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AND9008/D

Thermal Considerations for the ON Semiconductor Family of Discrete Constant Current Regulators (CCR) in DPAK, SMC and SMB packages for Driving LEDs

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APPLICATION NOTE

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Introduction:

This application note supplements AND8391/D adding thermal information for DPAK, SMB and SMC packages and includes performance data for both FR4 and Thermal (aluminum backed) MCPCB (Metal Clad PCB) material.

The ON Semiconductor Constant Current Regulator (CCR) family of devices offers 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. See application note AND8349/D for basic circuit considerations.

The two−terminal CCR requires no external components to regulate at the specified current. The three−terminal device allows for current adjustment by using an external resistor. In the automotive lighting market (see app note AND8349/D), these devices can be used wherever a constant current is needed to maintain luminosity under varying voltage conditions.

The purpose of this paper is to explore the temperature and power boundaries for devices in the DPAK, SMB and SMC package operating from typical currents of 50 mA to 350 mA in LED lighting applications. The DPAK adjustable devices available are rated at 60 mA to 100 mA and 90 mA to 160 mA. The fixed DPAK and SMC devices are rated at 350 mA. The SMB devices are rated at 50 mA ±10%, 30 mA ±10% and 20 mA ±15% with a higher breakdown voltage of 120 V. See appendix A for device list.

Reference to Data Sheet:

The data sheet 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.

Ireg−ss = The current through the device supplied to the LEDs under steady−state operating conditions (device on ≥5 min.)

Ireg−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 DPAK adjustable CCR Data Sheet 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 mounted on FR4 PCB material.

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

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THERMAL PERFORMANCE

The following Figures (Figures 1 through 10) and Tables (Table 1 through 10) provide the typical thermal performance based on a single printed circuit board (PCB) operated in still air.

Figure 1 shows power dissipation over changes in ambient temperature for the DPAK package on FR4 PCB material. Table 1 shows maximum power dissipation for a given heat spreader area at 85°C. These tables and graphs illustrate the effect of Cu area, thickness and also ambient temperature (T_A) over the range of −40°C to 85°C, which encompasses an area of interest for general LED operation. LED data sheets show an extreme reduction in luminosity above 85°C T_A.

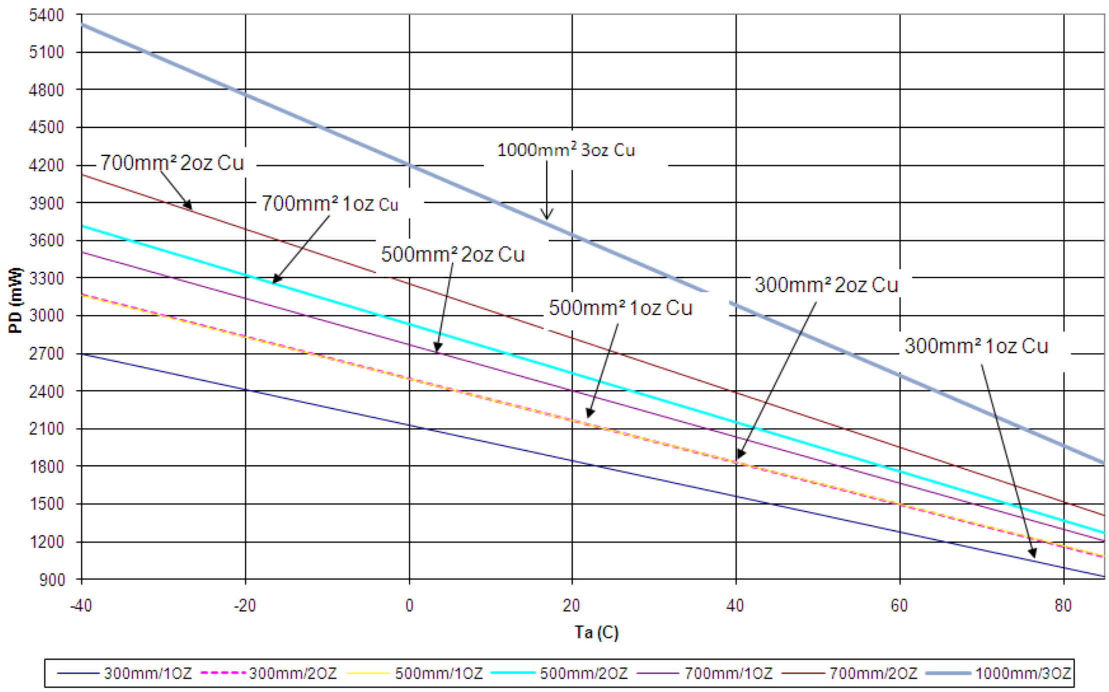


Figure 1. DPAK Thermal FR4 PD vs T_A for T_J of 150°C

Table 1.

PD max @ 85°C	DPAK
1000 mm 3 oz Cu	1821 mW
700 mm 2 oz Cu	1411 mW
700 mm 1 oz Cu	1201 mW
500 mm 2 oz Cu	1270 mW
500 mm 1 oz Cu	1082 mW
300 mm 2 oz Cu	1083 mW
300 mm 1 oz Cu	921 mW

Figure 2 shows power dissipation over changes in ambient temperature for the DPAK package on MCPCB material, Denka K1. Table 2 shows maximum power dissipation for a given heat spreader area at 85°C. These tables and graphs illustrate the effect of Cu area, thickness, clad material and ambient temperature (T_A) over the range of −40°C to 125°C, which encompasses an area of interest for general LED operation.

