AND9053/D

Thermal Foldback for CAT4101, LED Lighting

ON Semiconductor®

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APPLICATION NOTE

Introduction

Increased temperature to a LED decreases its lifetime, therefore thermal considerations need to be taken into account. This application note describes implementation of a thermal foldback technique for ON Semiconductor's linear constant current LED driver **CAT4101**.

Operation

Principally, thermal foldback functionality affects LED drive current limiting maximum allowed temperature at defined thermal sensing point (in this case low cost NTC, negative temperature coefficient resistor). Schematics of a linear constant current driver with thermal foldback are shown in Figure 2. CAT4101 (IC2) 1 A constant current LED driver is used according to recommendations provided in the product datasheet.

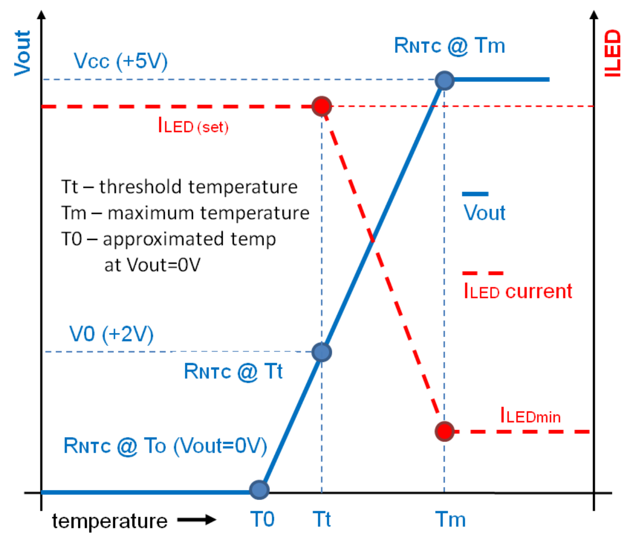

Figure 1. Thermal Foldback Slope

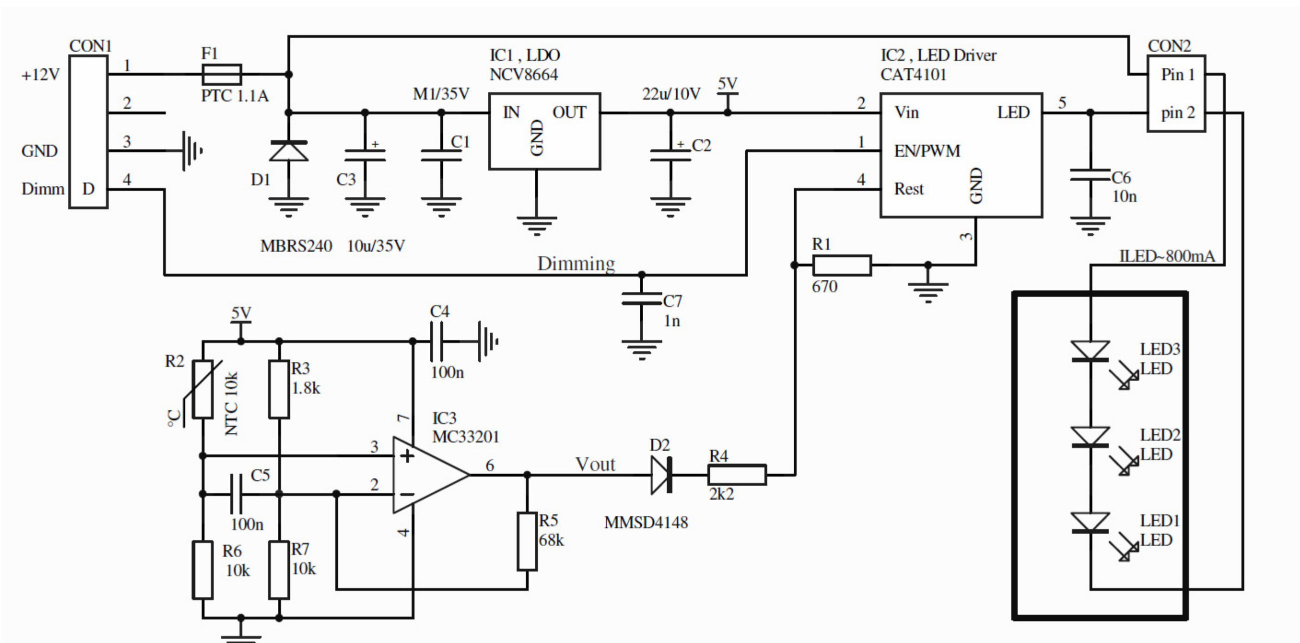

Figure 2. CAT4101 Schematic with Thermal Foldback

Please note that maximum allowed voltage between LED (pin5) and GND is 25 V. Capacitor C6 is recommended for additional ESD protection, it could also be substituted by appropriate ESD diodes. Supply voltage (+5 V Vin) for IC2 is provided by linear voltage regulator IC1. The same 5 V supply is used also as reference voltage for the Wheatstone bridge, formed by components R2 (NTC), R3, R6, R7 and C5 used for low pass filtering.

