

Intelligent Over Temperature Protection for LED Lighting Applications

Authors: Hakan Yilmazer, Bernd Pflaum

Abstract

LED lighting is becoming increasingly popular. It offers numerous advantages over conventional lighting, but there are still some issues. One is thermal management. Bernd Pflaum and Hakan Yilmazer from Infineon Technologies explain how LED driver ICs with smart over temperature protection help to increase lifetime and optimize system costs of LED lighting systems.

Contents

1 Introduction.....	4
2 LED lifetime depends on temperature.....	5
3 Different Approaches for Thermal Protection	6
4 IC Implementation of Smart Over Temperature Protection.....	7
5 Key Benefits of IC Implemented Over Temperature Protection	8
5 Summary	13
References	14
List of Figures	15

1 Introduction

System manufacturers are addressing thermal challenges by designing systems with appropriate heat sinks, high thermal conductivity enclosures and other advanced thermal design techniques. Generally these manufacturers do not consider the LED driver IC as a control component in the thermal system. The use of an LED driver IC with intelligent over temperature protection provides an additional control mechanism that can increase the lifetime of LED light sources significantly, ensuring the rated lifetime and reducing the incidence of defective products. Depending on the lighting manufacturer and application, useful lifetime for LED lighting products range from approximately 20,000 hours to more than 50,000 hours compared to less than 2,000 hours for incandescent bulbs. The intelligent thermal protection also helps to reduce system cost by enabling system integrators to design the heat sink with lower safety margin.

Despite the very high efficiency of LEDs compared to other light sources a large portion of the energy used to drive LEDs is converted to heat. Unlike other light sources, like incandescent bulbs, LEDs generate little or no infrared radiation. That's why the generated heat must be conducted from the LED die to the underlying circuit board and heat sinks, housings or luminaries frame elements. If this heat transfer system has design or manufacturing flaws, or the system experiences extremely high temperature conditions the LEDs, the driver IC or other heat sensitive components like electrolytic capacitors can be damaged.

The patent pending smart thermal management technology included in the latest LED driver ICs can help to protect the system from thermal failure resulting in improved LED system designs.

2 LED lifetime depends on temperature

In general, high quality LEDs are robust devices that can operate in excess of 100,000 hours, when properly operated. The lifetime of LEDs is directly related to the junction temperature to which they are exposed. Increasing temperatures can reduce the operating lifetime significantly. Figure 1 illustrates the light output over time (experimental data to 10,000 hours and extrapolation beyond) for two identical LEDs driven at the same current but with an 11K difference in T_j . Estimated useful life (defined as 70% lumen maintenance) decreased from about 37,000 hours to 16,000 hours, a 57% reduction by a temperature increase of only 11K.

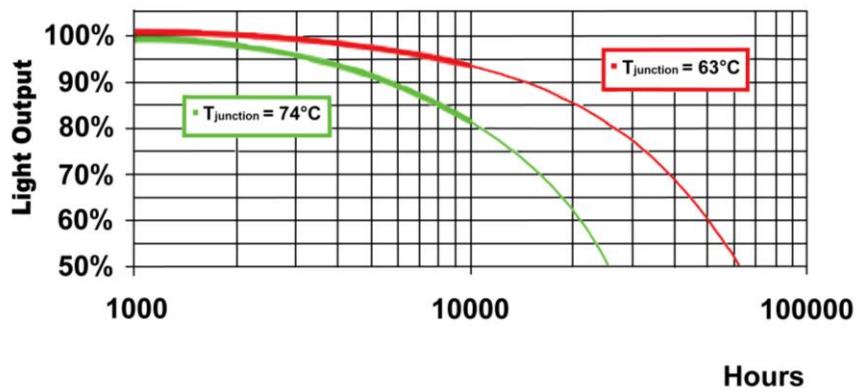


Figure 1: Lifetime of LEDs is a function of the junction temperature (Source: EOS)

3 Different Approaches for Thermal Protection

The thermal design is often focused on the heat sink and PCB design, while the opportunities for thermal management by the LED driver IC and driving circuit are not considered. Intelligent over temperature protection by the LED driver IC can increase the lifetime of LED light sources significantly.

