

Stability —
The overall ability of a resistor to maintain its initial resistance value over extended periods of time, when subjected to any combination of environmental conditions and electrical stresses.

Standard Resistance Value —
The resistance value tabulated by a decade chart is specified in the applicable military specification. Resistance values not listed in the chart for the appropriate tolerances are considered as non-standard for that specification.

Surface Mount —
See SMT/SMD.

Temperature Coefficient of Resistance (TCR) —
The rate of change in resistance value per 1°C in the prescribed temperature within the range of resistors operating temperature shall be expressed in the following formula:

\[ T.C.R. (\text{ppm/°C}) = \frac{(R-R_0)}{R_0} \times \frac{1}{(T-T_0)} \times 10^6 \]

R: Measured resistance(Ω) at T °C
R₀: Measured resistance(Ω) at To °C
T: Measured test temperature(°C)
To: Measured base temperature(°C)

Tolerance —
Usually applies to the extent from which the actual resistance reading may vary from the rated resistance value when it is actually tested.

Tracking —
The inherent capability of resistors from the same formulation and screened onto the same substrate to exhibit similar performance characteristics (e.g., drift, TCR).

Voltage (unit Volt, V) —
The electromotive force trying to move electrons from negative to positive; the “pressure” in the circuit.

Watt (W) —
Practical unit of electrical power. One watt is the power delivered when a current of one ampere is driven by one volt.
Wirewound Resistor —
A resistor in which the resistance element is a length of high-resistivity wire or ribbon, wound onto an insulating core, then encapsulated in a vitreous enamel, silicone or cement compound.

Zero Ohm Resistors —
Products that look like resistors, but actually have no resistance and instead perform as jumpers.