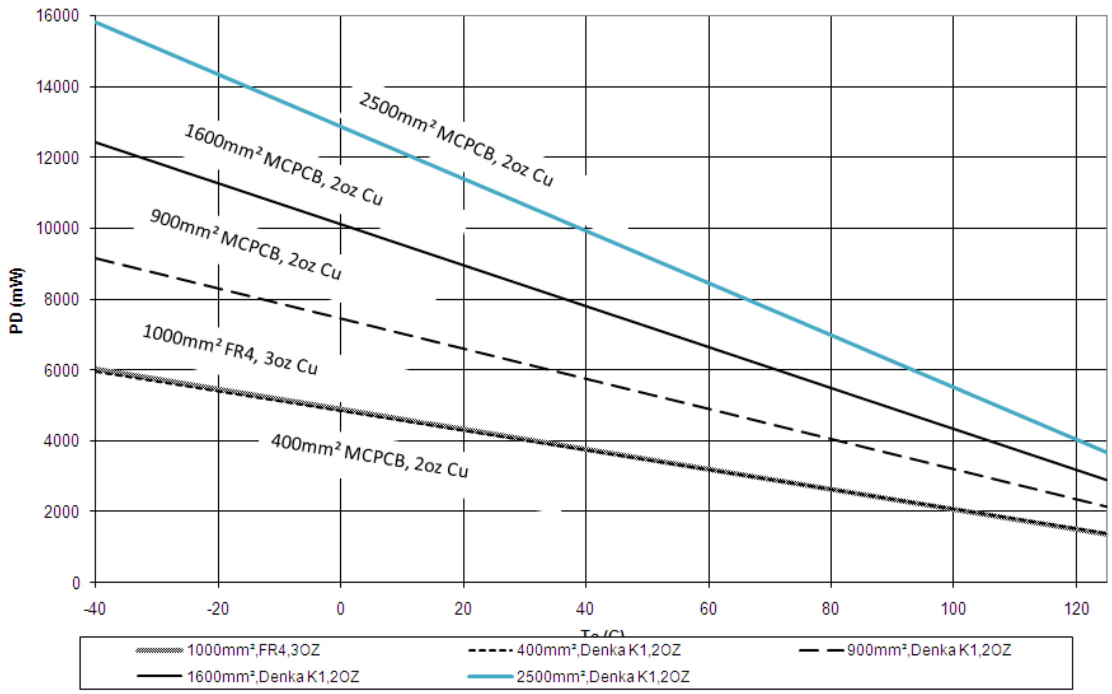


Figure 2. DPAK MCPCB PD vs. T_A for T_J = 175°C

Table 2.

PD max @ 85°C	DPAK
2500 mm^2, Denka K1, 2 oz	6618 mW
1600 mm^2, Denka K1, 2 oz	5202 mW
900 mm^2, Denka K1, 2 oz	3830 mW
400 mm^2, Denka K1, 2 oz	2486 mW
1000 mm^2, FR4, 3 oz	2521 mW

Figure 3 is a comparison between power dissipation over changes in ambient temperature for the DPAK package on FR4 PCB material and MCPCB, Denka K1 material. Table 3 shows maximum power dissipation for a given heat spreader area at 85°C.

The MCPCB affords a similar Power dissipation capability with a 60% decrease in area at 85°C for the same T_J. For HB (high brightness) LED's, this is necessary for application space limitations. The form factor for existing lighting applications dictates the size of the LED and driver PCB.

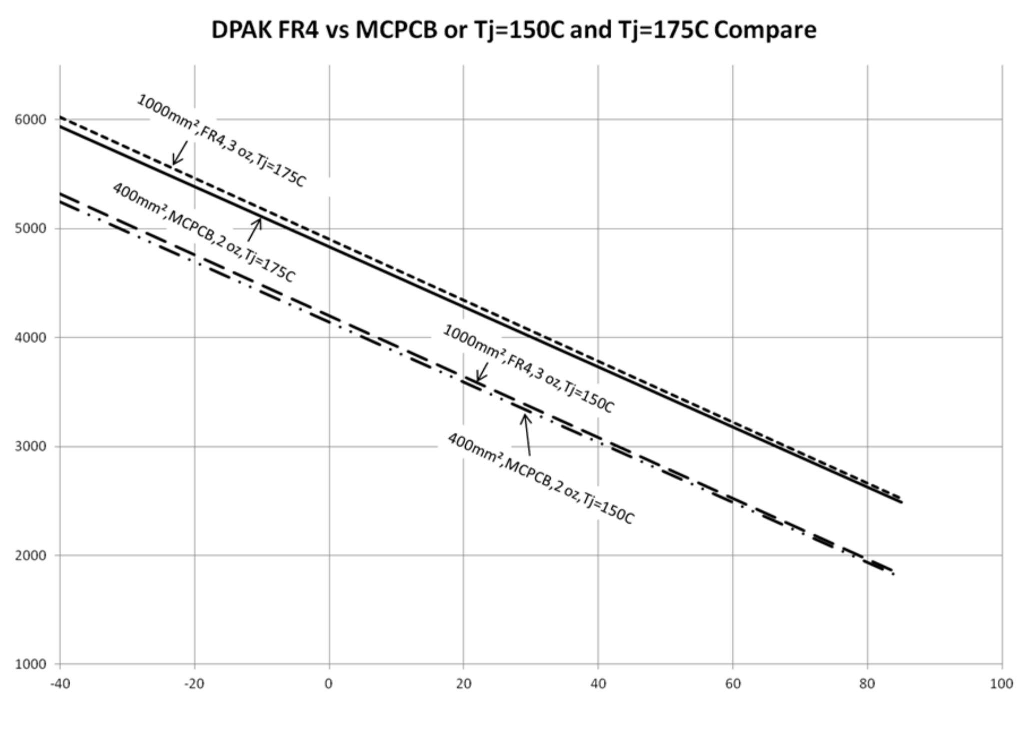


Figure 3. DPAK FR4 vs. MCPCB for T_J = 150°C and TJ = 175°C Compare

Table 3.

PD max @ 85°C	DPAK
400 mm^2, Denka K1, 2 oz/175°C	2486 mW
400 mm^2, Denka K1, 2 oz/150°C	1796 mW
1000 mm, FR4, 3 oz/175°C	2521 mW
1000 mm FR4, 3 oz/150°C	1821 mW

Figure 4 shows power dissipation over changes in ambient temperature for the SMC package on FR4 PCB material. Table 4 shows maximum power dissipation for a given heat spreader area at 85°C. These tables and graphs illustrate the effect of Cu area, thickness and also ambient temperature (T_A) over the range of −40°C to 85°C, which encompasses an area of interest for general LED operation. LED data sheets show an extreme reduction in luminosity above 85°C T_A.

