Thermal Considerations for Resistors

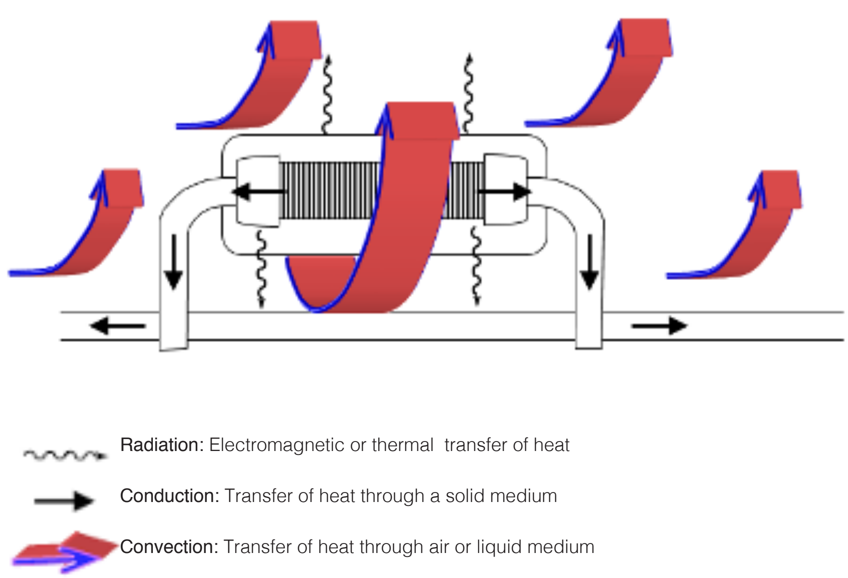
Introduction

Designing circuitry with resistors requires careful consideration of heat buildup and heat dissipation. By their very nature resistors generate heat (by converting electrical energy into heat energy) so it is important to ensure that effective release of such heat is achieved and heat buildup is avoided, since improper or ineffective heat dissipation is a major cause of resistor failure. Several factors should be reviewed and addressed when evaluating thermal aspects for resistors. These factors include external conditions, physical positioning and temperature rise characteristics. Heatsinks and fans also play a role in aiding heat dissipation.

External Conditions

In electronic circuits, temperature rise is significantly impacted by external conditions. Heat is transferred from regions of high temperature to regions of low temperature via radiation, conduction and convection. The following diagram depicts the three types of head dissipation and how each occurs in and around the component.

Heat Dissipation of a Typical Axial Lead Resistor



Radiation

Radiation is a type of heat transference between materials that occurs without any medium. In general, radiation is a minor contributor to heat dissipation. In fact it is often ignored in surface mount resistors, small leaded resistors (2 watts and below) and some heatsink resistors, but it can be quite significant in higher power resistors. Large power resistors typically operate at very high surface temperatures (275ºC to 350°C). At this level, radiation often accounts for 50% or more of the total power transferred.

Conduction
Conduction is the process of transferring heat through leads and terminations. It typically accounts for 50% or more of heat transfer for surface mount and small leaded resistors; it can be as much as 90% on heatsink resistors. The heatsink selection and mounting can therefore have a huge impact on resistor temperature rise and power capability. For optimum cooling without a heatsink, be sure to keep leads short and terminate them to points of sufficient mass to act as heatsinks. If available, specify heavy gauge lead wires. For additional information see Reference (1).

Convection
Natural convection is the process of allowing the air or liquid medium surrounding a component or heatsink to remove heat without applying external forced circulation. For instance, as a result of self-heating in a resistor body, the heat rises, creating its own natural velocity. To take advantage of this natural convection, it is important to mount resistors in such a way that the air flow is not impeded. When mounted, resistors should not come in contact with heat-insulating surfaces. When coating or potting circuits, the use of high thermal conductivity materials may help reduce body temperature whereas low thermal conductivity materials may impede the transfer of heat, resulting in an “oven effect”. Forced air or liquid convection can make a tremendous difference in cooling effectiveness. Improvements by an order of magnitude are achievable. For additional information see Reference (2).

