AND8349/D

Automotive Applications: The Use of Discrete Constant Current Regulators (CCR) for CHMSL Lighting

APPLICATION NOTE

LEDs are being proliferated into many automotive lighting applications. The Center High Mount Stop Lamp (CHMSL) is one of several automotive applications for LEDs. Interior lighting is another area where LEDs are very well suited due to their small size and high efficiency. Recent advancements in higher efficiency LEDs at lower costs have made these light sources the technology of choice for automotive lighting.

Since LED brightness is determined by operating current, optimum intensity may require a constant current approach to maintain consistent luminosity over the wide variation of battery voltage possible in automotive electrical systems. Battery voltage typically is 13.5 V; however, it can range from as low or less than 9 V in a faulty charging system to 24 V for several minutes in a double battery jump scenario.

The list of potential automotive lighting LED applications includes:

- CHMSL Arrays
- Instrument Cluster Backlighting
- Switch Cluster Backlighting and Tell-Tales (Icon Lighting)
- Dome Lighting
- Mirror Lights
- Fog Lights
- Convenience Lighting
- RGB Ambient Lighting
- Emergency Flashlight

Each application requires specific attention to light output and optical design, LED circuit topology, driver current requirements, and thermal management. It is the intent of this article to concentrate on CHMSL LED circuit requirements, and to discuss thermal management as it applies to the driver circuitry.

An innovative use of a new Patent Pending Discrete Technology (Constant Current Regulator – CCR) will be shown to have several distinct advantages for controlling the LED operating current compared to the common method of selecting a bias resistor to adjust the LED operating current.

Figure 1 shows a typical I-V curve for the NSI45030T1G device. The CCR is a current regulator that offers outstanding regulation for LEDs and other applications requiring a low cost, stable current source. Unlike costly switching regulators, a CCR is relatively EMI free, does not require startup circuitry, and operates as a current source or sink. Current regulation can be achieved for Anode-Cathode voltages ranging from as little as 1.8 V. No external components are required to regulate the typical value of 30 mA. Since these are CCR sources, parallel arrangements allow for higher load current applications. (Figure 7)

The CCR reduces the complexity of resistor biased designs for sensitive loads such as LED strings connected in series (Figure 4). Simply apply a voltage greater than $V_{overhead}$ to achieve an accurate regulated current.
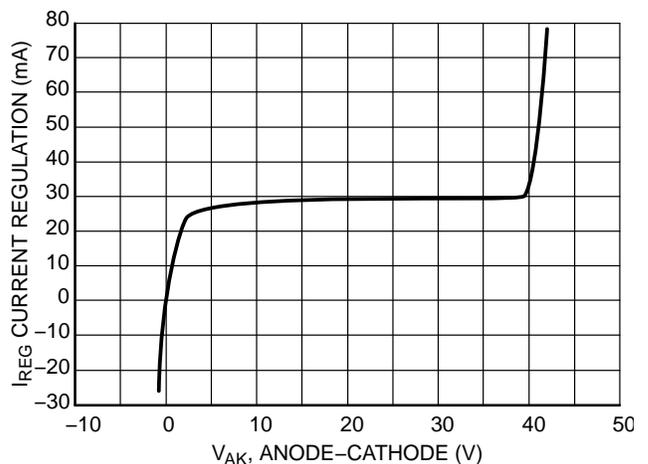

Figure 1. CCR IV Characteristics

A CCR is a nearly ideal current source providing constant current regardless of applied voltage above its operating minimum. In simple terms, a CCR can be considered a nonlinear voltage controlled resistor.

The Power Dissipation (P_d) in an LED is $P_d = I\ V$. Since the CCR acts as a voltage controlled resistor while the resistor biasing fixes the resistor value, the LED Power dissipation is shown to be nearly constant over a variable battery range. (Figure 3)

For automotive CHMSLs, a constant current source for LEDs reduces stress conditions caused by overdriving with current as compared to resistor biasing. A Reverse protection diode (MBRS140T3 in Figure 4) prevents a reverse voltage condition which can permanently damage an LED and protects the CCR from conducting in the reverse bias mode (Figure 1).

A basic CHMSL configuration with 3 Red LEDs in series is shown in Figure 4. A CCR provides a uniform intensity over full line voltage swings and greatly reduces LED power dissipation as compared to common resistor biasing. At 9 V battery input, a CCR provides a higher current than a typical biasing resistor value would provide (Figure 3). At 16 V a stable, constant current is supplied by the CCR.

