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Specifying Resistors Tutorial

The resistor is the most common and well-known passive electrical component. A resistor is a device connected into an electrical circuit to introduce a specified resistance. The resistance is measured in Ohms. As stated by Ohms Law (E=IR), the current through the resistor will be directly proportional to the voltage across it and inversely proportional to the resistance.

Resistors have numerous characteristics that determine their accuracy during use. The performance indices affect the accuracy to a greater or lesser extent depending on the application. Some of these indices are: Tolerance at DC, Temperature Coefficient of Resistance (TCR), Voltage Coefficient of Resistance (VCR), Noise, Stability with respect to Time and Load, Power Rating, Physical Size, and Mounting Characteristics. Resistor networks typically require temperature and voltage tracking performance.

Please refer to the application note: Glossary of Resistor Terminology for an expanded explanation of resistor terminology.

Selection Requirements

1. Determine the resistance in ohms and watts.
2. Determine the proper physical case size as controlled by voltage, watts, mounting conditions, and circuit design requirements.
3. Select the resistor that meets your needs for type, termination and mounting.

Step 1

Ohm's Law

$E=IR$ or $I=E/R$ or $R=E/I$

Ohm's Law, as shown in the above formula, enables one to define the voltage (E), current (I), or resistance (R) when two of the three terms are known. When current and voltage are unknown they must be measured in the model circuit.

Power Law

$W=I^2R$ or $W=EI$ or $W=E^2/R$

Watts (power) can be determined from the above formulas that are derived from Ohm's Law. R is measured in Ohms, E in volts, I in amperes, and W in watts.

Watts must be accurately determined before resistor selection. Simply stated any change in voltage or current produces a much larger change in wattage (heat dissipated by the resistor). The effects of relatively small increases in voltage or current must be determined because the increase in wattage may be significant enough to influence resistor selection. As stated in the above formulas the wattage varies as the square of the current or voltage. Allowances should be made for maximum possible voltage.

Step 2

Power Rating and Physical Size

A resistor operated at a constant wattage will reach a steady temperature that is determined largely upon the ratio between the substrate size (surface area) and the wattage dissipated. Temperature stabilizes when the sum of the heat loss rates (by radiation, convection, and conduction) equals heat input rate (wattage). The larger the resistor surface area per watt to be dissipated, the greater the heat loss rate and therefore the lower the temperature rise.

Free Air Wattage Rating (Maximum Power Rating) is defined as the wattage rating of resistors as established under specified standard conditions. The absolute temperature rise for a specific resistor is roughly related to the area of its radiating surface. It is also dependent upon a number of other factors such as thermal conductivity, ratio of length to width, heat-sink effects of mounting, and other minor factors.

The precise temperature limits corresponding to 100% rated wattage are somewhat arbitrary and serve primarily as design targets. Once a wattage rating has been assigned on the basis of an empirical hot spot limit, the verification of its correctness must be established through long term load life test (see Application Note: Life Test Data – High Voltage Chip Resistors) based on performance and stability standards rather than the measurement of hot spot temperature.

Step 3

Resistor Selection

Select the most suitable resistor that meets the requirements of the application. OhmCraft resistors are made to your specification. Refer to the appropriate data sheet to determine part number or call OhmCraft for assistance.

Wattage Rating

To allow for the differences between actual operating conditions and the **Free Air Wattage Rating** it is a general engineering practice to operate resistors at less than the nominal rating.

Voltage Rating

Determine maximum applied (working) voltage that the resistor will be exposed to and select the appropriate package size.

Pulse Operation

When a resistor is operated in a pulse application, the total power dissipated by the resistor is a function of the pulse's duty cycle. Typically, one will define the number of joules of energy the resistor must dissipate and choose a resistor accordingly. For additional information refer to our Pulse Resistor white paper or contact OhmCraft.

High Frequency

OhmCraft resistors, due to their design and construction, have very low capacitance and are inherently a non-inductive design. For additional information refer to our High Frequency Attributes Application Note.