Resistor Positioning

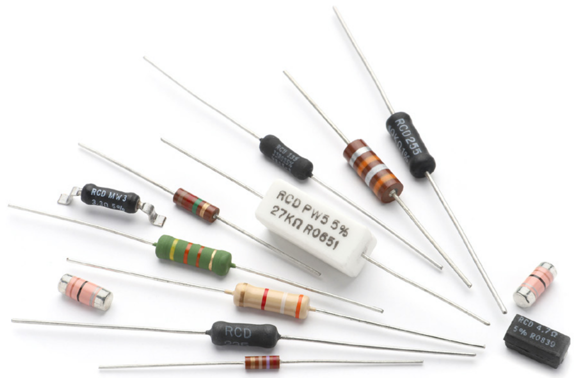
In addition to some of the mounting suggestions above, it is important to consider thermal EMF (electro-motive force). Whenever there is a junction between dissimilar metals, a small voltage is produced. The level of voltage varies with temperature. As such it is called a thermal EMF or “thermocouple” effect, since it is the same principal which enables thermocouples to act as temperature sensors. Since resistor leads are generally made from a material which is different than that of the resistance material, thermal EMF’s result from a heat source, either external and/or internal (self-heating). Consideration should be given to component placement to ensure uniform body temperature (i.e. avoid positioning a heat generating component at one end of resistor and avoid tying one lead to cool ground plane). Thermal EMF’s have polarity, therefore (as an example) one end of a resistor might be a +20μV/degree generator and the other end a -20μV/degree generator. In the ideal situation where both ends of the resistor are at the same temperature, the thermal EMFs are self-cancelling, resulting in an actual in-circuit thermal EMF near zero. Circuits sensitive to thermal EMF require consideration to optimize layout to achieve a uniform temperature at each end of the resistor body. For additional information see Reference (3).

Temperature Rise Characteristics

It is recommended that resistor components be selected to ensure reasonably low temperature rise levels. The temperature rise of a resistor can vary depending on resistance value, coating material, coating thickness, lead wire material, lead wire diameter and other factors. Estimated temperature rise for a sampling of RCD’s standard resistors, such as those shown below, is available in the Addendum (p.6). Information in that table is based on a free air (natural convection) environment, with resistors horizontally mounted; the exception is resistors with radial leads which are specifically designed to be vertically mounted. Please contact RCD for information on non-standard or modified versions and for items not listed.

Please note that the temperature rise information in the Addendum table should be utilized as an estimate for component selection; it should be verified by evaluating resistors under actual-use conditions. It is also important to note that since temperature rise can vary depending on raw material sources and other factors, standard resistors should not be used as “heaters”. RCD offers controlled designs for such applications; please contact us for assistance.

Examples of RCD's Standard Resistors



Temperature-Sensitive Resistors

The self-heating characteristic of a temperature-sensitive resistor is not as straightforward as it is with other resistors. This is due to the fact that as the temperature-sensitive resistor increases in temperature (due to the wattage dissipated), the resistance value increases, thereby resulting in a lower wattage level. For example, RCD temperature-sensitive resistor type 135 100Ω 3W will exhibit a temperature rise of approximately 200°C when 17.3V is applied. Note: 17.3V equates to 3W as determined by Ohm's Law below (where P is power, E is voltage and R is resistance).

$$P = E^2/R = (17.3V)^2 \div 100\Omega = 3 \text{ watts}$$

The same resistor wound with +6000 ppm TCR (Temperature Coefficient of Resistance) wire will exhibit a temperature rise of only 140°C, even though the same voltage level is applied. Of note, the relationship between temperature rise and TCR is not linear due to the fact that part of the resistance windings towards the ends of the body are heatsinked by the caps and leads and therefore do not exhibit the same temperature rise as the center windings.

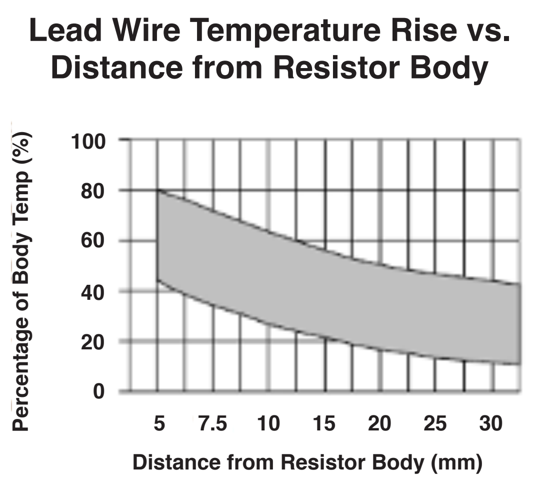
The following temperature rise table is provided as a guideline for RCD's temperature-sensitive (ATS) resistor series. Please note that temperature rise can vary significantly due to variations in coating thickness, mounting layout, PCB materials, resistor body size and lead-wire material. Therefore the information provided below is intended as an aid to assist in the general selection of parts. Users should test and verify components in actual use conditions to determine final suitability. Customized versions are available; please contact RCD for assistance.