The Wheatstone bridge single operational amplifier circuit is based on MC33201. This design has a good rejection of common mode noise. Voltage difference across the bridge (V_B) is amplified by Rail−to−Rail amplifier IC3 with defined temperature slope given by R5. Amplified signal from the bridge affects feedback signal to Rset pin of IC2. The current from Rset is mirrored to the driver LED current output (~800 mA). Typical voltage at Rset pin is 1.2 V and current flowing through R1 depends mainly on R1 resistance value, as shown in Figure 3.

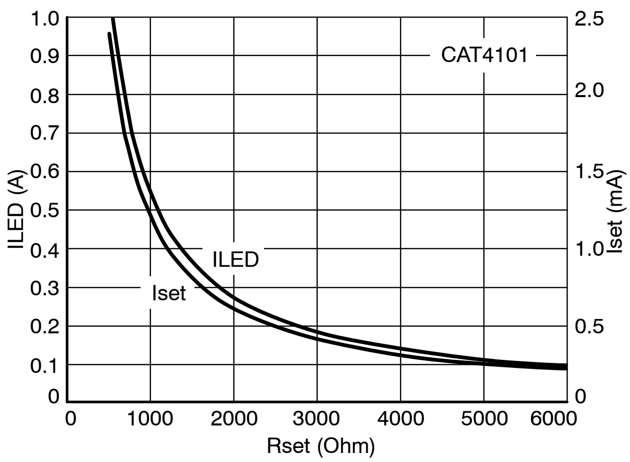

Figure 3. Rset vs. ILED and Iset

Diode D2 is used to exclude voltages below typical voltage on Rset pin (1.2 V). If voltage from IC3 is below 1.2 V plus forward voltage drop on D2 (0.8 V), the LED current is given by value of Rset (R1) only. After reaching and overcoming Tt (threshold) temperature voltage at IC3 output increases over 2 V and starts influence of Iset current (graphically interpreted in Figure 1). Resistor R4 is used to adjust minimum LED driver current at maximum output voltage (Vout) from IC3 (it can be used for instance as emergency illumination) and can be calculated as:

$$I_{LED} = k \cdot \left(I_{R1} - I_{R4}\right) = \frac{V_{Rset}}{R_1} - \frac{\left(V_{out} - V_{f\,D2} - V_{Rset}\right)}{R_4}$$

where k °~ 0.4575 for CAT4101, VRset ~ 1.2 V, VfD2 is forward voltage drop at diode D2 ~ 0.8 V.

The LED string is connected to CON2 (Anode to Pin 1). Vstring is limited by maximum allowed power dissipation of CAT4101 and max 25 volt between LED (pin5) and GND. Lower voltage drop on CAT4101 driver leads to higher efficiency. The power dissipated in the driver is basically the LED pin voltage times the LED current (in this case (12 V − 3 x 3.6 V) x 0.8 V = 0.96 W).

Thermal Foldback

The total power dissipated by the LEDs (P_{LED}) is the product of the string forward voltage and the LED current. Therefore, thermal foldback is necessary in many applications to protect LEDs against increased temperature caused, for instance, by improper installation. In general, there are two important parameters: a threshold temperature (Tt) after which the nominal operating current needs to be reduced, and a slope corresponding to the LED current decrease per temperature increase as shown in Figure 1. Increasing of temperature, sensed by NTC resistor, leads to its non−linear resistance decrease. Usually, the NTC manufacturers detail the resistance−temperature characteristic in their datasheets. Temperature dependence for 10 kΩ NTC resistor, used in this application note is shown in Figure 4 for nominal values.

