AND8391/D

Thermal Considerations for the ON Semiconductor Family of Discrete Constant Current Regulators (CCR) for Driving LEDs

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APPLICATION NOTE

Introduction

The ON Semiconductor Constant Current Regulator (CCR) family of devices offer outstanding regulation for LEDs and other current based loads, such as battery charging circuits. The CCR reduces the complexity of resistor biased designs for sensitive loads, such as LED strings connected in series. The CCR can also be connected in parallel for higher load current applications. The two-terminal CCR requires no external components to regulate at the specified current. These devices can be used wherever a constant current is needed to maintain luminosity under varying voltage conditions.

See application note AND8349/D for basic circuit considerations.

The purpose of this paper is to explore the temperature and power boundaries for devices in the SOD−123 and SOT−223 packages operating from typical currents of 20 mA to 30 mA in applications. The SOD−123 devices available are rated at 20 mA, 25 mA, and 30 mA. The SOT−223 devices are rated at 25 mA and 30 mA. See Appendix A for device list.

Reference to Datasheet

The datasheet describes the devices and defines the following terms that will be used throughout this note:

Vak = Voltage applied between the Anode and Cathode of the device.

$V_{overhead} = V_{IN} - V_{LEDs}$

$I_{reg(SS)}$ = The current through the device supplied to the LEDs under steady−state operating conditions (device on ≥ 10 sec)

$I_{reg(P)}$ = The current through the device supplied to the LEDs under pulse test conditions (≤ 300 μsec)

V_R = Reverse Voltage

P_D = Device power dissipation, typically in mW

T_A = Ambient Temperature in °C

T_J = Device Junction Temperature in °C

The SOD−123 and SOT−223 Datasheet Thermal Characteristics table lists the thermal performance of each device as related to the heat spreader area and thickness. These datasheet tables and curves show thermal specifications and limits with the device junction temperature (T_J) operating at 150°C, the maximum allowable continuous junction temperature.

Operating at $T_{J\,max}$ continuously is not recommended for long term reliability.

Figure 1 shows power dissipation over changes in ambient temperature for the SOD−123 package. Figure 2 shows θ_{JA} (°C/W) and P_D (W) for various Cu areas and thicknesses. These tables and graphs illustrate the effect of Cu area, thickness and ambient temperature (T_A) over the range of −40°C to 85°C, which encompasses the area of interest for LED operation. LED data sheets show an extreme reduction in luminosity above 85°C T_A.

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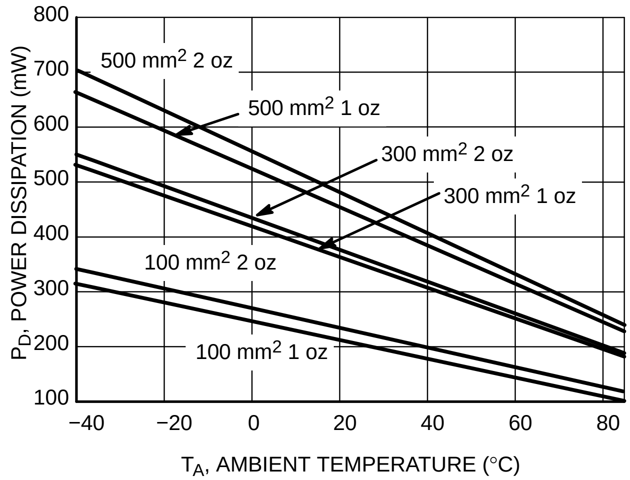

Figure 1. Power Dissipation vs. Ambient Temperature (SOD−123) @ T_J = 150°C for Variable Copper Heat Spreader

P_D max @ 85°C

500 mm^2 2 oz Cu	241 mW
500 mm^2 1 oz Cu	228 mW
300 mm^2 2 oz Cu	189 mW
300 mm^2 1 oz Cu	182 mW
100 mm^2 2 oz Cu	117 mW
100 mm^2 1 oz Cu	108 mW