Temperature-Sensitive Resistors
Estimated Temperature Rise vs. TCR of Wire

RCD Resistor Type	°C/W for TCR of 0 ppm	°C/W for TCR of +1000 ppm	°C/W for TCR of +3500 ppm	°C/W for TCR of +6000 ppm
ATS110	170	156	130	117
ATS125	125	115	95	86
ATS135	70	64	53	48
ATS145	65	60	50	45
ATS150	65	60	50	45
ATS155	57	52	43	39
ATS160	44	40	34	30
ATS170	35	32	27	24
ATS175	24	22	18	17

Additional Considerations

In some circumstances it is important to understand the thermal aspects of the resistor's lead wire/solder joint as relates to the self-heating effect of leaded resistors under load. Please refer to the graph below which provides an approximation of lead wire temperature (as a percent of the resistor's body temperature) based on distance from the resistor body. For example, if a resistor is expected to have a 200ºC hot-spot temperature rise (above ambient), the temperature rise of the lead wires will be roughly 50% that of the body, or 100ºC. Lead wire temperature varies due to material composition, diameter, resistor construction and PCB geometry, as discussed below. These variations are reflected in the data range (band) in the graph below.



Lead Wire Composition
Copperweld© (copper plated steel) leads have lower thermal conductivity than copper so they do not dissipate heat as well as copper. As a result, copperweld leads typically exhibit lower percentage-of-body-temperature values (bottom half of the curve in the graph above). Copperweld leads have higher resistivity than copper and therefore will have a greater impact on in-circuit resistance and TCR of low value resistors. Copperweld leads are available on most RCD products by specifying Option 'CW'.

Lead Wire Diameter
Heavier gauge leads should be specified when it is important to reduce solder joint temperature. The heavier gauge leads are more effective at conducting the heat to the solder joint (which acts as a heatsink). This results in lower temperature of the resistor and the solder joint.

Resistor Construction
The use of specialty high-thermal conductivity cores to increase power ratings results in greater transfer of heat to the ends of the body and subsequently into the lead wires. These higher power versions (such as RCD Option "B", Series 200) would generally have lead wire temperatures in the top half of the curve in the graph above.

PCB Geometry
Designs that utilize heavy copper traces or ground planes (which act as heatsinks) provide reductions in the temperature rise of the lead wires and solder joint. The graph above was developed based on typical PCB layouts; by increasing the heatsink mass, designers can often reduce temperature levels significantly (often below the low range in the graph above).

IN CONCLUSION

When designing electronic circuits with resistors, many factors play a role in heat build-up and heat dissipation, including external conditions, physical positioning, temperature rise characteristics, temperature sensitivity and lead wire configuration. All of these factors warrant consideration to ensure that resistors have appropriate heat dissipation in order to avoid component failure. As with most electronic designs the intertwining nature of these factors must be evaluated as a whole in order to come up with a practical and technically acceptable solution for a specific application.

For assistance please contact RCD at +1-603-669-0054 or via email at sales@RCDcomponents.com.

REFERENCES

(1) Application Guide R-34A, "Mounting Guidelines for RCD Heat Sinkable Resistors"

(2) Application Guide R-33, "Forced Air Convection Across Power Resistors"

(3) Application Guide R-32, "Thermal EMF"

Note: this March 2021 Tech Tip is based on RCD's Application Guide R-35

HELPFUL INFORMATION

- Resistor Products from RCD
- Temperature-Sensitive Resistors
- Additional Technical Resources

The estimated temperature rise for a sampling of RCD's standard resistors appears in the Addendum on the next page.

To access downloadable versions of this and prior technical tips please click here.

If you have any questions about this Technical Tip, suggestions for future Technical Tips, or need assistance with our standard or custom products, please contact us.

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ADDENDUM

Standard Resistors Estimated Temperature Rise

RCD Resistor Type	RCD Resistor Description	Temperature Rise (°C/W)
125	WW	130
130	WW	110
133	WW	90
135	WW	64
155	WW	58
160	WW	44
170	WW	36
175	WW	25
202	WW	130
210	WW	105
232	WW	75
235	WW	43
255	WW	36
272	WW	27
605	WW, AH	9[5]
605B	WW, AH	6[5]
610	WW, AH	7[5]
610B	WW, AH	4.5[5]
615	WW, AH	5[5]
615B	WW, AH	4[5]
620	WW, AH	3[5]
620B	WW, AH	2.3[5]
625	WW, AH	2[5]
625B	WW, AH	1.5[5]
630	WW, AH	1.2[5]
635	WW, AH	1[5]
635B	WW, AH	0.75[5]
640	WW, AH	0.70[5]
640B	WW, AH	0.60[5]
ATS	WW, TS	See p.3
BLU0402	SM	380[1]
BLU0603	SM	320[1]
BLU0805	SM	260[1]
BLU1206	SM	180[1]
BLU1210	SM	140[1]
CC1/4	SU	140

