UNITRODE

Design Note

DN-71

Using Copper PCB Etch for Low Value Resistance

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INTRODUCTION

Current sensing in power supplies and motor controls demand the use of a very low value resistor. Each application varies in need for resistance value, power rating, size, form factor, inductance, temperature coefficient and accuracy. To meet some of these applications, the copper of a printed circuit board (PCB) can be utilized, but has some distinct limitations. This design note provides design equations and recommendations for designing resistors with PCB copper.

DESIGN OF A COPPER PCB RESISTOR

The resistance, as a function of temperature, for a piece of metal, is given by the equation:

$$R(T) = \frac{S(T) \bullet l}{a}$$

with the units

R	=	Resistance, Ω
S(T)	=	Resistivity, Ω–cm
l	=	Length, cm
a	=	Area, cm^2

The characteristics of copper which are pertinent to the design of a copper PCB resistor are [1]

Electrical Resistivity:
$1.7241 \bullet 10^{-6}\Omega - cm$ @ 20°C

Temperature Coefficient of Resistivity:
+0.0039 per °C

Composition:
99.5% Pure Copper, typically

These constants apply to the standard commercially annealed copper used in PCB technology.

The resistivity of copper, as a function of temperature, is therefore defined as:

$$S(T) = 1.7241 \bullet 10^{-6} \bullet [1 + 0.0039 \bullet (T - 20)]\Omega - cm$$

where T is the copper temperature in °C.

One PCB Definition which is also pertinent to resistor design is:

1oz copper is defined as 1 ounce of copper deposited over 1 square foot of surface area. This results in a copper clad PCB with a typical copper thickness of 0.0014 inches ±0.0002 inches. 2oz copper is simply twice as thick.

Using these parameters to calculate the resistance of a given length, width, and thickness of copper PCB etch results in the formula:

$$R(T) = \frac{S(T)[\Omega - cm] \bullet Length[cm]}{Width[cm] \bullet Thickness[cm]}$$

$$= \frac{S(T)[\Omega - cm] \bullet \frac{1000mils}{2.54cm} \bullet Length(mils)}{Width(mils) \bullet Thickness(mils)}$$

The use of a low value sense resistor implies that the current in that resistor can be quite high. A copper etch on a PCB will self heat due to the power dissipated by the resistor. MIL-STD-275E [2] provides design guidelines relating copper etch current to temperature rise and etch dimensions. Figure 1 recreates sections of the MIL-STD-275E curves. A temperature rise, above ambient temperature, can be found by knowing the current and the area of the copper etch.

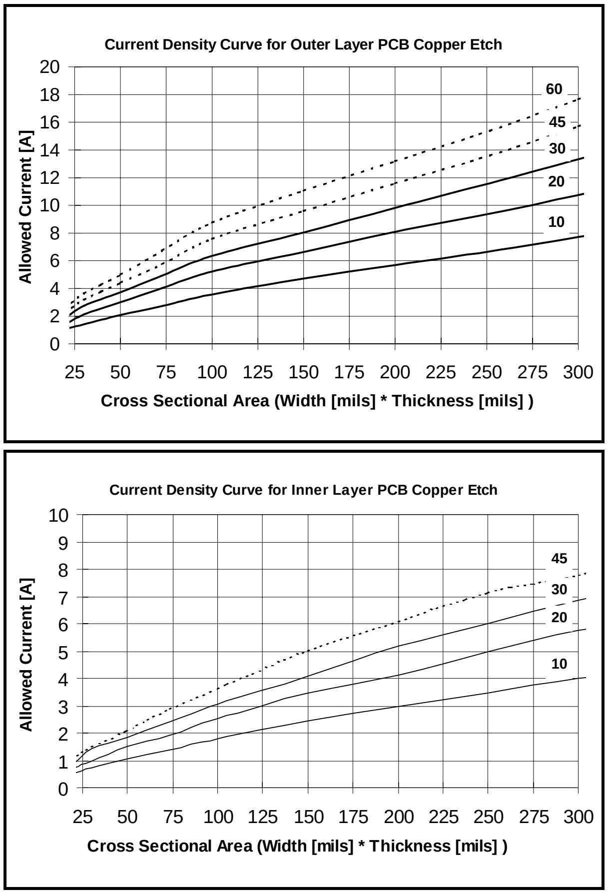

Figure 1. MIL-STD-275E Current Density vs Temperature Rise Curve for Outer and Inner Copper Layers

Example: Calculate the length and width of a 10mΩ MAXIMUM PCB resistor using 1oz on an outer layer of a PCB. The resistor must carry 10A maximum while maintaining no more than a 30°C temperature rise above ambient. Ambient temperature for normal operation is 10°C to 60°C.

Step 1:

Find the cross sectional area to carry 10A with ≤ 30°C rise, and solve for the minimum width of the resistor.

