Application Hint 25

Minimum Size Copper Sense Resistors

by Jerry Kmetz

Overcurrent Sense Resistors

The Micrel MIC5156/7/8 Super LDO™ Regulator Controllers require a moderately low-value current-sensing resistor. Building the resistor from printed-circuit board (PCB) copper is attractive; arbitrary values can be provided inexpensively. The ever-shrinking world of electronic assemblies requires minimizing the physical size of this resistor, which can present a power-dissipation issue that must be resolved to provide a reliable solution. Making the resistor too small could cause excessive heat rise, leading to PCB trace damage or destruction (a fuse rather than a controlled resistor).

A demonstration board is available for evaluating the MIC5158. The circuit is designed to produce a 3.3V, 5A output from a 5V input. The design goal was to occupy as little PCB space as practical, so minimizing sense resistor area was important. In Figure 1 this resistor is shown as R_S.

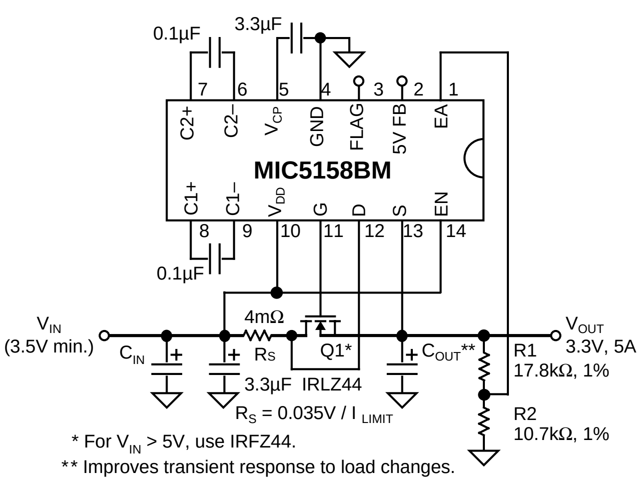

Figure 1. Regulator Circuit Diagram

Resistor Design Method

Three design equations provide a resistor that occupies the minimum area. This method considers current density as it relates to heat dissipation in a surface layer resistor.

(1) $$\rho_S(T) = \frac{\rho\left[1 + \alpha\left(T_A + T_{RISE} - 20\right)\right]}{h}$$

where:

$\rho_S(T)$ = sheet resistance at elevated temp. (Ω/□)
ρ = 0.0172 = copper resistivity at 20°C (Ω • µm)
α = 0.00393 = temperature coefficient of ρ (per °C)
T_A = ambient temperature (°C)
T_{RISE} = allowed temperature rise (°C)
h = copper trace height (µm, see Table 1).

(2) $$w = \frac{1000\, I_{MAX}}{\sqrt{\dfrac{T_{RISE} \div \theta_{SA}}{\rho_S(T)}}}$$

where:

w = minimum copper resistor trace width (mils)
I_{MAX} = maximum current for allowed T_{RISE} (A)
T_{RISE} = allowed temperature rise (°C)
θ_{SA} = resistor thermal resistance (°C • in²/W)
$\rho_S(T)$ = sheet resistance at elevated temp. (Ω/□).
Note: $\theta_{SA} \approx 55$°C • in²/W (see Figure 3).

(3) $$l = \frac{w\,R}{\rho_S(T)}$$

where:

l = resistor length (mils)
w = resistor width (mils)
R = desired resistance (Ω)
$\rho_S(T)$ = sheet resistance at elevated temp. (Ω/□).

Design Example

The 4-mΩ current-sensing resistor (R_S) of Figure 1 is designed as follows: (1) based on copper trace height and an allowed temperature rise for the resistor, calculate the sheet resistance (Equation 1); (2) based on the maximum current the resistor will have to sustain, calculate its minimum trace width (Equation 2); and (3) based on the desired resistance, calculate the required trace length (Equation 3).

Calculate Sheet Resistance

This design uses 1 oz/ft² weight PCB material, which has a copper thickness (trace height) of 35.6µm. See Table 1. It was also decided to allow the resistor to produce a 75°C temperature rise, which would place it at 100°C (worst case) when operating in a 25°C ambient environment. Then:

$$\rho_S(T) = \frac{\rho\left[1 + \alpha\left(T_A + T_{RISE} - 20\right)\right]}{h}$$

$$\rho_S(T) = \frac{0.0172\left[1 + 0.00393\,(25 + 75 - 20)\right]}{35.6}$$

$\rho_S(T) = 635 \times 10^{-6}$ Ω = 0.635 mΩ/□.