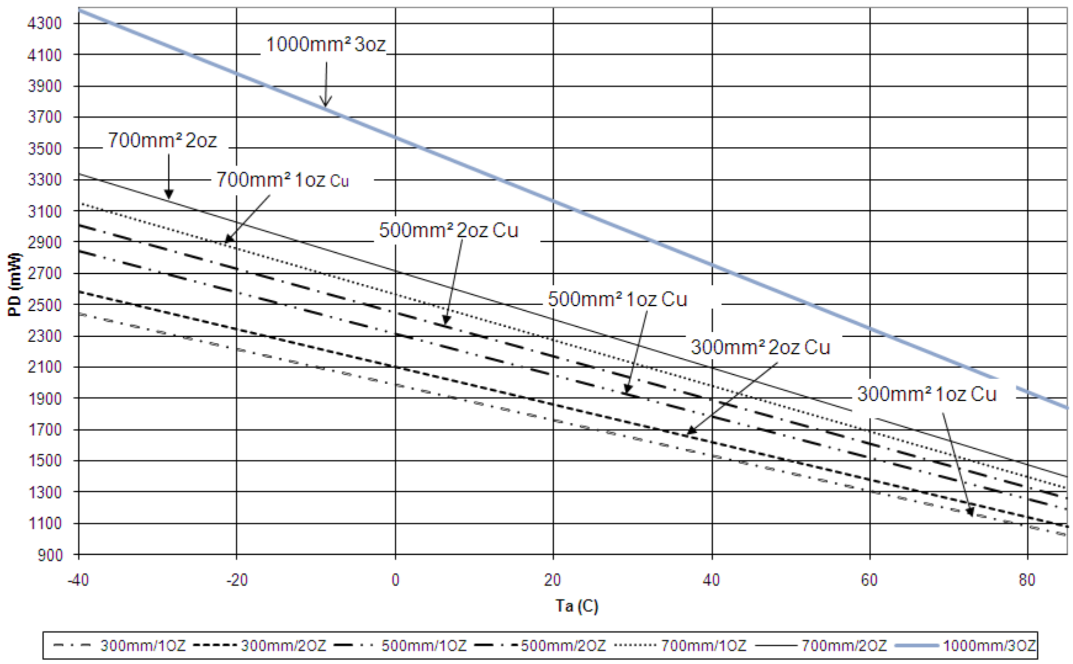


Figure 4. SMC FR4 PCB PD vs. T_A for T_J = 175°C

Table 4.

PD max @ 85°C	SMC
1000 mm, 3 oz Cu	1837 mW
700 mm, 2 oz Cu	1398 mW
700 mm, 1 oz Cu	1320 mW
500 mm, 2 oz Cu	1261 mW
500 mm, 1 oz Cu	1192 mW
300 mm, 2 oz Cu	1080 mW
300 mm, 1 oz Cu	1023 mW

Figure 5 shows power dissipation over changes in ambient temperature for the SMC package on MCPCB material, Denka K1. Table 5 shows maximum power dissipation for a given heat spreader area at 85°C. These tables and graphs illustrate the effect of Cu area, thickness, clad material and ambient temperature (T_A) over the range of −40°C to 125°C, which encompasses an area of interest for general LED operation.

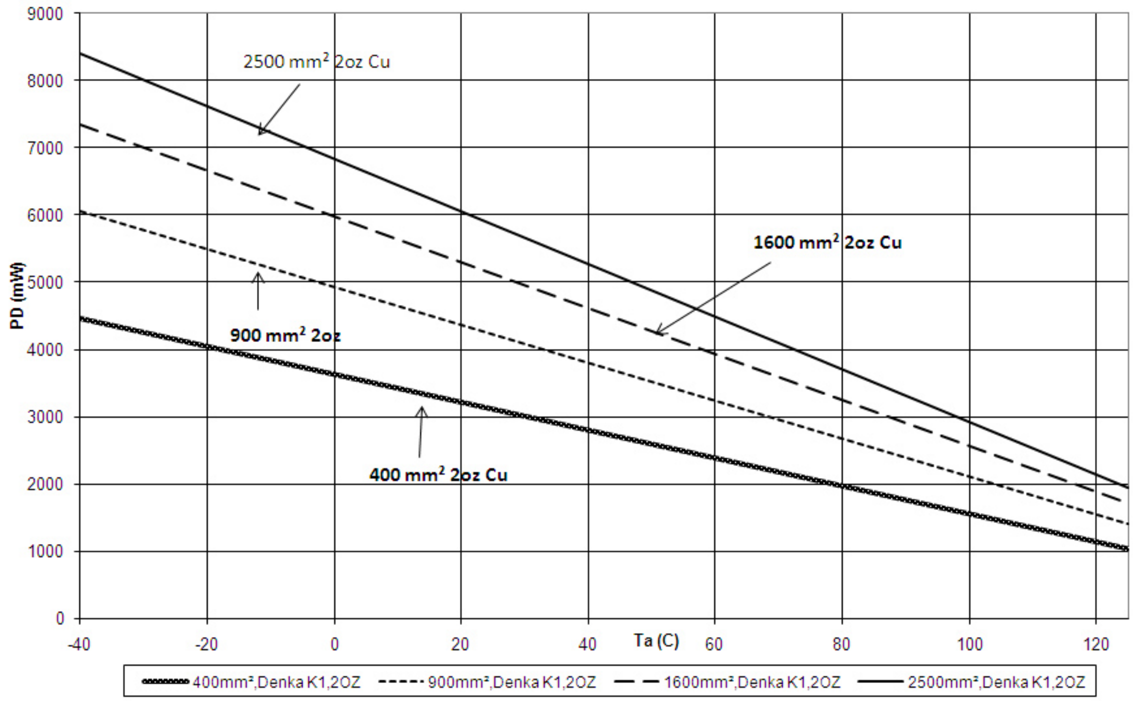


Figure 5. SMC MCPCB PD vs. T_A for T_J = 175°C

Table 5.

PD max @ 85°C	SMC
2500 mm^2, Denka K1, 2 oz	3516 mW
1600 mm^2, Denka K1, 2 oz	3072 mW
900 mm^2, Denka K1, 2 oz	2535 mW
400 mm^2, Denka K1, 2 oz	1867 mW

Figure 6 is a comparison between power dissipation over changes in ambient temperature for the SMC package on FR4 PCB material and MCPCB, Denka K1 material. Table 6 shows maximum power dissipation for a given heat spreader area at 85°C.

The MCPCB affords a similar Power dissipation capability with a 60% decrease in area at 85°C. For HB (high brightness) LED's, this is necessary for application space limitations. The form factor for existing lighting applications dictates the size of the LED and driver PCB.