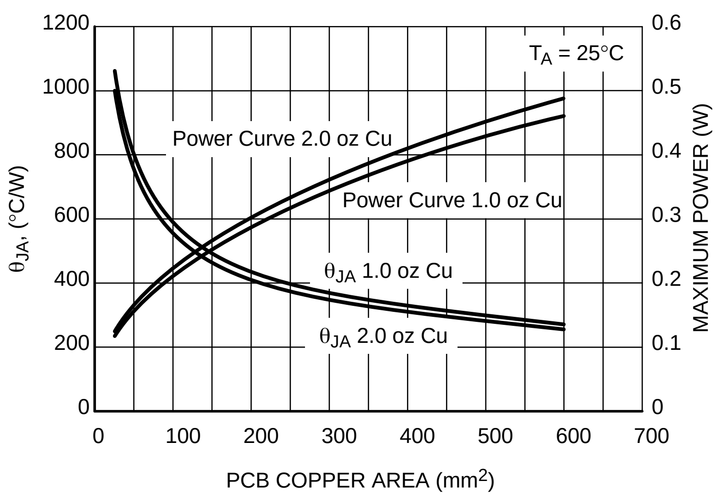

Figure 2. SOD−123 NSI14030T1G θ_{JA} and P_D vs. Cu Area

Figure 3 shows power dissipation over changes in ambient temperature for the SOT−223 package. Figure 4 shows θ_{JA} (°C/W) and P_D (W) for various Cu areas and thicknesses. These tables and graphs illustrate the effect of Cu area, thickness and ambient temperature (T_A) over the range of −40°C to 85°C which encompasses the area of interest for LED operation.

NOTE: 300 mm^2 2 oz Cu area has better thermal performance than 500 mm^2 1 oz Cu for this package.

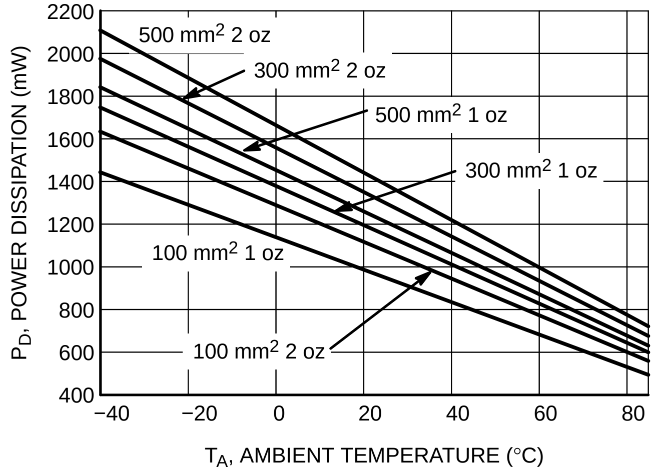

Figure 3. Power Dissipation vs. Ambient Temperature (SOT−223) @ T_J = 150°C

P_D max @ 85°C

500 mm^2 2 oz Cu	722 mW
300 mm^2 2 oz Cu	676 mW
500 mm^2 1 oz Cu	631 mW
300 mm^2 1 oz Cu	598 mW
100 mm^2 2 oz Cu	559 mW
100 mm^2 1 oz Cu	494 mW

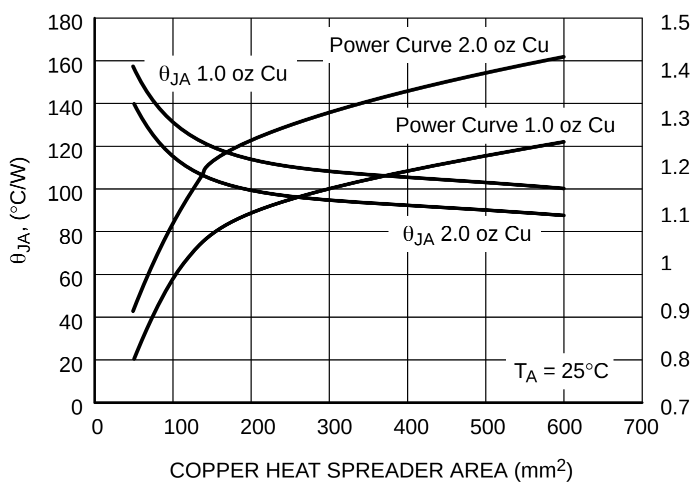

Figure 4. SOT−223 θ_{JA} and P_D vs. Cu Area

PC board design and the use of multilayer board material will affect the thermal performance. See ON Semiconductor application notes AND8220/D and AND8222/D for further information.