Figure 2 shows a comparison of CCR vs. Resistor Bias current over battery voltage variation from 9 V to 16 V. The LED current, and therefore intensity, is constant with the CCR device compared to the resistor bias.
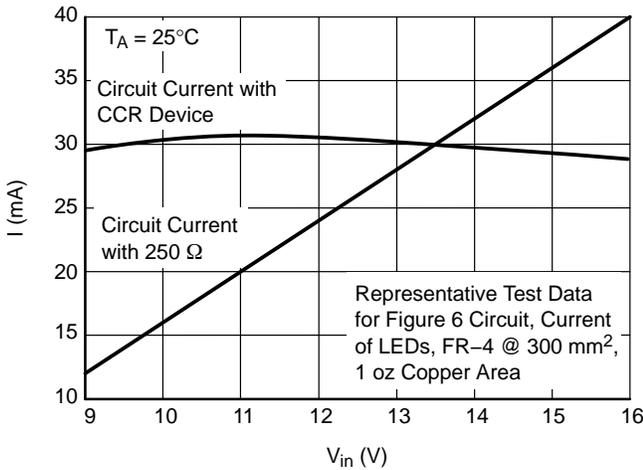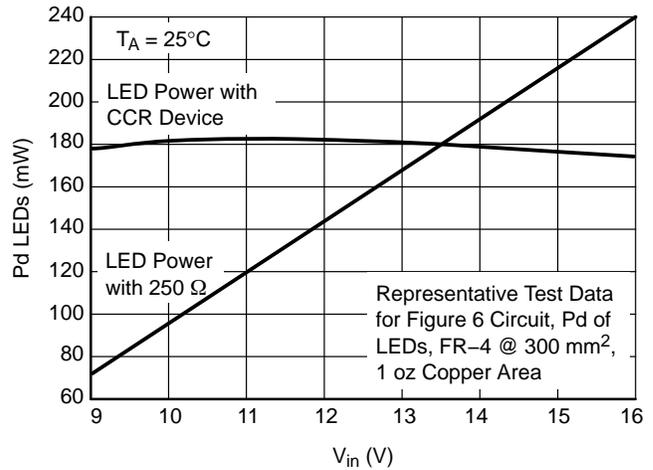

Figure 2. Series Circuit Current
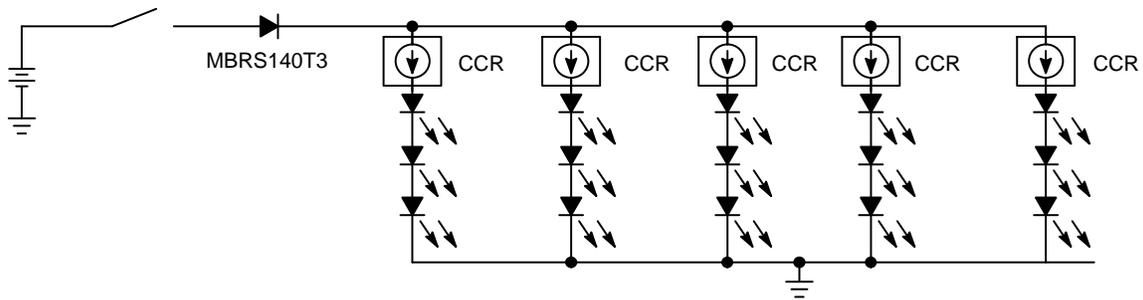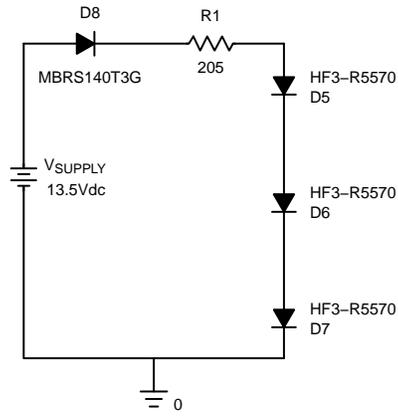

Figure 3. LED Power

Figure 4.

Figure 5.