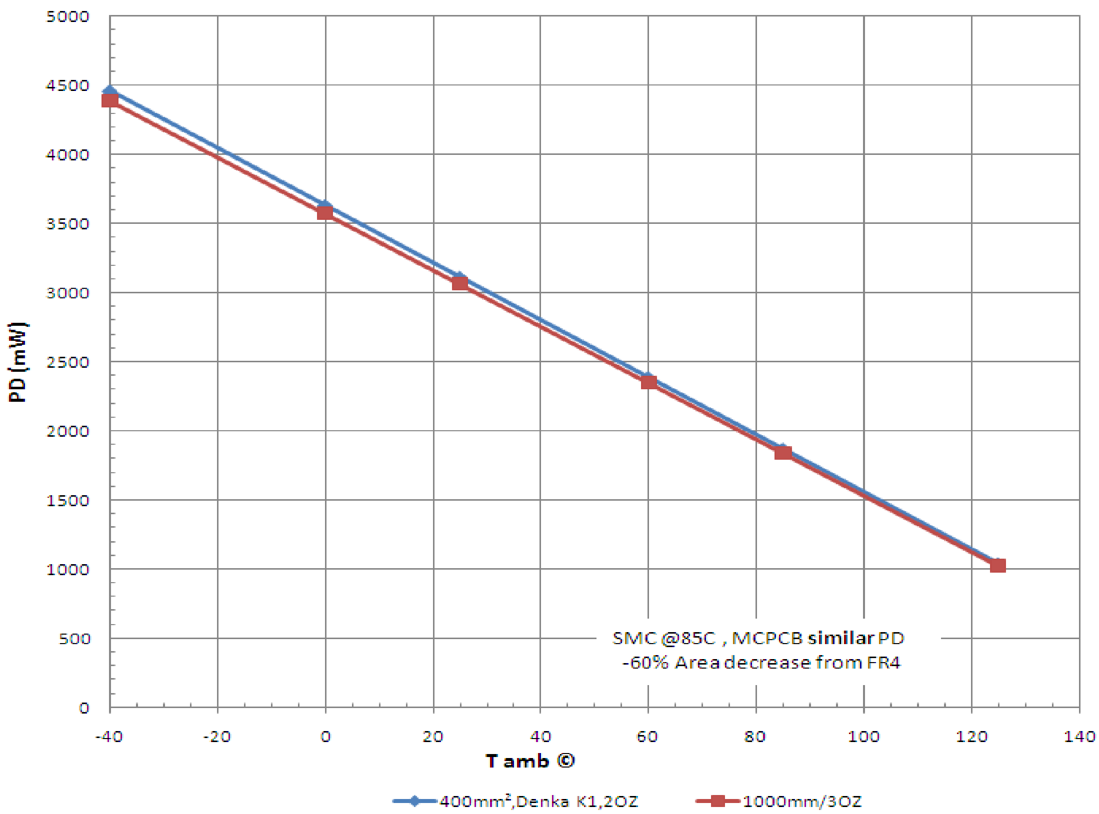


Figure 6. SMC FR4 vs. MCPCB Compare PD vs. T_A for T_J = 175°C

Table 6.

PD max @ 85°C	SMC
400 mm^2, Denka K1, 2 oz	1867 mW
1000 mm, FR4, 3 oz	1837 mW

Figure 7 shows power dissipation over changes in ambient temperature for the SMB package on FR4 PCB material. Table 7 shows maximum power dissipation for a given heat spreader area at 85°C. These tables and graphs illustrate the effect of Cu area, thickness and also ambient temperature (T_A) over the range of −40°C to 85°C, which encompasses an area of interest for general LED operation. LED data sheets show an extreme reduction in luminosity above 85°C T_A.

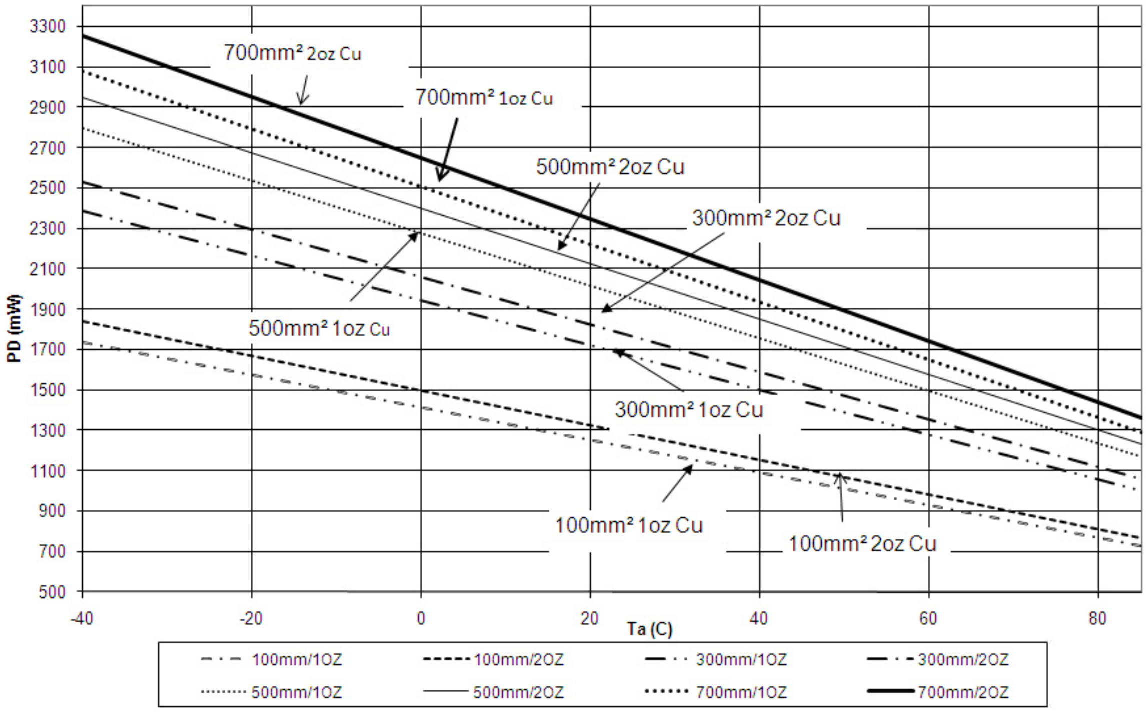


Figure 7. SMB FR4 Thermal PD vs. T_A for T_J of 175°C

Table 7.

PD max @ 85°C	SMB
700 mm, 2 oz Cu	1362 mW
700 mm, 1 oz Cu	1289 mW
500 mm, 2 oz Cu	1233 mW
500 mm, 1 oz Cu	1169 mW
300 mm, 2 oz Cu	1059 mW
300 mm, 1 oz Cu	1000 mW
100 mm, 2 oz Cu	769 mW
100 mm, 1 oz Cu	726 mW

Figure 8 shows power dissipation over changes in ambient temperature for the SMB package on MCPCB material, Denka K1. Table 8 shows maximum power dissipation for a given heat spreader area at 85°C. These tables and graphs illustrate the effect of Cu area, thickness, clad material and ambient temperature (T_A) over the range of −40°C to 85°C, which encompasses an area of interest for general LED operation.