RCD Resistor Type	RCD Resistor Description	Temperature Rise (°C/W)
CC1/2	SU	100
CC1	SU	50
CF (standard)	FI	35-90[7]
CF (Opt. S)	FI	60-90[7]
GP (standard)	FI	40-60[6]
GP (Opt. S)	FI	60-90[6]
HDP126	PF, SP	5.5[5]
HDP220	PF, SP	2.9[5]
HDP247	PF, SP	1.5[5]
MC0402	SM	380[1]
MC0603	SM	320[1]
MC0805	SM	260[1]
MC1206	SM	180[1]
MC1210	SM	140[1]
MC2010	SM	115[1]
MC2512	SM	75[1]
MC2040	SM	35[1]
MCF (standard)	SM	40-60[7]
MCF25 (Opt. S)	SM	160
MGP (standard)	SM, FI	40-60[6]
MGP (Opt. S)	SM, FI	60-90[6]
MP220	PF	5[5]
MPF1	SM, FI	100[3]
MPF2	SM, FI	50[3]
MPF2S	SM, FI	75[4]
MPF3	SM, FI	33[3]
MPF3S	SM, FI	50[4]
MWM1/2	SM	180[1]
MWM1/2L	SM	170[1]
MWM1	SM	100[1]
MWM1L	SM	95[1]
MWM2	SM	60[1]
MWM2L	SM	65[1]
MWM2S	SM	75[1]
MWM3	SM	40[1]
MWM3S	SM	45[1]

RCD Resistor Type	RCD Resistor Description	Temperature Rise (°C/W)
MWM5	SM	30[1]
MW1/2	WW, SM	125[1]
MW1	WW, SM	98[3]
MW2	WW, SM	65[3]
MW25	WW, SM	54[3]
MW35	WW, SM	46[4]
MW3	WW, SM	50[3]
MW5	WW, SM	40[4]
PW2	WW, CE	60
PW3	WW, CE	45
PW5	WW, CE	35
PW7	WW, CE	25
PW10	WW, CE	19
PW15	WW, CE	15
PW20	WW, CE	11
PW22	WW, CE	11
PW25	WW, CE	10
RMF1/2	FI, PF	140
RMF1	FI, PF	100
RMF2	FI, PF	75
RMF3	FI, PF	50
RMF5	FI, PF	30
RMF5S	FI, PF	40
RMF7	FI, PF	27
RSF1A	FI, PF	110
RSF1B	FI, PF	90
RSF2B	FI, PF	60
RSF3B	FI, PF	44
RSF5B	FI, PF	32
RSF7B	FI, PF	25
RW1	WW	110
RW2	WW	90
RW3	WW	60
SF1	WW, SM, LO	88[1]
SFG2	WW, SM, LO	70[1]
T	WW	250-325[2]

Footnote Descriptions:

[1] The temperature rise of surface mount resistors is highly dependent on the PC board material, termination pad geometry and component mounting density. Temperature rise is approximate and based on DIN44050 board material, single component or low mounting density and conventional pad sizes with 2oz copper traces (trade width equal to component width). Temperature rise when mounted on alumina ceramic substrate is typically 25% to 40% less.

[2] Temperature rise at full rated power

[3] The temperature rise of surface mount resistors is highly dependent on the substrate material, termination pad goemetry and component mounting density. Temperature rise is approximate and based on DIN44050 PCB materials with 500 sq.mil circuit traces.

[4] The temperature rise of surface mount resistors is highly dependent on the substrate material, termination pad geometry, and component mounting density. Temperature rise is approximate and based on DIN44050 PCB materials with 1000 sq.mil circuit traces.

[5] Approximate thermal resistance ($R_{\theta JC}$)

[6] Temperature rise at full rated power; contact factory for Series GP/MGP detailed temperature rise chart

[7] Temperature rise at full rated power; contact factory for Series CF/MCF detailed temperature rise chart

Resistor Descriptions:

AH = Aluminum-Housed
CE = Ceramic Encased
FI = Film
LO = Low Ohm
PF = Power Film
SM = Surface Mount
SP = Specialty
SU = Surge, Pulse, Composition
TS = Temperature Sensitive
WW = Wirewound