Ambient operating temperature (T_A) and estimated device power will help determine which package to use.

Figures 2 and 4 can be used to quickly determine which package and heat sink is a good candidate for the application.

Current Regulation: Pulse Mode vs. Steady-State

NOTE: All curves are based upon a typical 30 mA CCR device.

There are two methods of measuring current regulation: Pulse mode ($I_{reg(P)}$) testing is applicable for factory and incoming inspection of a CCR where the test times are a minimum ($t \leq 300$ μs). DC steady-state ($I_{reg(SS)}$) testing is applicable for application verification where the CCR will be operational for seconds, minutes or hours. ON Semiconductor has correlated the difference in $I_{reg(P)}$ to $I_{reg(SS)}$ for stated board material, size, copper area and copper thickness. $I_{reg(P)}$ will always be greater than $I_{reg(SS)}$ due to the die temperature rising during $I_{reg(SS)}$. This heating effect can be minimized during circuit design with the correct selection of board material, metal trace size and weight for the operating current, voltage, and board operating temperature (T_A) and package. (Refer to the Thermal Characteristics table in datasheet).

The curves of Figure 5 for the SOD−123 and Figure 6 for the SOT−223 packages show the relationship between I_{reg} and time. I_{reg} decreases with time due to the effect of power on the die.

I_{reg} vs. TIME

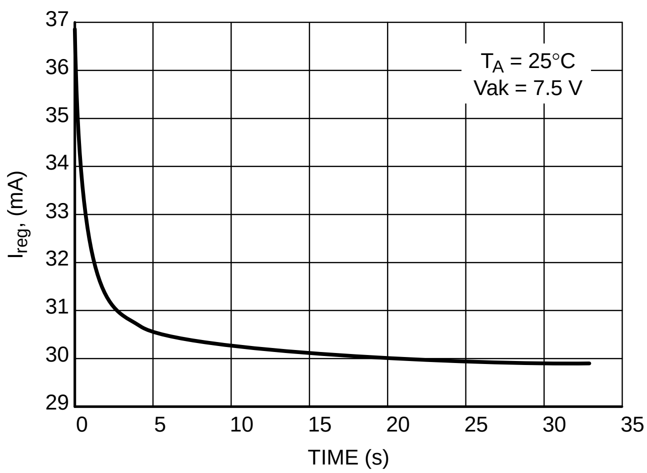

Figure 5. Typical SOD−123 30 mA, 300 mm^2, 1 oz Cu, In Still Air

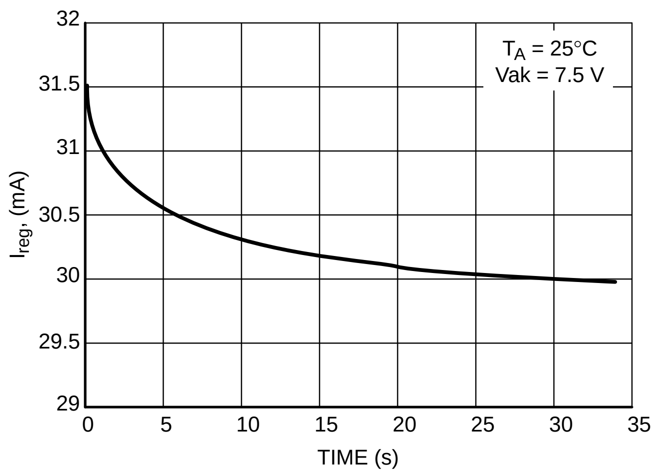

Figure 6. Typical SOT−223 30 mA, 300 mm^2, 2 oz Cu, In Still Air

Correlation studies show that for each package steady state I_{reg} there is a corresponding Pulsed I_{reg} value. Notice on these two-terminal devices that the SOT−223 $I_{reg(P)}$ has a lower value than the SOD−123 $I_{reg(P)}$, which results in $I_{reg(SS)}$ of 30 mA. This is due to the better $R_{\theta JA}$ of the SOT−223. See Figures 7 and 8. The slope of the line in Figures 7 and 8 will change if the actual footprint and board thermal properties differ from the footprint listed in the figures.