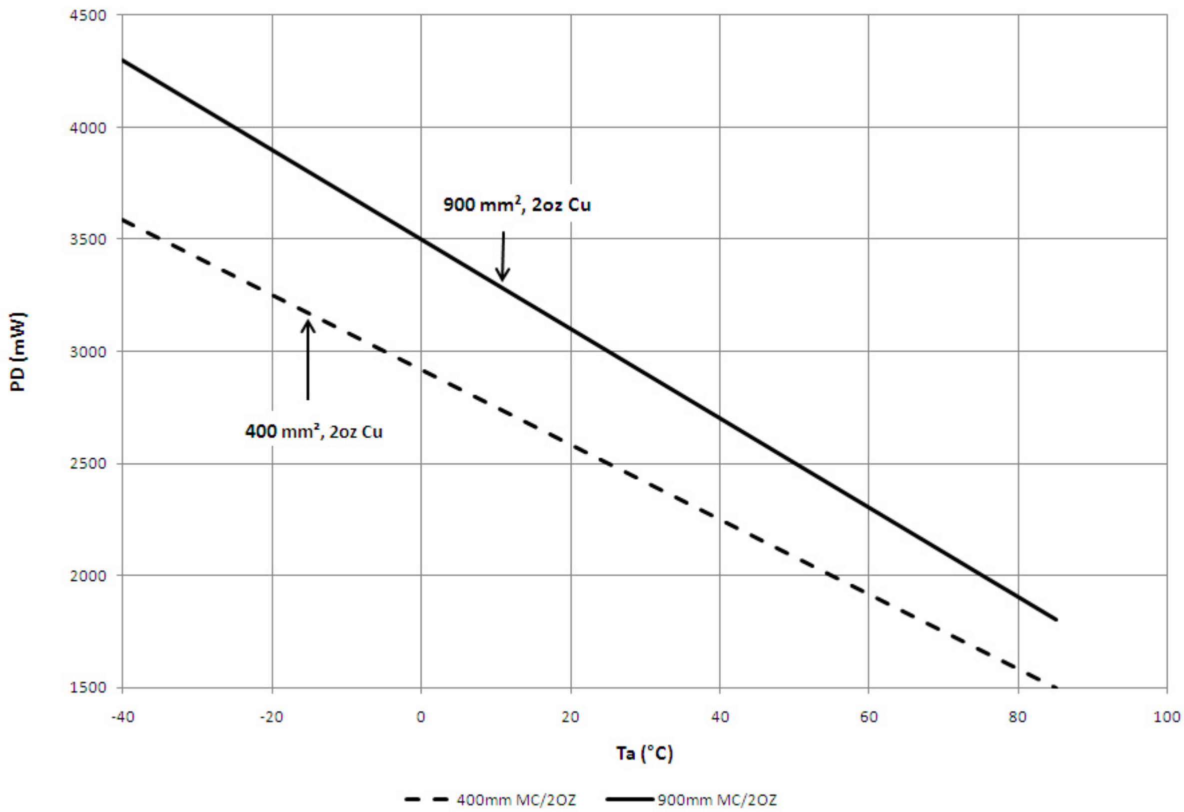


Figure 8. SMB MCPCB PD vs. T_A for T_J of 175°C

Table 8.

PD max @ 85°C	SMB
900 mm, MC/2 oz	3000 mW
400 mm, MC/2 oz	2500 mW

Figure 9 is a comparison between power dissipation over changes in ambient temperature for the SMB package on FR4 PCB material and MCPCB, Denka K1 material. Table 9 shows maximum power dissipation for a given heat spreader area at 85°C.

The MCPCB 400 mm^2, 2 oz Cu affords a 10.1% increase in Power dissipation capability with a 43% decrease in area compared to FR4 700 mm^2, 2 oz Cu at 85°C. For HB (high brightness) LED's, this is necessary for application space limitations. The form factor for existing lighting applications dictates the size of the LED and driver PCB.