Temperature protection with LED driver ICs can be implemented in a variety of ways. Some LED driver devices include a sense pin to which an external temperature sensor may be attached. Different temperature sensing devices, including diodes, on-chip sensors, positive temperature coefficient (PTC) or negative temperature coefficient (NTC) thermistors can be used in LED lighting applications to protect the LEDs from overheating. NTC thermistors are often the preferred choice for temperature sensing and control in many of these applications, primarily because of their small package sizes and attractive price/performance ratio. But accuracy, response time and thermal gradient depend on the way the NTC thermistor is mounted. Once the temperature is accurately sensed, the response to overtemperature must be considered. The typical response is to trigger an abrupt turn off of the current to the LEDs when a critical temperature has been detected. These devices then can “restart” when the temperature is reduced or wait until a power cycle to restart. There are some disadvantages related to these methods:

- The abrupt shut-down method leads to setting the shut-down at a very high temperature in order to avoid incorrectly triggered shutdown. While this high value usually protects from catastrophic failures it still can result in significant reduction in the lifetime of the LEDs.
- Turning off the LED current means that the light is switched off abruptly. This can cause a serious situation like panic in public areas.
- Most drivers automatically restart when the system has cooled. Once restarted the system will heat up and shut-down can occur again resulting in a disturbing flicker effect.
- Drivers that latch “off” after the failure which requires a power on reset which is often not easy to implement or even not possible.

In security relevant applications (e.g. the illumination of emergency exits, escape routes, emergency shut-down switches, etc.) a simple shut-down of the LED driver is insufficient as maintaining the illumination is essential. This shut down behavior may also be insufficient in non-security related applications where light output is necessary under extreme conditions such as hot environments. Finally, it is desirable to reduce the required external components necessary to operate the LED driver and to protect the driver as well as the LEDs. The components required to provide the thermal protection should be inexpensive and easy to integrate into an illumination device.

4 IC Implementation of Smart Over Temperature Protection

Leveraging the key idea of a patent to use the LED driver IC as a thermal sensor a patent pending technology has been developed to protect the LEDs with a slope dimming characteristic and adjustable trigger temperature for the start of thermal protection to overcome the limitations of conventional LED system designs. The new technology was implemented in the recently announced DC/DC hysteretic buck LED driver with high side current sensing (Figure 2).