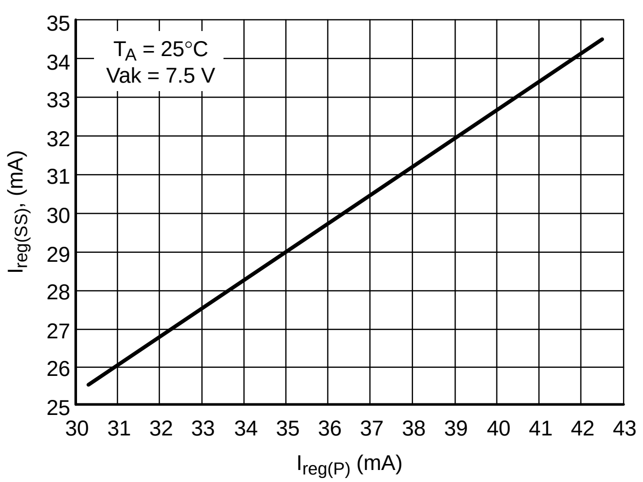

Figure 7. $I_{reg(SS)}$ vs. $I_{reg(P)}$ Testing SOD−123, 300 mm^2, 1 oz Cu, In Still Air

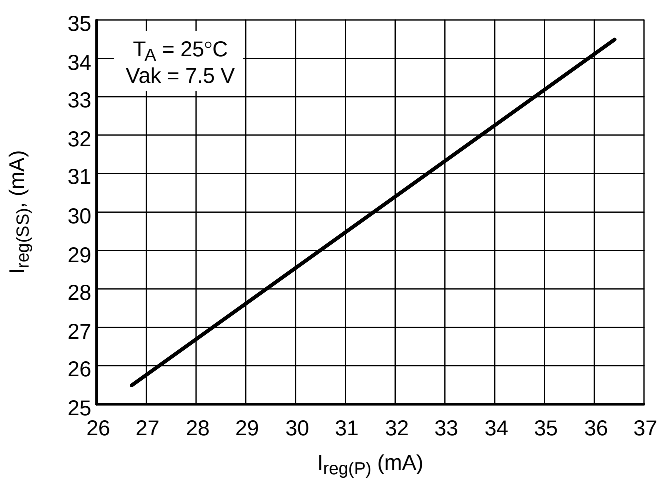

Figure 8. $I_{reg(SS)}$ vs. $I_{reg(P)}$ Testing SOT−223, 300 mm^2, 2 oz Cu, In Still Air

The negative temperature coefficient trend of a SOD−123 CCR has a benefit as it avoids thermal runaway. There are two areas of interest on the curves of Figure 9. The first is for a given T_A. Each curve shows a decrease in $I_{reg(SS)}$ as Vak increases and therefore P_D increases. There also is the ambient temperature affect on I_{reg} for a fixed Vak condition. Both the SOD−123 (Figure 9) and SOT−223 (Figure 10) show a decrease in $I_{reg(SS)}$ as T_A increases.

See ON Semiconductor application note AND8223/D for additional information.

SOD−123 devices exhibit a greater negative temperature coefficient as shown in Figure 9 than corresponding SOT−223 devices as shown in Figure 10, due to the difference in the package $R_{\theta JA}$. The SOD−123 package reaches thermal saturation with less power applied than the SOT−223 package.