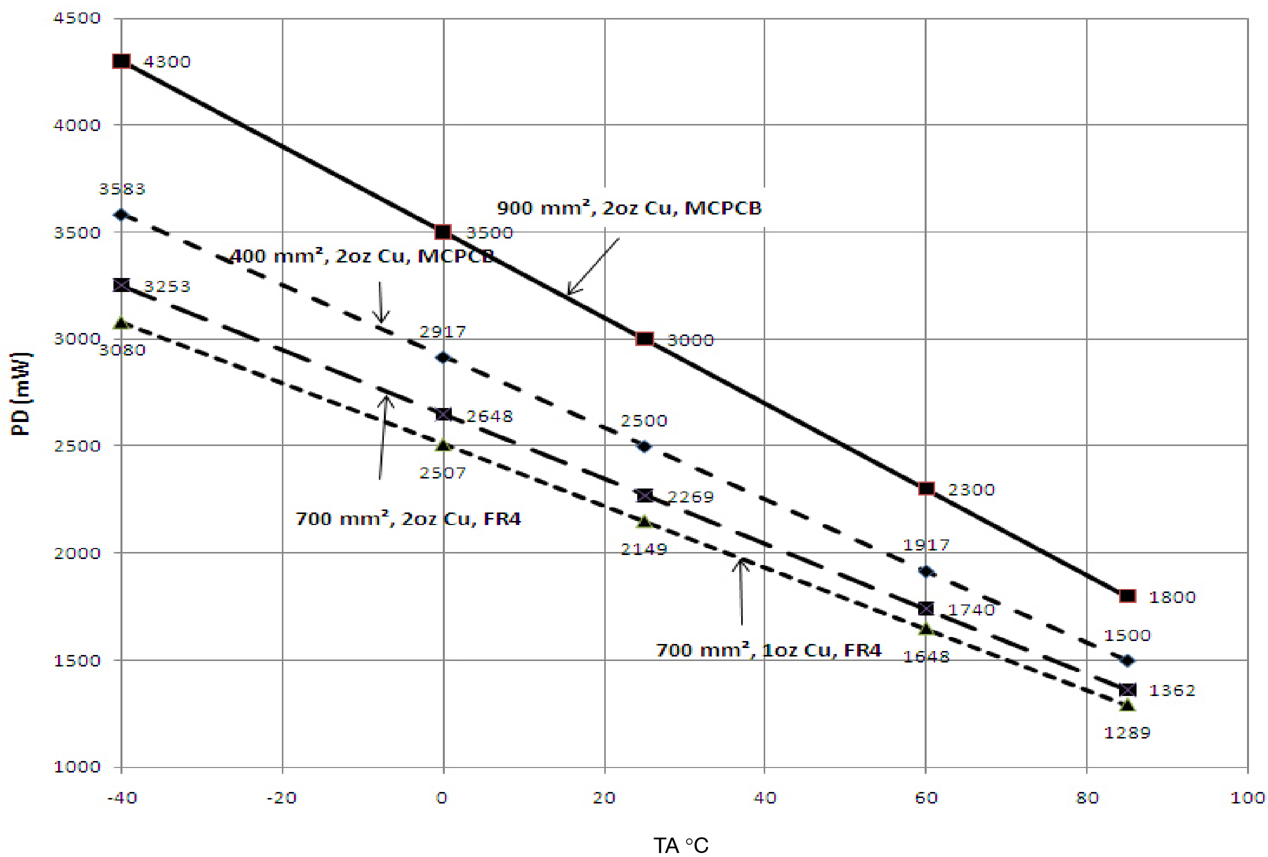


Figure 9. SMB FR4 vs. MCPCB Compare PD vs. T_A for T_J of 175°C

Table 9.

PD max @ 85°C	SMB
900 mm^2, Denka K1, 2 oz	1800 mW
400 mm^2, Denka K1, 2 oz	1500 mW
700 mm, FR4, 2 oz Cu	1362 mW
700 mm, FR4, 1 oz Cu	1289 mW

Figure 10 is a summary comparison between power dissipation over changes in ambient temperature for the DPAK, SMC and SMB packages on FR4 PCB material and MCPCB, Denka K1 material.

This chart will assist in selection of circuit board material and size knowing the operating ambient temperature of a circuit and the maximum device power dissipation.

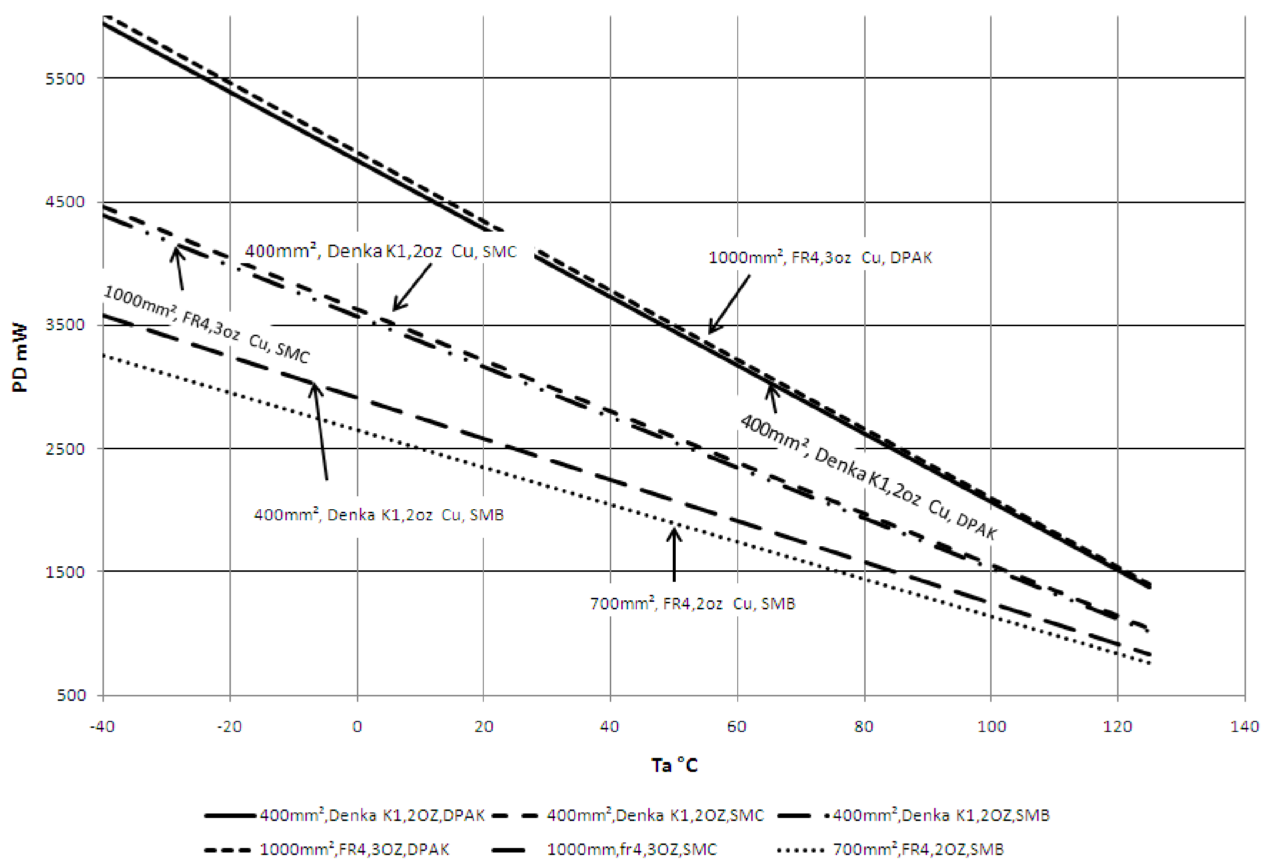


Figure 10. Summary DPAK, SMC, SMB for T = 175°C

Table 10.

PD max @ 85°C	DPAK, SMC, SMB	
400 mm^2, Denka K1, 2 oz	DPAK	2486 mW
400 mm^2, Denka K1, 2 oz	SMC	1867 mW
400 mm^2, Denka K1, 2 oz	SMB	1500 mW
1000 mm, FR4, 3 oz Cu	DPAK	2521 mW
1000 mm, FR4, 3 oz Cu	SMC	1837 mW
700 mm, FR4, 2 oz Cu	SMB	1362 mW

Application Examples

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.

The data provided in this application note can be used to determine which package and heat sink is a good candidate for design−in.

The negative temperature coefficient trend of a CCR has a benefit as it helps to avoid thermal runaway.

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

The PD of the HB LED's needs to be included for total circuit PD and total PCB area determination.

Heat sinks attached to the PCB heat spreader are typically used to implement a total power solution.