Figure 5 shows a typical resistive bias for a single CHMSL LED string. The resistor value is calculated to take into account the V_{fwd} across the series connected LED string. If a specific supply voltage, such as 13.5 V, is used, a specific resistor can be chosen to supply a 30 mA drive current.

Example for a 3 Red LED String:

$V_{supply} - V_{sw\_bat} - V_{rpd} - (I_{\_led} \times R_1) - (3 \times V_{fwd}) = 0$ V
$V_{sw\_bat} = 0$ V
$V_{supply} = 13.5$ V Typical
$V_{rpd} = 0.8$ V
$V_{fwd} = 2.20$ V
$I_{\_led} = 30$ mA

$$R_1 = \frac{13.5 \text{ V} - 0.8 \text{ V} - 3(2.20 \text{ V})}{30 \text{ mA}}$$ (eq. 1)

= 203 Ω or 205 Ω (Standard 1% Value).

This method for setting the current with a specific resistor is well known. By knowing the LEDs worst case V_{fwd}, and the light intensity required, a specific range of resistor values can be chosen. However, as the supply voltage varies from 9 V to 16 V, the current changes in the LED which affects the intensity. With the same 205 Ω resistor and 9 V supply, rearranging the equation and solving for $I_{\_led}$ yields 7.8 mA. Assuming all of the parameters remain constant and the supply voltage is elevated to 16 V, an $I_{\_led}$ value of 42 mA is calculated. Again, the intensity of the LED is affected.

A CCR from ON Semiconductor would keep the current and intensity constant over this supply voltage range (Figure 2).

Here is how you can use ON Semiconductor's CCR to determine how many series LEDs it can drive.
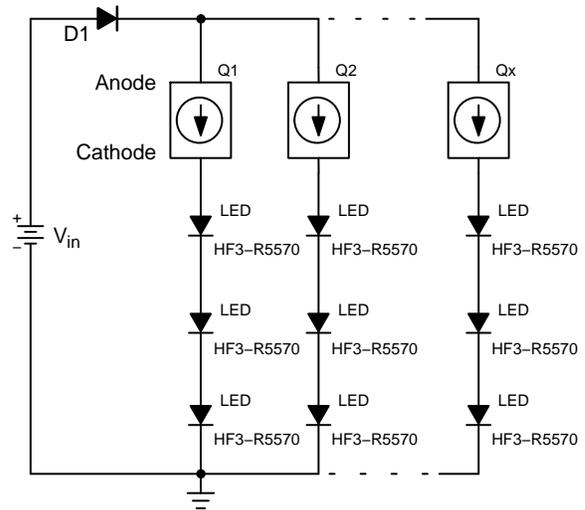

Figure 6. Typical Application Circuit (30 mA each LED String)

Number of LED's that can be connected is determined by:
D1 is a reverse battery protection diode
LED's = (V_{in} − (Q_X V_F + D1 V_F)) / LED V_F
Example: V_{in} = 12 Vdc, Q_X V_F = 3.5 Vdc, D1VF = 0.7 V
LED V_F = 2.2 Vdc @ 30 mA
(12 Vdc − 4.2 Vdc)/2.2 Vdc = 3 LEDs in series.

For application versatility, if more Current drive is required, the CCRs can be connected in parallel to boost the regulated current.
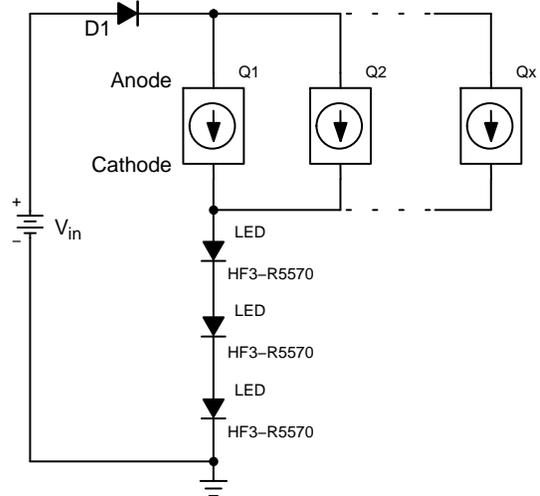

Figure 7. Typical Application Circuit (90 mA each LED String)