From Figure 1, 205 mils^2 are required to carry 10 Amperes. 1oz copper is 1.4mils thick, resulting in a minimum width for the resistor of 146mils.

Set Width = 150mils

Step 2:

Find the length of the resistor, insuring that it is designed for 10mΩ maximum at 60°C ambient +30°C rise (copper temperature is 90°C).

From the equations

$$S(90) = 1.7241 \bullet 10^{-6} \bullet [1 + 0.0039 \bullet (90 - 20)]\ \Omega - \text{cm}$$

and

$$R(90) = \frac{S(90)\left[\frac{\Omega - \text{cm}}{°\text{C}}\right] \bullet \frac{1000\text{mils}}{2.54\text{cm}} \bullet \text{Length[mils]}}{\text{Width[mils]} \bullet \text{Thickness[mils]}}$$

Solving for R(90°C) = 10mΩ, using150 mils for Width and 1.4 mils for Thickness results in Length = 2.43 inches.

Final Dimensions (inches): 2.43 (L) x 0.150 (W) x 0.0014 (T)

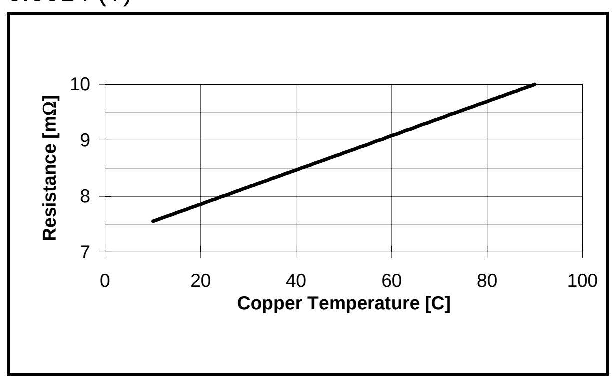

Figure 2. Resistance vs Copper Temperature for Example Design

The final resistance, as a function of the copper temperature, is shown in Figure 2.

Table 1 provides the required dimensions for a 1oz PCB copper resistor given a maximum current and desired voltage drop. Table 1 assumes a maximum operating ambient temperature of 60°C, with the width specified for a 30°C temperature rise. The required resistance is equal to V/I and is calculated at a copper temperature of 90°C.

AMPS	Desired Voltage Drop 10mV	25mV	50mV	Width [in]
	PCB Etch Length [in]			
1	0.162	0.405	0.810	0.010
2	0.243	0.608	1.215	0.015
3	0.405	1.013	2.025	0.025
4	0.648	1.620	3.240	0.040
5	0.891	2.228	4.456	0.055
6	1.053	2.633	5.266	0.065
7	1.377	3.443	6.886	0.085
8	1.701	4.253	8.506	0.105
9	2.025	5.063	10.126	0.125
10	2.430	6.076	12.152	0.150
11	2.754	6.886	13.772	0.170
12	3.078	7.696	15.392	0.190

Table1. Dimension Solver for Given Current and Desired Voltage Drop for 90°C Maximum Copper Temperaturre

Some PCB physical and layout characteristics should be considered when designing a PCB resistor.

- The thickness tolerance of PCB copper may vary from supplier to supplier and relative to location on a PCB. A typical tolerance is ±0.2mils/oz.
- Etchback will reduce the copper area, thus increasing the resistance per unit length. Etchback has a larger impact with narrow runs, where the width/thickness ratio is lower. It is recommended that widths of ≥ 0.025 inches be used.
- The copper resistor, if it is on an outer PCB layer, should be solder masked over the entire resistive area. Solder on the copper will reduce the resistance.
- Vias through the resistor will effect the resistance.
- Curved or serpentine resistor patterns may be utilized as long as the overall width and length, including curves, is understood.
- A copper resistor connected to two larger copper planes will have a lower temperature rise than predicted by the MIL-STD-275E curves due to the heatsinking of those copper planes.

CONCLUSIONS

The design of a PCB copper resistor is straightforward once operating parameters such as voltage drop, operating current and operating ambient temperature are known. Tolerances due to PCB technology will effect the accuracy of a PCB resistor and should be considered. The length-to-width ratio of a PCB resistor is quite large due to the low resistivity of copper, but when the area is available on a PCB, this resistor is essentially free.

Applications which require current limiting are ideal for use with a PCB resistor, as current limiting can be set quite accurately at the maximum operating temperature where current limiting is most critical. Average current mode control applications require precise voltage drops independent of temperature and current levels. PCB resistors are therefore not recommended for use as an Average Current Mode control sense resistor.

REFERENCES

[1] Reference Data for Radio Engineers, Howard W. Sams & Co. Inc., Sixth Edition 1977.

[2] MIL-STD-275E, NOTICE 1, 8 July 1986, Military Standard Printed Wiring for Electronic Equipment.

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