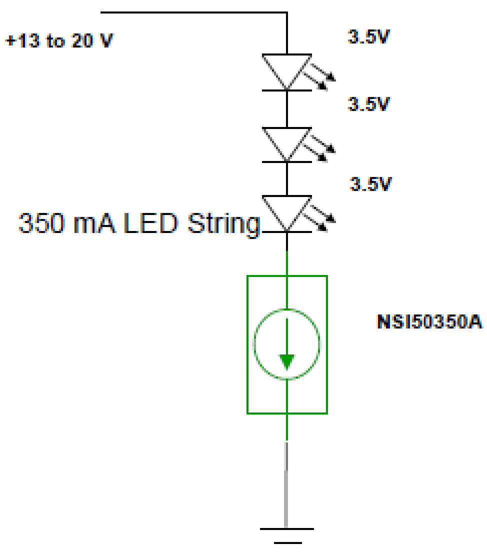


Figure 11.

Circuit Design Example 1:

For a series circuit (Figure 11), the power dissipation of the CCR is determined by: (Vsource $-V_{LEDS}$) x I_{REG}. Using the worst case scenario; i.e, highest Vsource, Lowest LED V_F, and highest target I_{REG}. Thus, a 20 V source driving three white LEDs with a Vf of 3.5 V and 350 mA I_{REG} would give: (20 V−(3x3.5 V)) x 0.350 A = 9.5 V x .35 A = 3.325 W.

For an ambient temperature of 85°C, from the P_D curves, a SMC with 2500 mm^2, 2 oz Cu MCPCB would suffice. A DPAK with 900 mm^2, 2 oz Cu MCPCB would also work. The negative temperature coefficient (NTC) of the CCR will actually lower the power dissipation by reducing the circuit current thus allowing a safety margin.

Each LED will produce 3.5 V x 0.35 A = 1.23 W of additional power to be thermally dissipated.

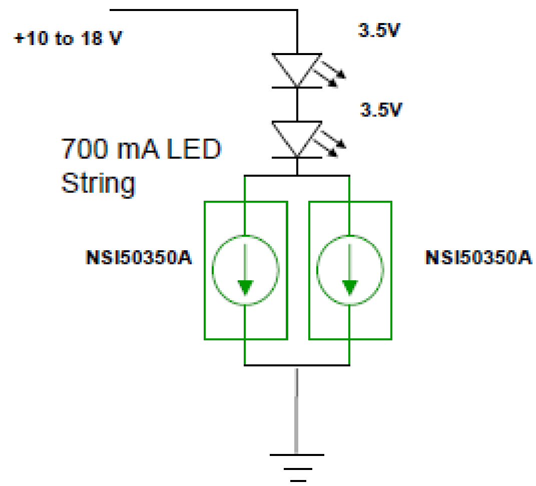


Figure 12.

Circuit Design Example 2:

For a series circuit with parallel CCR drivers (Figure 12), the power dissipation of each of the the CCRs is determined by: (Vsource − V_{LEDS}) x I_{REG}. Using the worst case scenario; i.e, highest Vsource, Lowest LED V_F, and highest target I_{REG}. So, a 18 V source driving two white LEDs with a Vf of 3.5 V and 350 mA I_{REG} would give: (18 V− (2 x 3.5 V)) x 0.350 A = 11 V x .35 A = 3.85 W for each CCR. By splitting the total power between 2 CCR's, the thermal effect can be spread over a larger area and less concentrated.

For an ambient temperature of 85°C, from the P_D curves, each DPAK with 900 mm^2, 2 oz Cu MCPCB would suffice. The negative temperature coefficient (NTC) of the CCR will actually lower the power dissipation by reducing the circuit current thus allowing a safety margin.

Each LED will produce 3.5 V x 0.70 A = 2.45 W of additional power to thermally dissipate.

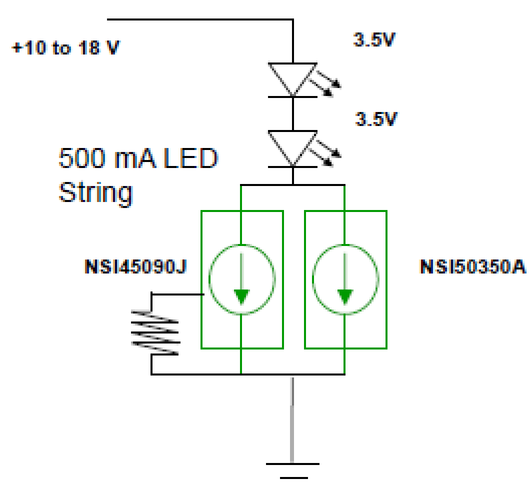


Figure 13.

Circuit Design Example 3:

For a series circuit with parallel CCR drivers capable of adjusting the required current (Figure 13), the power dissipation of each of the the CCRs is determined by: (Vsource – V_{LEDS}) x I_{REG}. Using the worst case scenario; i.e, highest Vsource, Lowest LED V_F, and highest target I_{REG}. So, a 18 V source driving two white LEDs with a Vf of 3.5 V and 350 mA I_{REG} for the fixed current CCR would give: (18 V− (2 x 3.5 V)) x 0.350 A = 11 V x .35 A = 3.85 W. The adjustable CCR PD is (18 V− (2x3.5V)) x .150 A = 11 V x .15 A = 1.65 W. By splitting the total power between 2 CCR's, the thermal effect can be spread over a larger area and less concentrated.

For an ambient temperature of 85°C, from the P_D curves, the fixed DPAK with 900 mm^2, 2 oz Cu MCPCB would suffice while the adjustable DPAK would require only a 400 mm^2, 2 oz Cu MCPCB. The negative temperature coefficient (NTC) of the CCR will actually lower the power dissipation by reducing the circuit current thus allowing a safety margin.

Each LED will produce 3.5 V x .50 A = 1.75 W of additional power to thermally dissipate.

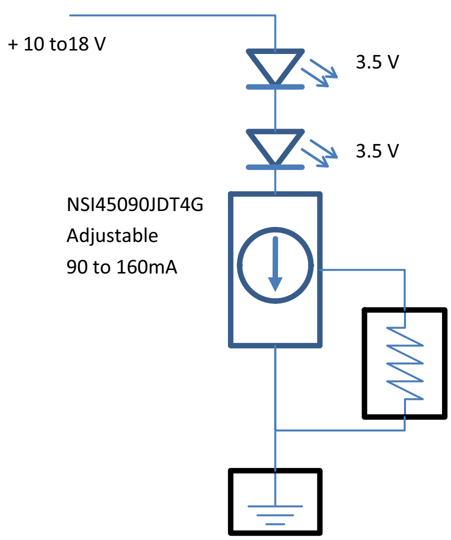


Figure 14.