Number of LED's that can be connected is determined by:
D1 is a reverse battery protection diode
Example: V_{in} = 12 Vdc, Q_X V_F = 3.5 Vdc, D1VF = 0.7 V
LED V_F = 2.6 Vdc @ 90 mA
(12 Vdc − (3.5 + 0.7 Vdc))/2.6 Vdc = 3 LEDs in series.
Number of Drivers = LED current/30 mA
90 mA/30 mA = 3 Drivers (Q1, Q2, Q3)

Vbat (+)

MBRS140T3G
(Reverse Protection Diode)

Jumper(s) selects DUT

Bias Resistor
(250 Ω)

NSI45030T1G
(CCR)

V_LED
Test Point

Vbat (-)

Jumper(s) to add/remove
LED from circuit

HF3-R5570
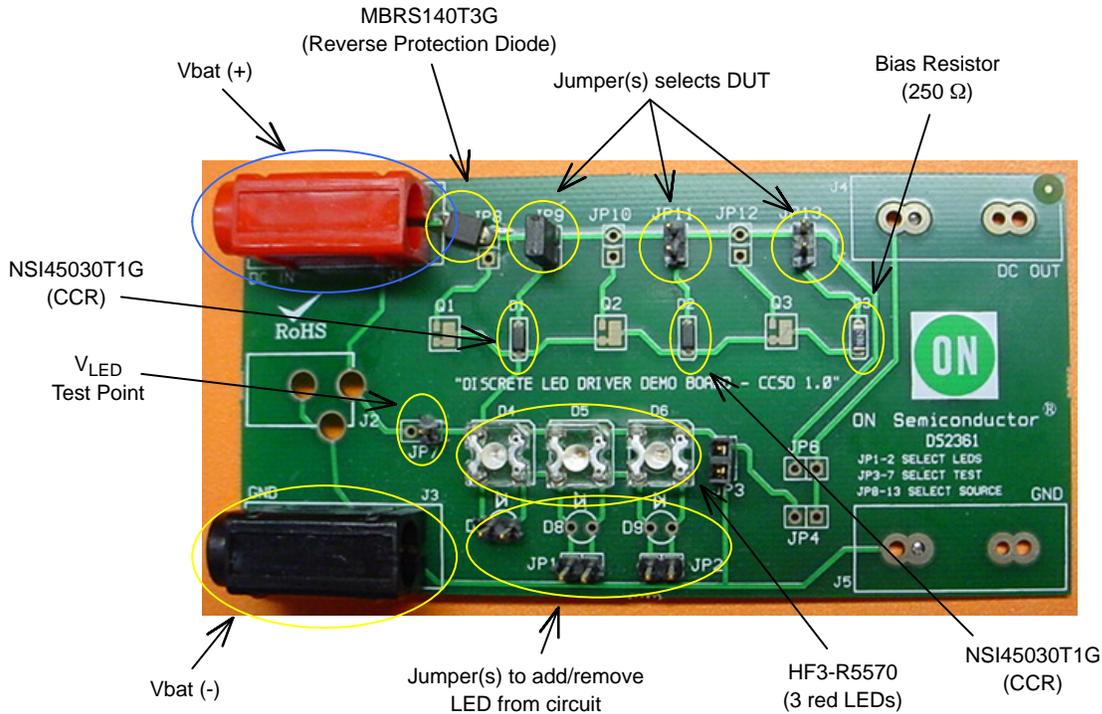(3 red LEDs)

NSI45030T1G
(CCR)

Figure 8.

CCR Demo Board

This demo board (Figure 8) is the circuit shown in Figure 6. It is used to generate several curves and can be used to validate the CCR operation.

Figure 9 shows a comparison of power dissipation in a CCR vs. Power dissipation in a Bias Resistor over battery voltage variation from 9 V to 16 V. The CCR Power is less than a Bias Resistor at higher operating voltages. At higher Battery voltage, a higher wattage Power resistor would be required increasing the circuit cost.

Figure 10 shows a typical Current/Voltage curve for a CCR device. ON Semiconductor's CCR is designed to

have a slight negative trend as the power dissipation increases. This negative trend reduces the power dissipation in the CCR compared to the increasing power dissipation for a bias resistor (Figure 9) and helps to prevent thermal runaway. Since reduction in current is small, the change in LED intensity is minimal.