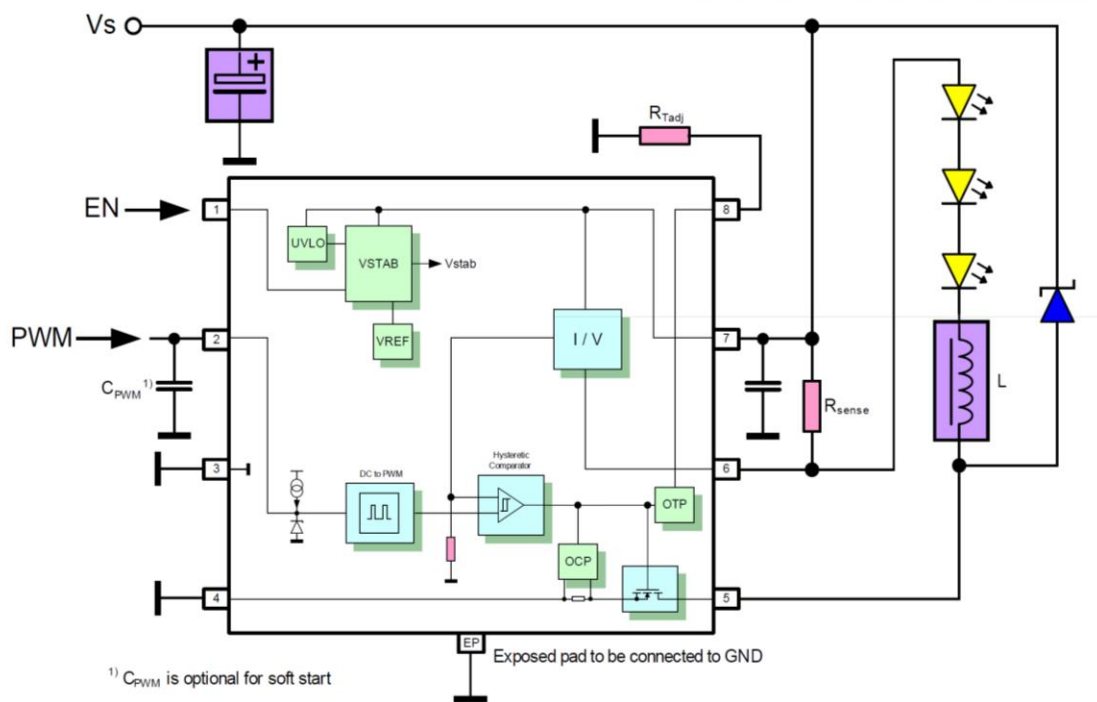


Figure 2: Application circuit with the new ILD6070 driver: The current reduction is triggered at a threshold of the solder point temperature of the LED driver IC which is adjustable using an external resistor connected to the T_{adj} pin

5 Key Benefits of IC Implemented Over Temperature Protection

Saving system cost by using the driver IC as a thermal sensor for thermal protection

The driver IC can be used as a reference temperature to determine the LED temperature in systems where the driver is thermally coupled to the LEDs. This saves cost of NTC, additional wiring and connector pins. In addition the design for thermal protection is simplified.

In case where the driver IC cannot be installed with a tight thermal coupling the ILD6 series devices can also use an external NTC sense element to protect the system (figure 3). The NTC thermistor is placed near to the LEDs to sense the temperature of the LEDs accurately.

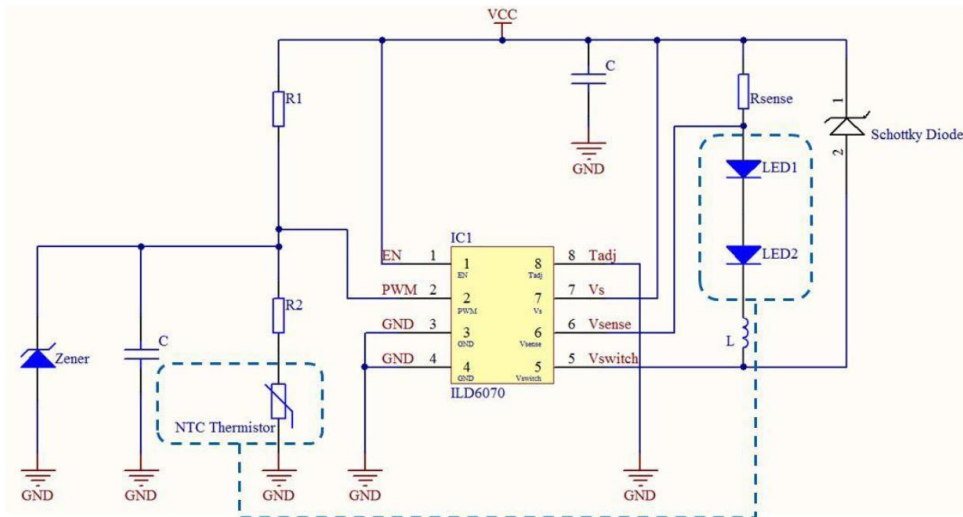


Figure 3: Depending on the application, the new driver ICs can use both internal temperature protection and external NTC for thermal protection

Protection of LED lifetime by slope dimming mechanism

Reducing the LED average current with an integrated slope dimming mechanism protects the lifetime of the LEDs by reducing their junction temperature.