Circuit Design Example 4:

For a series circuit (Figure 14), the power dissipation of the CCR is determined by: (Vsource −V_{LEDS}) x I_{REG}. Using the worst case scenario; i.e, highest Vsource, Lowest LED V_F, and highest target I_{REG}. Thus, an 18 V source driving two white LEDs with a Vf of 3.5 V and 136 mA I_{REG} would give: (20 V−(3x3.5 V)) x .136 A = 11 V x .136 A = 1.5 W.

For an ambient temperature of 85°C, from the P_D curves summary (Figure 10), the DPAK, with 400 mm^2, 2 oz Cu MCPCB or a 700 mm^2, 2 oz Cu FR4 PCB would suffice. The negative temperature coefficient (NTC) of the CCR will actually lower the power dissipation by reducing the circuit current thus allowing a safety margin.

Each LED will produce 3.5 V x .136 A = 0.476 W of additional power to thermally dissipate.

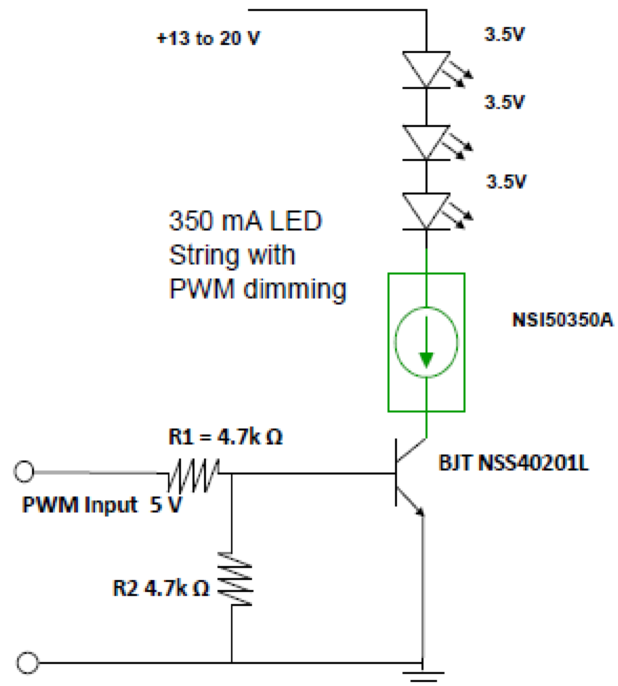
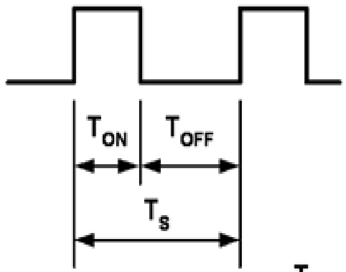


Figure 15.

Circuit Design Example 5:

For a series circuit with PWM dimming capability(Figure 15), the power dissipation of the CCRs is determined by analysis for worst case condition to account for 100% duty cycle. See Example 1. For analysis data. The method of pulsing the current through the LEDs is known as Pulse Width Modulation (PWM) and has become the preferred method of changing the light level. LEDs being a silicon device, turn on and off rapidly in response to the current through them being turned on and off. The switching time is in the order of 100 nanoseconds, this equates to a maximum frequency of 10 MHz. Applications will typically operate from a 100 Hz to 100 kHz. Below 100 Hz the human eye will detect a flicker from the light emitted from the LEDs. Between 500 Hz and 20 kHz the circuit may generate audible sound. Dimming is achieved by turning the LEDs on and off for a portion of a single cycle. This on off cycle is called the Duty cycle (D) and is expressed by the amount of time the LEDs are on (Ton) divided by the total time of a on/off cycle (Ts).



$$\text{Duty Cycle} = \text{Duty Ratio} = D = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{T_{ON}}{T_S}$$

Figure 16.

The data and examples presented in this application note and on the datasheets support the behavior described above in fine detail. Additionally, it was shown that an external bipolar junction transistor or bias resistor transistor can be used with a CCR for PWM to control the current and decrease power in the CCR.

Summary

The preceding Graphs and Tables show the size advantage of using MCPB versus standard FR4 material. It was presented that using MCPCB material can increase power dissipation by approximately 30% while decreasing board area by approximately 40%. This size tradeoff incurs a higher material costs; but, with size restrictions in LED lighting applications, this may become necessary.

APPENDIX A

SOD−123 Devices Are:

NSI45015WT1G, Steady State I_{REG} = 15 mA ±20%

NSI45020T1G, Steady State I_{REG} = 20 mA ±15%

NSI45025T1G, Steady State I_{REG} = 25 mA ±15%

NSI45030T1G, Steady State I_{REG} = 30 mA ±15%

NSI45020AT1G, Steady State I_{REG} = 20 mA ±10%

NSI45025AT1G, Steady State I_{REG} = 25 mA ±10%

NSI45030AT1G, Steady State I_{REG} = 30 mA ±10%

NSI50010YT1G, Steady State I_{REG} = 10 mA ±30%

SOT−223 Devices Are:

NSI45025ZT1G, Steady State I_{REG} = 25 mA ±15%

NSI45030ZT1G, Steady State I_{REG} = 30 mA ±15%

NSI45025AZT1G, Steady State I_{REG} = 25 mA ±10%

NSI45030AZT1G, Steady State I_{REG} = 30 mA ±10%

NSI45020JZT1G, Adjustable I_{REG} = 20 −40 mA ±15%

NSI45035JZT1G, Adjustable I_{REG} = 35−70 mA ±15%

DPAK Devices Are:

NSI45060JDT4G, Adjustable I_{REG} = 60 −100 mA ±15%

NSI45090JDT4G, Adjustable I_{REG} = 90 −160 mA ±15%

NSI50350ADT4G, Steady State I_{REG} = 350 mA ±10% (Product Preview)

SMC Devices Are:

NSI50350AST1G, Steady State I_{REG} = 350 mA ±10% (Product Preview)

SMB Devices Are:

TBD, Vak max = 120 V, Steady State I_{REG} = 50 mA ±10% (Product Preview)

TBD, Vak max = 120 V, Steady State I_{REG} = 30 mA ±10% (Product Preview)

TBD, Vak max = 120 V, Steady State I_{REG} = 20 mA ±15% (Product Preview)

SC−74 Devices Are:

NSI45019JPT1G, Adjustable I_{REG} = 19 −TBD mA ±15%, PWM enhanced (Product Preview)

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