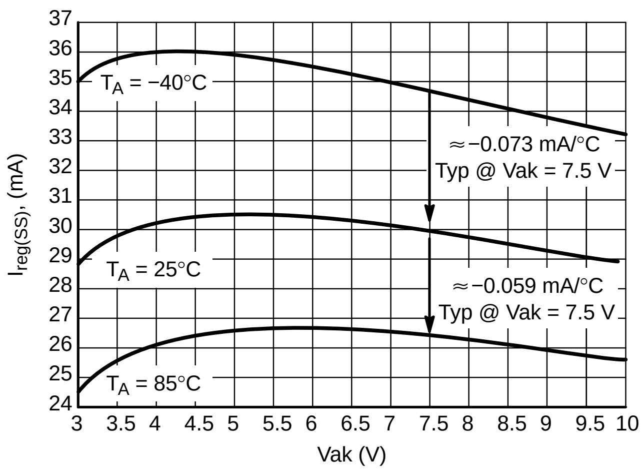

Figure 9. Typical SOD−123 30 mA, 300 mm^2, 1 oz Cu, In Still Air

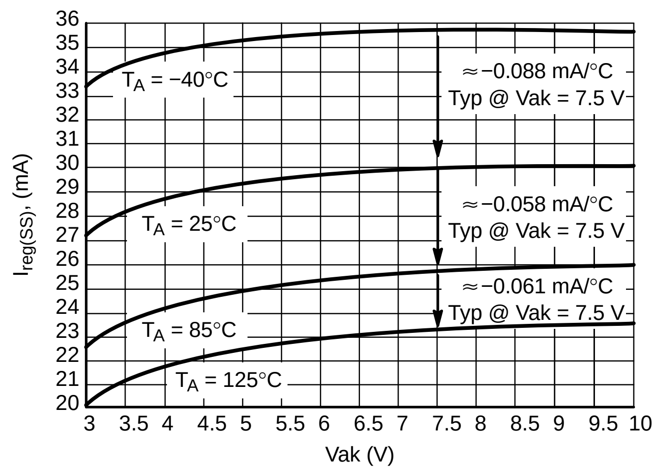

Figure 10. Typical SOT−223 30 mA, 300 mm^2, 2 oz Cu, In Still Air

The following design examples will show how to determine which package device and the Cu needed for a simple circuit.

Circuit Design

Example 1:

For a series circuit (Figure 11), the power dissipation of the CCR is determined by:

$(V_{source} - (V_{LEDS} + V_{RPD})) \times I_{reg}$. Using the worst case scenario; i.e, highest V_{source}, Lowest LED V_F, and highest target I_{reg}. Using a 16 V source (auto voltage regulator high output) driving two white LEDs with a Vf of 4.2 V, a reverse protection diode (RPD) with a V_F of 0.2 V and 30 mA I_{reg} would give: (16 V − (2 × 4.2 V + 0.2 V)) × 0.030 A = 7.4 V × 0.03 A = 222 mW.

For an ambient temperature of 85°C, from the P_D curves of Figures 1 and 3 a SOD−123 with 500 mm^2 1 oz Cu would suffice. A SOT−223 with 100 mm^2 1 oz Cu would also work.

Example 2:

Three Red LEDs with each having a V_F of 2.0 Vdc @ 30 mA. DC voltage of 16 Vdc. Ambient temperature max of 85°C. Available heat sink area for device is 300 mm^2 of 1 oz Cu.

P_D of device = (16 Vdc – (3 × 2.0 Vdc) + 0.2 Vdc) × 30 mA = 294 mW

SOD−123 P_D max @ 85°C, 300 mm^2 of 1 oz Cu = 182 mW

SOT−223 P_D max @ 85°C, 300 mm^2 of 1 oz Cu = 598 mW

The SOT−223 gives a margin of safety in the application.

Or, knowing that 294 mW of power needs to be dissipated, we can select a SOT−223 device using 100 mm^2 of 1 oz Cu.

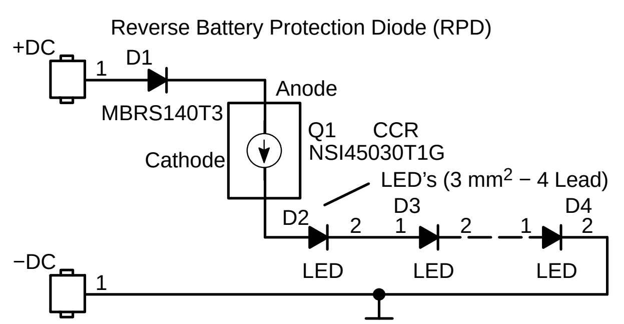

Figure 11.

The following graphs show the relationship between $I_{reg(SS)}$ and T_A for both the SOD−123 and SOT−223 for a stated Cu area and thickness in still air. They also give the slope of the line which can be used to estimate T_J at a specific T_A.