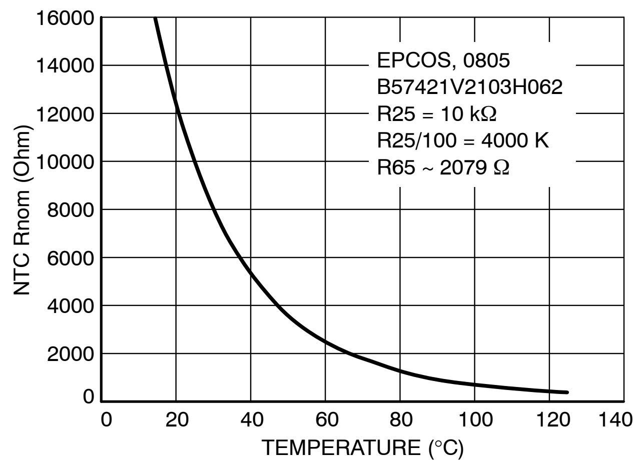

Figure 4. 10 kΩ NTC Resistor Characteristic

The nominal resistance of an NTC is the resistance at 25°C (R25) and in many datasheets this will be given a multiplier of 1. Then the resistance at a higher temperature will have a multiplier less than 1 (for instance R100 multiplier is 0.0674 therefore R100 = 0.0674 x R25).

Change of individual components R3, R5, allows selecting both above mentioned parameters of the thermal foldback profile. Slope is given by feedback resistor R5, which can be calculated as

$$R_5 = \frac{R_3 \cdot R_7 \cdot V_{CC} - V_B \cdot R_3 \cdot R_7}{\left(R_3 + R_7\right) \cdot V_B}$$

where (V_B is voltage across C5, bridge differential voltage)

$$V_B = \frac{R_6 \cdot V_{CC}}{R_6 + R_{2@Tm}} - \frac{R_6 \cdot V_{CC}}{R_6 + R_{2@T0}}$$

R2@Tm is NTC resistance at Tm (max temperature) and R2@T0 is approximated temperature when output voltage from IC3 amplifier is crossing zero (Figure 1) and can be calculated as:

$$R_{2@T0} = \frac{\left(R_{2@Tt} - R_{2@Tm}\right) \cdot V_{CC}}{\left(V_{CC} - V_0\right)} + R_{2@Tm}$$

Resistance R3 is recommended to keep close to R2@Tt value. To help estimate bridge components and feedback resistor simple XLS calculator is provided. Example calculation for selected R6 = R7 = 10 k, R3 = 1.8 k, Vcc = 5 V, V0 = Vrset + VfD2 = 2 V, NTC resistances from Epcos datasheet for B57421V2103H062 R2@Tm = 1553 Ohm (74°C) and R2@Tt =1732 Ohm (70°C) is:

$$R_{2@T0} = \frac{(1732 - 1553) \cdot 5}{(5 - 2)} + 1553 \approx 1851 \text{ Ohm}$$

$$V_B = \frac{10\text{ k} \cdot 5}{1.8\text{ k} + 1553} - \frac{10\text{ k} \cdot 5}{10\text{ k} + 1851.3} \approx 0.1089 \text{ V}$$

$$R_5 = \frac{1.8\text{ k} \cdot 10\text{ k} \cdot 5 - 0.1089 \cdot 1.8\text{ k} \cdot 10\text{ k}}{(1.8\text{ k} + 10\text{ k}) \cdot 0.1089} \approx 68.5\text{ k}\Omega$$