The protection circuit should ideally result in LED power deliver that has a smooth protection characteristic as a hard switching may lead to flickering.

If a light source driven by the new LED drivers is exposed to a higher temperature condition than foreseen in the thermal design, the driver ICs will reduce the average current of the LED continuously in a slope dimming characteristic; not abruptly.

This continuous range of adjustment allows the system to come to an equilibrium point that provides continued operation of the light source under exposure to the extraordinary condition with reduced light output. If the thermal equilibrium is overrun by additional thermal load this gradual reduction continues until a minimum of 25% of the target LED average current is reached and the light source will continue to provide light output with a luminance level of minimum 25% of the target light output.

The smart slope dimming mechanism enables customers to design their lighting solutions according to the main operating temperature range. Unforeseen peak temperature conditions which could destroy LED system can be protected by the smart slope dimming feature. This offers the option to design lower safety margin for heat sink size and herein save system costs.

The general concept behind this approach is described in figure 4. An LED driver is coupled to an LED (or a series circuit of LEDs) and configured to provide a load current i_L to the LEDs. The LED driver generates the load current i_L in accordance with an internal drive signal V_{DRIVE} such that the average load current matches the drive signal. Thus, the drive signal indirectly determines the average load current and, in turn, the luminous intensity of the LED. A temperature measurement circuit generates the drive signal V_{DRIVE} such that it depends on temperature. The LED driver should be placed close to the LEDs to sense the temperature precisely.

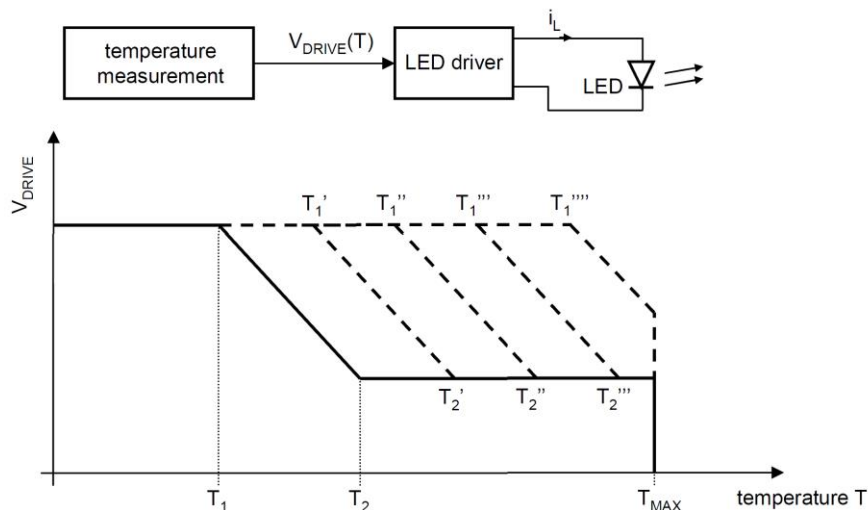


Figure 4: Basic concept of the adjustable temperature protection

When a specific first temperature (T_1 in Figure 4) is reached, the drive voltage V_{DRIVE} is reduced. The decrease of the drive voltage V_{DRIVE} continues as the temperature continues rising. When a specific second temperature (T_2) is exceeded, the drive voltage remains approximately constant. However, if the temperature still rises and exceeds a maximum temperature T_{MAX} then a thermal shutdown is initiated.

The patent pending circuit design is based on standard components like resistors, diodes, capacitors, transistors, comparators or operational amplifiers (Figure 5). The temperature measurement is handled using serial SI diodes placed near the power stages, as the hottest and most sensitive parts in the driver IC. If LEDs are heating up the power stages would recognize the temperature difference. The diodes are also placed close to power stages to protect the IC itself from overheating.