The formula for estimating T_J is: $T_J = (P_D \times R_{\theta JA}) + T_A$ ($R_{\theta JA}$ value from datasheet)

For the SOD−123 @ 25°C, T_J = (225 mW × 360°C/W) + 25°C = 106°C (as shown on the graph).

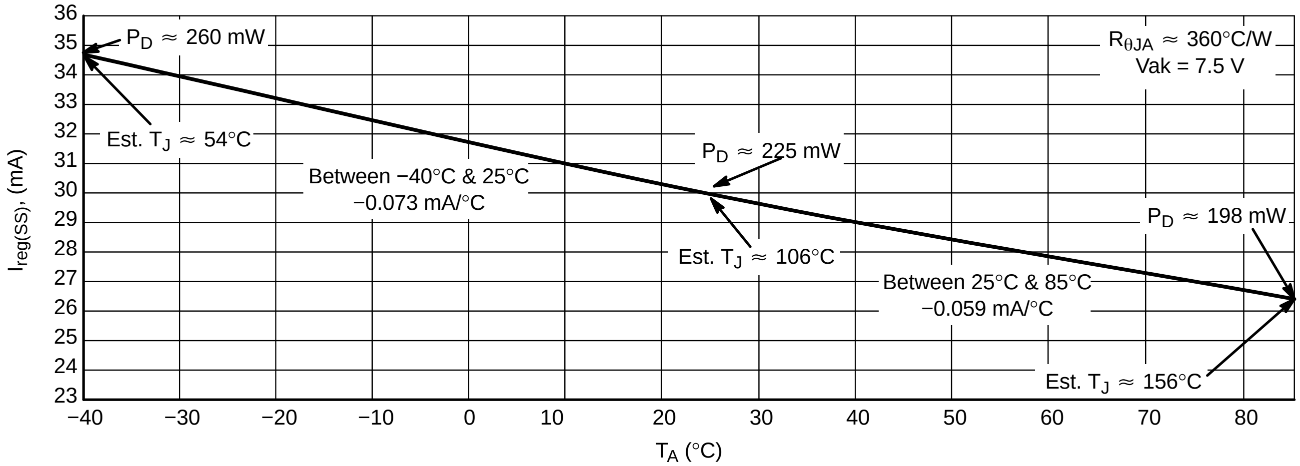

Figure 12. Typical SOD−123 30 mA, 300 mm^2, 1 oz Cu, In Still Air

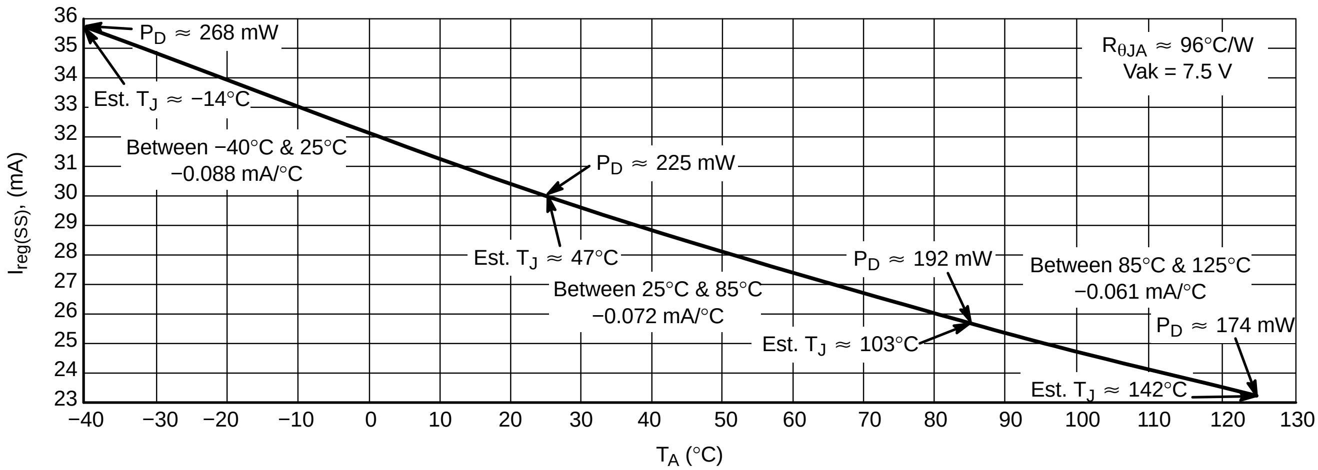

Figure 13. Typical SOT−223 30 mA, 300 mm^2, 2 oz Cu, In Still Air

PWM Current Control

The power dissipation of the CCR can be reduced when used in a pulse width modulation (pwm) controlled circuit Figure 14. The dc average current will be $I_{reg(SS)}$ × duty cycle %. For a typical 30 mA CCR at 20% duty cycle, T_A of 25°C, the average current through the LEDs will be 6.0 mA.

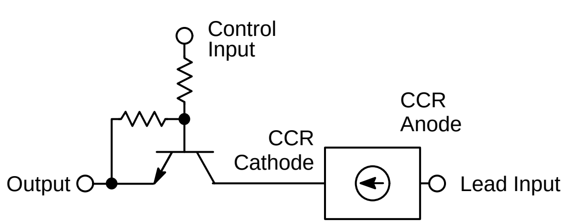

Figure 14.

The device and heat sink will require analysis for worst case condition to account for 100% duty cycle.

Figures 15 and 16 will assist to determine the temperature rise caused by a power pulse.

Example: If the control input is a 500 Hz, 20% duty cycle pwm applied to the three red LED circuit of Figure 11, the R(t) for 300 mm^2 of 1 oz Cu for a SOD−123 from Figure 15 would be ≈ 90°C/W. Therefore; 216 mW × 90°C/W = 19.4°C temperature rise.