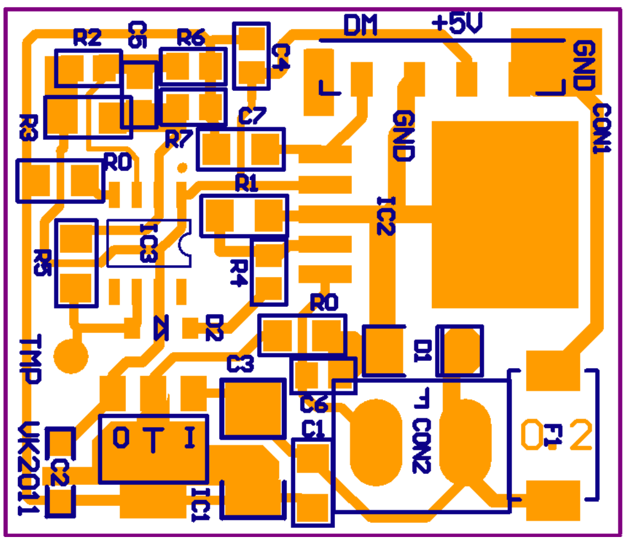

Figure 5. MCPCB Assembly, TOP Layer View

Conclusion and Application Example

In an ideal case, foldback functionality should not be activated during proper operation, but in the case of unexpected situations like increased ambient temperature, improper installation, etc, it will help to protect lighting solution and keep its lifetime high. When an over temperature condition occurs, the thermal foldback circuitry reduces the regulated current through the LEDs, while continuing to operate it (dimming). In Figure 9, practical application of 10 W LED accent lamp is shown. PCB Layout for driver based on MCPCB (Metal Core Printed Circuit Board) is shown in Figure 5. Here, LED driver supply around 800 mA to three serial connected 3 W LEDs. Achieved results for different ambient temperatures are shown in Figure 6 (inactive thermal foldback, regular fixture functionality) and Figure 7 (activated thermal foldback, increased ambient temperature). As can be seen, calculated and achieved results are consistent. This approach can be applied to multichannel design for instance for street lighting, flower stimulation lights and many others.

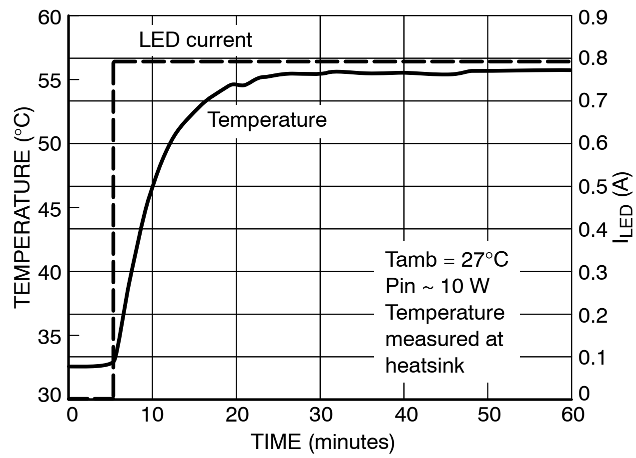

Figure 6. Achieved Results, Inactive Thermal Foldback, Pin~10 W, Vin = 12 V, Ta = 24°C, Regular Operation

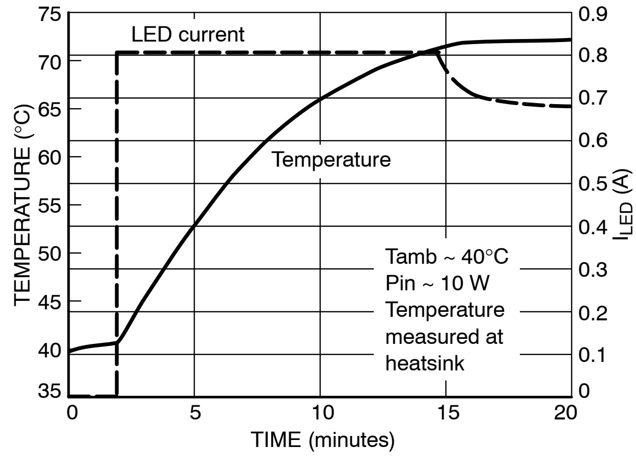

Figure 7. Achieved Results, Activated Thermal Foldback, Pin~10 W, Vin = 12 V, Ta~40°C

Please note according to NTC datasheet there is resistance variation, therefore to match required temperature, precise NTC resistors or individual resistance measurement at Tt and Tm are required.