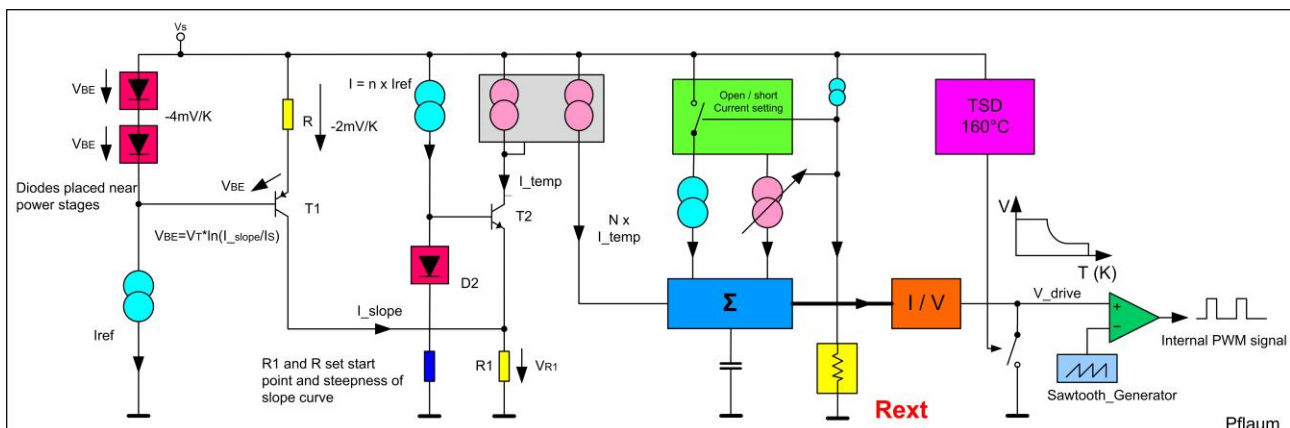


Figure 5: Simplified block diagram of the smart over temperature protection circuit

It is important to note, that the V_{drive} signal is compared with an internal Sawtooth signal to generate an internal PWM signal for the dimming. The current I_{temp} is composed on the temperature dependent I_{slope} current and a fixed temperature independent current created by transistor T2, SI diode D2 and resistor R1. The external resistor (R_{ext}) controls a current source part which is added to the temperature dependent current $N \times I_{temp}$. Based on this analog circuit the trigger point where the slope starts can be selected. At $R_{ext} = short / open$ dedicated currents are implemented, which set certain slope characteristics. Both states are detected by comparator circuits.

The slope curve is decreasing with a certain incline to a minimum value defined by the protection circuit. Is the minimum value reached as the driver is overheating, the protection circuit keeps the LED lighting on a defined level. If the temperature further increases to more than $160^{\circ}C$ the V_{drive} signal and therefore the LED current is completely switched off.

Optimization between lifetime and cost for thermal system by adjusting the triggering point for thermal protection

Luminary manufacturers can adjust the temperature that the protection engages by selecting the value of a low cost external resistor according to the end customer and application needs.

The current reduction is triggered at a threshold temperature of the junction temperature of the LED driver IC which is adjustable by an external resistor. The trigger point and the related profile can be set by using a resistor connected between the T_{adj} pin and GND pin (Figure 2). Based on the adjustable approach, the starting point of the current reduction at high temperature can be designed according to the specific LED lamp requirements. Therefore the light system designers can optimize their products between cost and lifetime. In case a long lifetime has to be guaranteed to end customers the system integrators may decide to adjust a trigger point at a lower temperature. If system cost is the main competitive criterion the triggering point can be set at a higher temperature in order to ensure nominal light output at higher temperatures and to protect the system by the thermal protection function of the IC instead of increasing the heat sink size to cover extremes of the operating conditions. The lifetime of this LED system design will be shorter than the firstly mentioned design due to the higher junction temperature of the LEDs.