Calculate Minimum Trace Width

The design example provides an output current of 5A. Because of resistor tolerance and the current-limit trip-point specification of the MIC5158 (0.028 to 0.042V), a trip-point of 8.75A is chosen. It was also decided to allow for as much as 10A of current during the sustained limiting condition. Then:

$$w = \frac{1000\ I_{MAX}}{\sqrt{\frac{T_{RISE} \div \theta_{SA}}{\rho_S(T)}}}$$

$$w = \frac{1000 \times 10}{\sqrt{\frac{75 \div 55}{635 \times 10^{-6}}}}$$

w = 215.8 mils ≈ 216 mils.

Calculate Required Trace Length

The length of a 4-mΩ resistor is determined via Equation 3 as follows:

$$l = \frac{w\,R}{\rho_S(T)}$$

$$l = \frac{216 \times 0.004}{635 \times 10^{-6}}$$

l = 1360.6 mils ≈ 1361 mils.

Resistor Layout

To avoid errors caused by voltage drops in the power leads, the resistor should include Kelvin sensing leads. Figure 2 illustrates a layout incorporating Kelvin sensing leads.

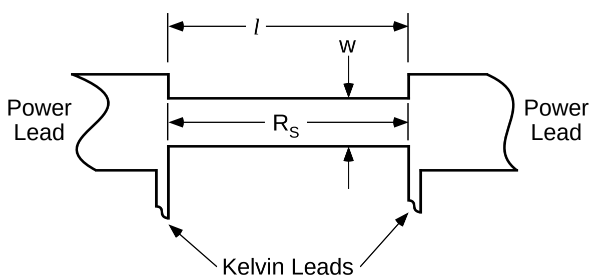

Figure 2. Typical Resistor Layout

Thermal Considerations

The above equations produce a resistance of the desired value at *elevated temperature*. It is important to consider resistance at temperature because copper has a high temperature coefficient. This design method is appropriate for current-sensing resistors because their accuracy should be optimized for the current they are intended to sense.

References

Table 1 and Figure 3 are provided as support and background information. Table 1 provides an input needed for Equation 1 (trace height), and Figure 3 indicates that 1 in^2 (645 mm^2) of solder-masked copper in still air has a thermal resistance of 55°C/W. Different situations; e.g., internal layers or plated copper, will have different thermal resistances. Other references include:

MIL-STD-275E: *Printed Wiring for Electronic Equipment.*

Application Hint 17: “Calculating P.C. Board Heat Sink Area For Surface Mount Packages,” *Micrel 1995 Databook.*

Application Hint 21: “Sense Resistors for the Super LDO™ Regulator,” *Micrel 1995 Databook.*

PCB Weight	Copper Trace Height	
(oz/ft^2)	(mils)	(µm)
1/2	0.7	17.8
1	1.4	35.6
2	2.8	71.1
3	4.2	106.7

Table 1. Copper Trace Heights

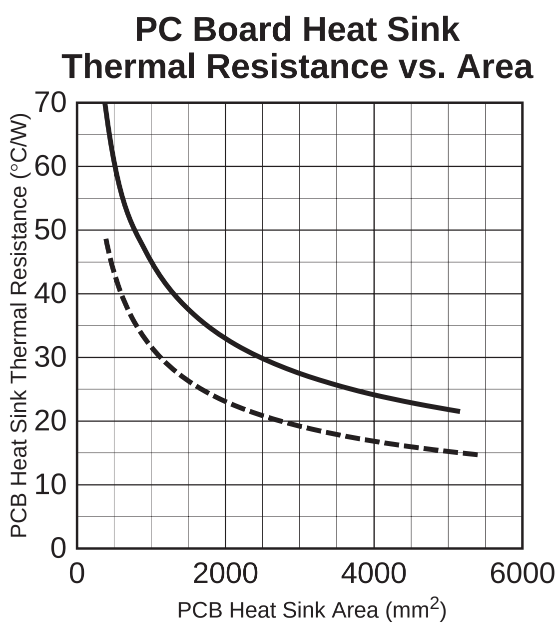

Figure 3. Thermal Resistance of Copper Trace Area