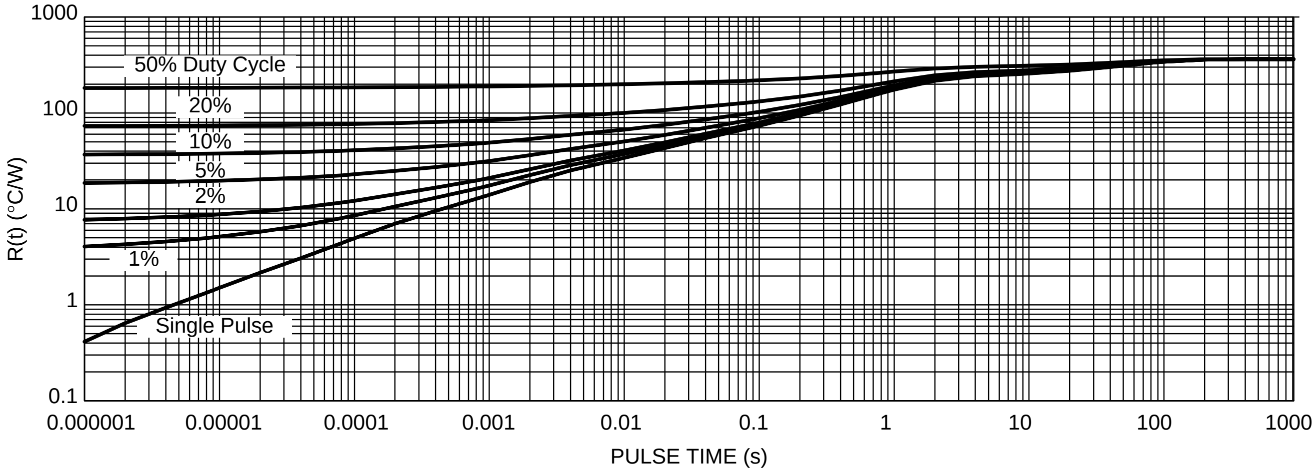

Figure 15. SOD−123 NSI45030T1G PCB Cu Area 300 mm^2 PCB Cu thk 1.0 oz

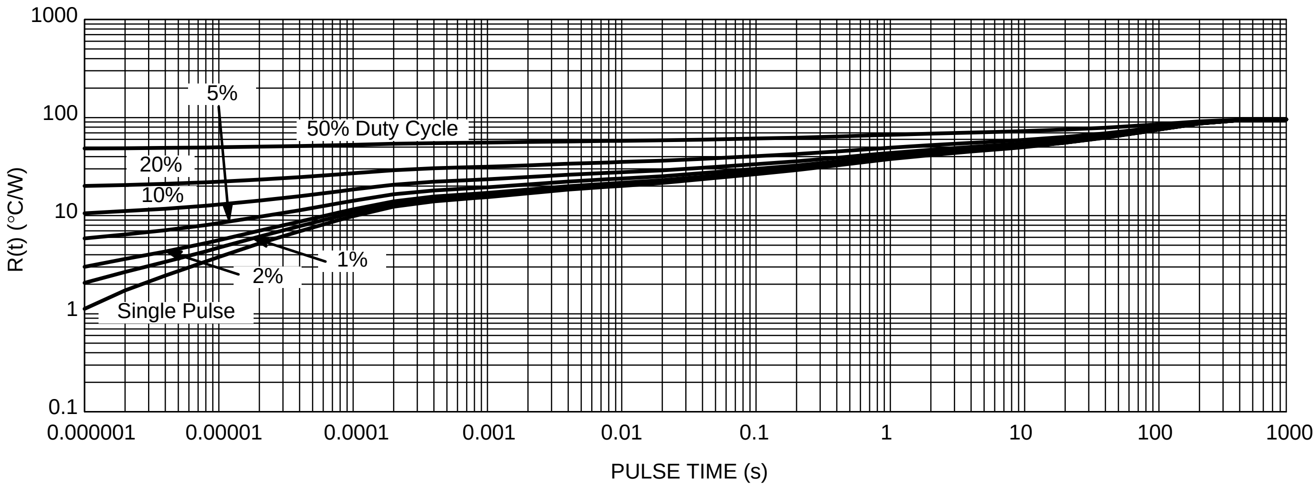

Figure 16. CCR SOT−223 NSI45030ZT1G PCB Cu Area 300 mm^2 PCB Cu thk 2.0 oz

Summary:

The thermal behavior of a CCR is generalized in the following matrix:

	T_A ↑	Heatsink Area ↑	Vak ↑
$I_{reg(SS)}$	↓	↑	NC*
T_J	↑	↓	↑

*In general SOD−123 for 3 V < Vak < 10 V, all other variables constant: $I_{reg(SS)}$ changes < 2 mA (less @ T_A > 25°C).
In general SOT−223 for 3 V < Vak < 10 V, all other variables constant: $I_{reg(SS)}$ changes < 3 mA.

Figure 17.

APPENDIX A

SOD−123 devices are:

NSI45020T1G, Steady State $I_{reg(SS)}$ = 20 mA ±15%
NSI45025T1G, Steady State $I_{reg(SS)}$ = 25 mA ±15%
NSI45030T1G, Steady State $I_{reg(SS)}$ = 30 mA ±15%
NSI45020AT1G, Steady State $I_{reg(SS)}$ = 20 mA ±10%
NSI45025AT1G, Steady State $I_{reg(SS)}$ = 25 mA ±10%
NSI45030AT1G, Steady State $I_{reg(SS)}$ = 30 mA ±10%

SOT−223 devices are:

NSI45025ZT1G, Steady State $I_{reg(SS)}$ = 25 mA ±15%
NSI45030ZT1G, Steady State $I_{reg(SS)}$ = 30 mA ±15%
NSI45025AZT1G, Steady State $I_{reg(SS)}$ = 25 mA ±10%
NSI45030AZT1G, Steady State $I_{reg(SS)}$ = 30 mA ±10%

APPENDIX B

Application Note	Title
AND8349/D	Automotive Applications The Use of Discrete Constant Current Regulators (CCR) For CHMSL Lighting
AND8220/D	How To Use Thermal Data Found in Data Sheets
AND8222/D	Predicting the Effect of Circuit Boards on Semiconductor Package Thermal Performance
AND8223/D	Predicting Thermal Runaway

The products described herein (NSI45020T1G, NSI45025T1G, NSI45030T1G, NSI45020AT1G, NS145025A51G, NSI45030AT1G, NSI45025ZT1G, NSI45030ZT1G, NSI45025AZT1G, NSI45030AZT1G) have patents pending.

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