Figure 11 shows thermal estimates for the NSI45030T1G device with various heatsink footprints. If the heatsink area is increased, the ambient operating temperature may be increased. It is up to the circuit designer to understand the thermal environment of the application and allow for device thermals as specified in the device data sheet.
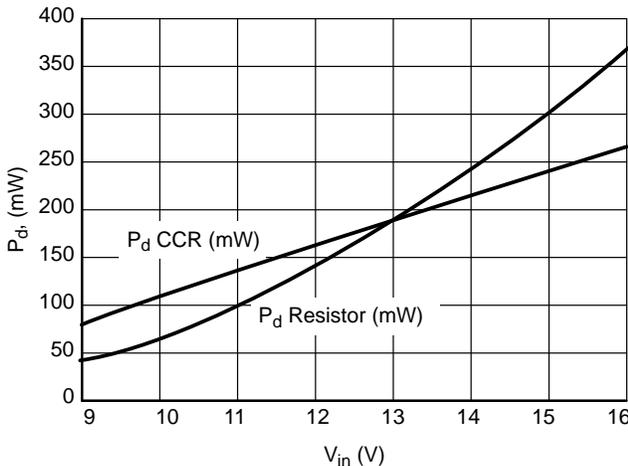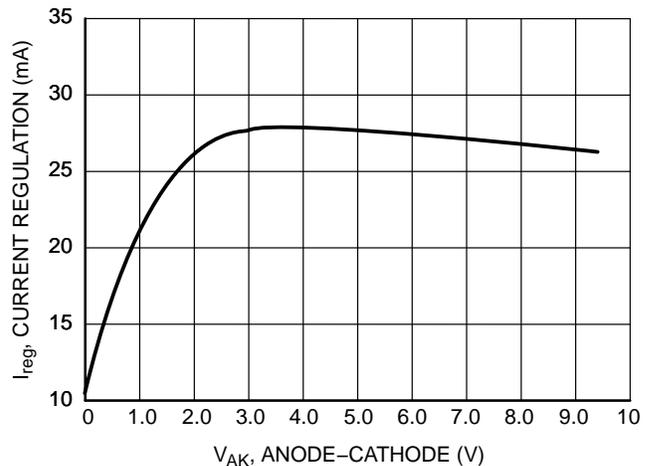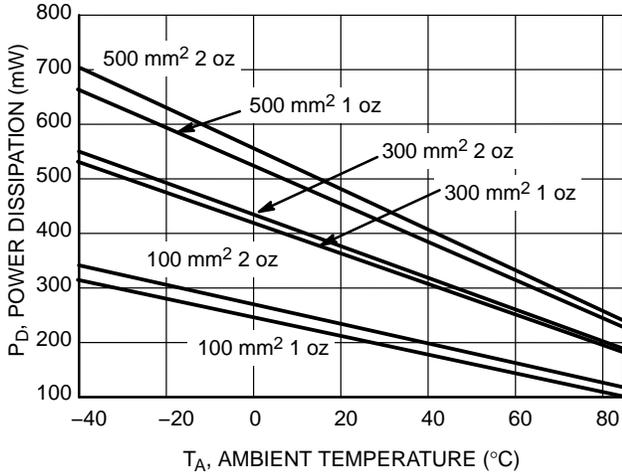

Figure 9. CCR P_d vs. Resistor Pd

Figure 10. CCR–IV Characteristics @ 25°C

THERMAL ESTIMATES FOR THE SOD-123 CCR DEVICE

Figure 11. Power Dissipation vs. Ambient Temperature @ 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

Summary:

Simple, Economical and Robust (SER), the solid state CCR will allow the user to achieve the expected long life of their LED array.

CCRs will improve the efficiency and extend the life of CHMSL LEDs. They will minimize design time and speed up time to market.

Eliminating the large range of resistor values that must be uniquely chosen to compensate for the LED's variation in its V_{fwd} is the best benefit to CCR LED biasing.

Since LED brightness is determined by operating current, optimum intensity will be attained by using a CCR approach to maintain consistent luminosity over the wide variation of battery voltage in automotive electrical systems.

SOT−223 package devices are also available which improve power dissipation. See application note AND8391/D for a through thermal discussion for both the SOD−123 and SOT−223 packages.

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
AND8391/D	Thermal Considerations for the ON Semiconductor Family of Discrete Constant Current Regulators (CCR) for Drivings LEDs
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 (NSI45030T1G) has patents pending.