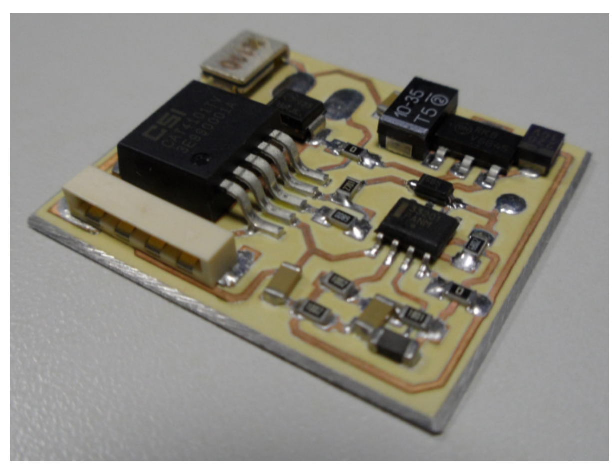

Figure 8. Realization on MCPCB, Bergquist Al = 1 mm

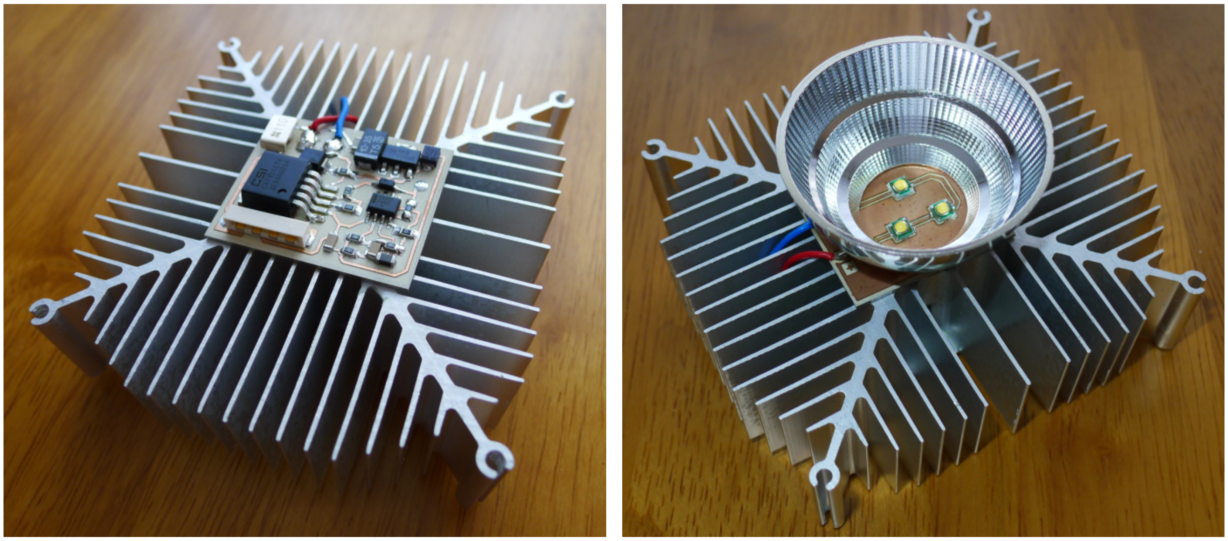

Figure 9. Application Example, 10 W LED Lamp

Table 1. CAT4101 BOARD LIST OF COMPONENTS

Name	Manufacturer	Description	Package	Part Number	Quantity
C1	AVX	Ceramic Capacitor	Size 1206	M1 / 35 V	1
C2	AVX	Tantalum Capacitor	TANT−32−16	22 u / 10 V	1
C3	AVX	Tantalum Capacitor	TANT−60−32	10 u / 35 V	1
C4, C5	AVX	Ceramic Capacitor	Size 0805	100 n	2
C6	AVX	Ceramic Capacitor	Size 0805	10 n	1
C7	AVX	Ceramic Capacitor	Size 1206	1 n	1
CON1	AVX	SSL AVX connector	SSL9159−4P	Interface	1
CON2	NA	PCB Terminal	TB2P5	LED	1
D1	ON Semiconductor	Schottky Diode 3 A / 60 V	SMB	MBRS240	1
D2	ON Semiconductor	Schottky Power Rectifier 0.5 A, 30 V	SOD−123	MMSD4148	1
R0	Vishay	0 Ohm shunt	Size 1206	Comment	2
F1	Bourns MF−SM Series	Bourns MF−SM Series − PTC Resettable Fuses	MF−SM−2920	PTC 1.1 A	1
IC1	ON Semiconductor	Low IQ Low Dropout 5V / 100 mA Linear Regulator (Automotive)	SOT−223	NCV8664	1
IC2	ON Semiconductor	3 A, Adjustable Output Voltage, Step−Down Switching Regulator	D2PAK5	CAT4101	1
IC3	ON Semiconductor	Low Voltage, Rail−to−Rail Operational Amplifier	SOIC 8	MC33201	1
R1	Yageo	SMD Resistor RC1206 1/4 W	Size 1206	670 Ohm	1
R2	EPCOS	10 k NTC Resistor	Size 0805	B57421V2103H062	1
R3	Yageo	SMD Resistor RC1206 1/4 W	Size 1206	10 k	1
R4	Yageo	SMD Resistor RC0805 1/4 W	Size 0805	2k2	1
R5	Yageo	SMD Resistor RC1206 1/4 W	Size 1206	68 k	1
R6	Yageo	SMD Resistor RC0805 1/4 W	Size 0805	10 k	1
R7	Yageo	SMD Resistor RC0805 1/4 W	Size 0805	1.8 k	1

***Build note:** All components except of LEDs are placed on MCPCB (Metal Core Printed Circuit Board), as shown in Figure 5 and Figure 8. The MCPCB is thermally attached to heat sink with LEDs (Figure 9). Ideally NTC resistor should be located at LED MCPCB or close to it, but in this application this was not really required.

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