It should be noted that the heat sink must be designed in a way to maintain the operating temperature range of LEDs during normal operation.

Figure 6 shows measurement results of the profile with output LED current's duty cycle versus junction temperature of the ILD6070 driver by using 0 Ω , 10 k Ω , 20 k Ω , 35 k Ω and open at T_{adj} pin.

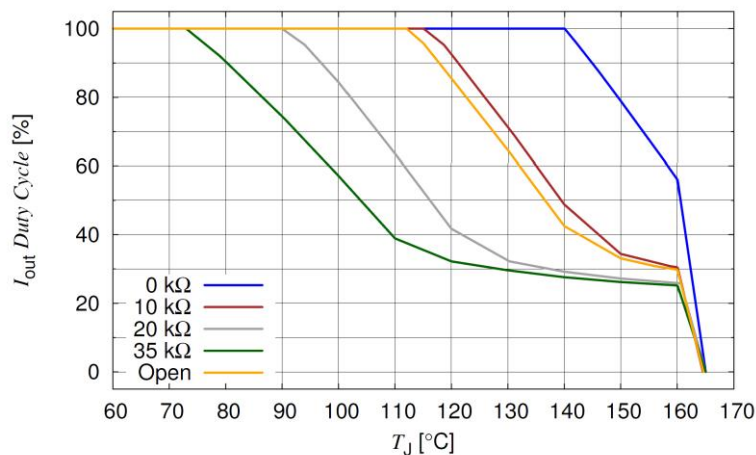


Figure 6: The adjustable trigger point defines the starting point and the shape of the slope

Maintaining light color during thermal protection due to PWM dimming method

Dimming by generating an internal PWM signal during thermal protection ensures that the light color doesn't change. Since the light color remains practically unchanged it might not be visible to end users that the LED system is in thermal protection mode.

The integrated temperature protection circuit will start to reduce the LED current by internal PWM modulation once the certain temperature trigger point of the slope characteristic of the IC is exceeded.

The LED current will be modulated by changing the duty cycle of an internal generated 1.6 kHz PWM signal due to thermal protection mode. As a result the output light generated by the LED will be modulated by the PWM pulses, as well. The key advantage of having PWM modulated light output is that the wavelength spectrum and therefore the color of the light remained unchanged.

As shown in figure 7, the wavelength spectrum is only reduced in magnitude at different setting on the adjustable external resistance. For this experimental set up the module has been heated up by LEDs and the hot ambient air to 120°C, where the IC works at thermal protection mode.

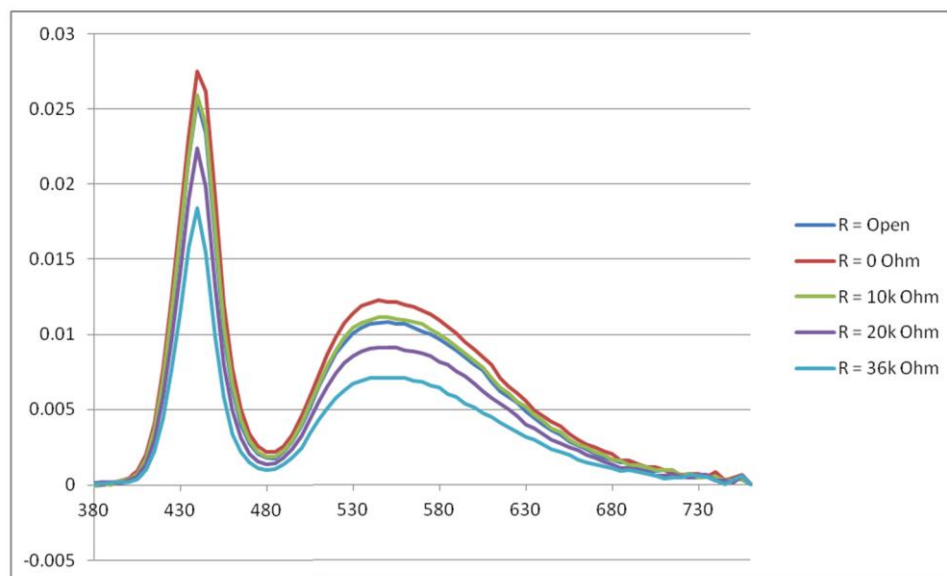


Figure 7: PWM modulated light output keeps the color unchanged during thermal protection