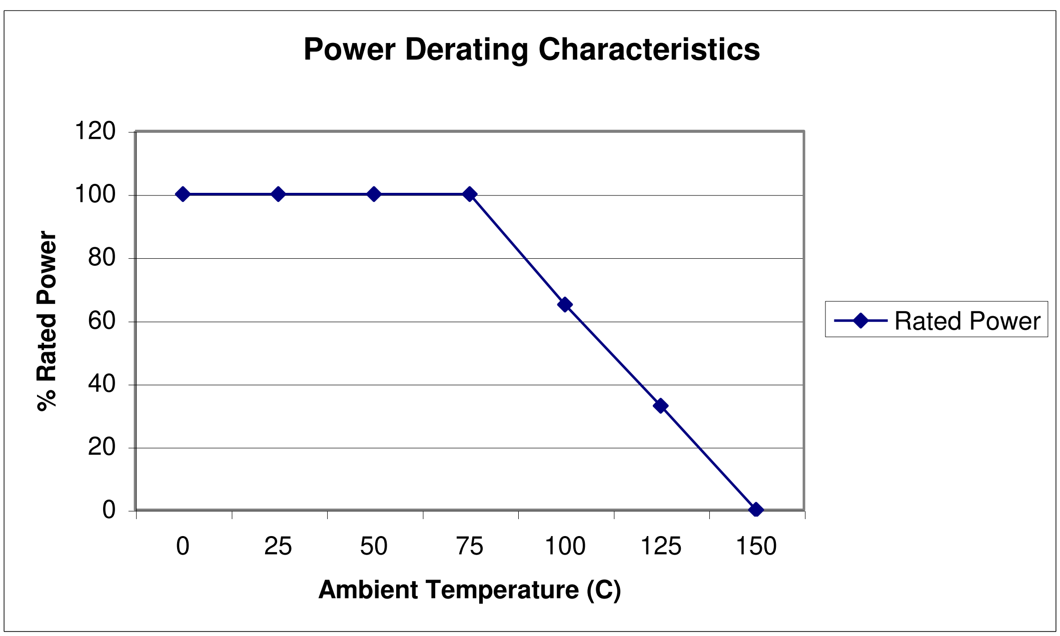
Military and Other Specification

The special physical operating and test requirements of the applicable industrial or military specification must be considered. Contact OhmCraft for additional information.

Effect of the power ratings on components

All the components of an electrical apparatus including resistors, capacitors, rectifiers, and semi-conductors have their own limitations as to the maximum temperature at which they can reliably operate. The attained temperature in operation is the sum of the ambient temperature plus the temperature rise due to the heat dissipation in the equipment.

Ambient Temperature Derating, below defines the percent of full load that power resistors can dissipate as a function of ambient temperature.



Temperature Coefficient of Resistance

Temperature Coefficient of Resistance (TCR) is expressed as the change in resistance in ppm (0.0001%) with each degree of change in temperature Celsius (°C). MIL STD 202 Method 304 is often referenced as a standard for measuring TCR. This change is not linear with temperature. TCR is typically referenced at +25°C and changes as the temperature increases or decreases. It can be either a bell or S shaped curve. It is treated as being linear unless very accurate measurements are required, then a temperature correction chart is used. A resistor with a TCR of 100 ppm will change 0.1% over a 10-degree change and 1% over a 100-degree change. An example of a TCR curve can be found in the application note: Glossary of Resistor Terminology.

The following formula expresses the rate of change in resistance value per 1 °C in a prescribed temperature range.

$$TCR\ (ppm/°C) = (R-R_0)/R_0 \times 1/(T-T_0) \times 10^6$$

- R: Measured resistance (Ω) at T °C
- R_0: Measured resistance (Ω) at T_0 °C
- T: Measured test temperature °C
- T_0: Measured test temperature °C

In the context of a resistor network, this TCR value is called **absolute TCR** in that it defines the TCR of a specific resistor element. The term **TCR tracking** refers to the difference in TCR between each specific resistor in the network.

Voltage Coefficient of Resistance

The Voltage Coefficient of Resistance is the change in resistance with applied voltage. This is entirely different and in addition to the effects of self-heating when power is applied. A resistor with a VCR of 100 ppm/V will change 0.1% over a 10 Volt change and 1% over a 100 Volt change. VCR becomes very important in high Ohmic value resistor (100M Ω and above) where typical VCRs can be greater than 1000 ppm/V to specify the voltage that will be applied. Failing to do this may result in a resistor that will not meet your specification.

The rate of change in resistance value per 1 volt in the prescribed voltage range is expressed by the following formula:

$$VCR\ (ppm/V) = (R_0-R)/\ R_0 \times 1/(V_0-V) \times 10^6$$

- R: Measured resistance (Ω) at base voltage
- R_0: Measured resistance (Ω) at upper voltage
- V: Base voltage
- V_0: Upper voltage

In the context of a resistor network, this VCR value is called the **absolute VCR** in that it defines the VCR of a specific resistor element. The term **VCR tracking** refers to the difference in VCR between each specific resistor network. Please refer to the application note: Voltage Ratio Tracking and Voltage Coefficient of Resistance.

Summary

When specifying a resistor, the following parameters MAY be of interest. Please use this chart to help you define the operating characteristics for your specific application. All of them may not important for your specific application. Also, please do not hesitate to contact Ohmcraft for application help.

Parameter	Value	Typical Units
Resistance – E/I	________________________	Ohms
Tolerance[1]	________________________	%
Watts – I^2R	________________________	Watts
Maximum Voltage[2]	________________________	Volts
TCR Requirement	________________________	ppm/°C
VCR Requirements	________________________	ppm/V
For a divider, such as the HVD Series		
Absolute TCR	________________________	ppm/°C
TCR Tracking	________________________	ppm/°C
Absolute VCR	________________________	ppm/V
VCR Tracking	________________________	ppm/V
Ratio[3]	________________________	(example 100:1)
For Pulse withstanding applications:		
Pulse	________________________	Joules
Capacitor Size	________________________	Farads
Pulse Type	________________________	[RC decay, Flat Top, or Transient]
Time Constant	________________________	milliseconds
Duty Cycle	________________________	[What is waveform? Application?]

[1]Tolerance is defined as the ± percentage the Ohmic value can vary from nominal.

[2] Refer to appropriate data sheet (SM Series 350 volts or less, HVC Series 300 to 2500 volts, HVR Series 2KV to 40KV, and HVD Series 4KV to 40 KV).

[3]Ratio can be defined as $R_{(High)} / R_{(Low)}$ or $R_{(High)} + R_{(Low)} / R_{(Low)}$. Please specify!