5 Summary

A key challenge in implementing high quality and durable LED lighting systems is managing the heat emitted from the LED components and electronics. Luminary designers are advised to consider other ways than only the heat sink design in order to manage the high thermal load at the PCB. This results in various benefits for luminary manufacturers and end users:

- Improved total cost of ownership by increasing the lifetime of the LED system
- No outage of light in thermal protection mode, in most cases there will be sufficient light available
- Reduced system costs for thermal protection since
 - no NTC is required if the driver IC can be thermally coupled to the LEDs
 - the heat sink design can be optimized
- Flexibility
 - to use the LED driver IC with or without an NTC depending on the distance between the driver IC and the LEDs
 - to adjust the trigger temperature for the start of thermal protection depending on end customer and application needs

With this smart thermal management technology described here and used in the latest LED driver generation, the lifetime and cost of LED designs can be significantly improved.

References

- [1] “Thermal Management of White LEDs”, DOE, February 2007
- [2] “Solving the System-Level Thermal Management Challenges of LEDs”, Mentor Graphics Whitepaper, 2011
- [3] Application Note “ILD6070 60V/0.7A Highly Efficient Step Down LED Driver With Adjustable Thermal Protection“, Infineon Technologies, July 2013
- [4] Application Note “ILD6150/ ILD6070 Thermal Management for LED Light Engine”, Infineon Technologies, August 2013
- [5] Detailed information about the LED drivers with smart thermal protection can be found under the link www.infineon.com/lowcostleddriver

List of Figures

Figure 1: Lifetime of LEDs is a function of the junction temperature (Source: EOS)	5
Figure 2: Application circuit with the new ILD6070 driver: The current reduction is triggered at a threshold of the solder point temperature of the LED driver IC which is adjustable using an external resistor connected to the T_{adj} pin	7
Figure 3: Depending on the application, the new driver ICs can use both internal temperature protection and external NTC for thermal protection	8
Figure 4: Basic concept of the adjustable temperature protection	9
Figure 5: Simplified block diagram of the smart over temperature protection circuit	10
Figure 6: The adjustable trigger point defines the starting point and the shape of the slope	11
Figure 7: PWM modulated light output keeps the color unchanged during thermal protection	12

Published by
Infineon Technologies AG
85579 Neubiberg, Germany

© 2013 Infineon Technologies AG.
All Rights Reserved.

Visit us:
www.infineon.com

ATTENTION PLEASE!

The information given in this document shall in no event be regarded as a guarantee of conditions or characteristics ("Beschaffenheitsgarantie"). With respect to any examples or hints given herein, any typical values stated herein and/or any information regarding the application of the device, Infineon Technologies hereby disclaims any and all warranties and liabilities of any kind, including without limitation warranties of non-infringement of intellectual property rights of any third party.

INFORMATION

For further information on technology, delivery terms and conditions and prices please contact your nearest Infineon Technologies Office (www.infineon.com).

WARNINGS

Due to technical requirements components may contain dangerous substances. For information on the types in question please contact your nearest Infineon Technologies Office. Infineon Technologies Components may only be used in life-support devices or systems with the express written approval of Infineon Technologies, if a failure of such components can reasonably be expected to cause the failure of that life-support device or system, or to affect the safety or effectiveness of that device or system. Life support devices or systems are intended to be implanted in the human body, or to support and/or maintain and sustain and/or protect human life. If they fail, it is reasonable to assume that the health of the user or other persons may be endangered.