Intelligent LED lighting control with thermal monitoring

By Charles Pencil, Applications Eng. Sr. Staff, Cypress Semiconductor Corp.

With new LED lights, one of the most difficult, demanding, and costly section of a design is thermal management. Without sufficient thermal management, the results can be catastrophic, ranging from leaving you in the dark to setting a building afire. Thermal management of LED lights, however, is one of the most difficult, demanding, and costly section of a design. This article will discuss how to implement negative temperature coefficient (NTC) thermal management to achieve safer LED designs that consume less power.

With traditional filament base bulbs, any heat generated is from the filament, which is well isolated from direct contact. With LED lights, the LED is the source of light and the heat generated by the LED is in direct contact the LED light bulb. The direct contact is a result of how the LEDs have to be attached to the driver circuit. To remove the heat, thermal dissipation or management is required to move the heat away from the LEDs and driver circuit. The thermal management or removal of heat is necessary to provide a LED light that is capable of many hours of operation.

To understand why thermal management is important, consider an application where a replacement LED light is installed in a generic light socket, such as a wall sconce or recessed ceiling fixture, and controlled by an on/off wall switch. This application will have poor heat dissipation since the thermal dissipation in most standard lights is dependent upon thermal convection or air flow to remove heat from the light, and there is such dissipation in a wall sconce or recessed ceiling fixture.

Without sufficient thermal management, the results can be catastrophic, ranging from needing to replace an LED light that has stopped working to literally setting a building afire. Using intelligent LED light control to monitor the LED light temperature, implementing thermal management is much simpler and the LED light will be safer since the light can reduce its power as the temperature increases.

Negative temperature coefficient (NTC) thermal management

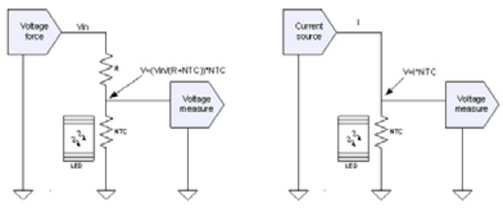
The basis for an NTC circuit is to improve LED light safety and reduce design complexity by monitoring the temperature of the LED light. As the temperature increases, the controller reduces the lumens and thereby allows the LED to maintain safe levels. Put in other terms, as the temperature increases, decrease the lumens and its converse, as the temperature decreases, increase the lumens.

To measure the temperature change of an LED light, the voltage across an NTC can be measured. The voltage measured has a direct relationship to the temperature of the NTC, and the NTC will reduce in resistance as the temperature of the NTC increases with its surrounding circuits. There are two basic methods for determining temperature using an NTC.

Method one is to use the NTC in a voltage divider circuit where the system forces a known voltage and then measures the voltage at the NTC node. As the NTC temperature increases, its resistance decreases. The decreased resistance results in a change of the voltage-divider ratio. The voltage at the NTC node also reduces as the temperature increases.

Method two is to force a known current through the NTC and measure the voltage at the NTC. As the NTC temperature increases, its resistance decreases. The decreased resistance results in a change of voltage at the NTC node according to Ohm's law. As the resistance decreases and the current remains consistent, the voltage at the NTC node decreases as well.

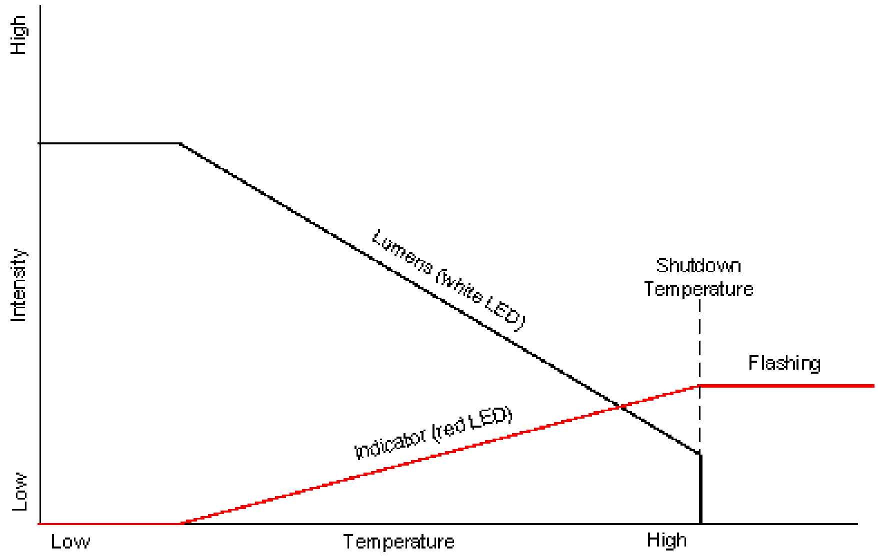
Using either method to monitor LED light temperature is simple and straightforward to implement for improved operation and safety. The following diagram shows both methods using an LED as the source of temperature increase.



[+] Feedback

Over-temperature or LED failure?

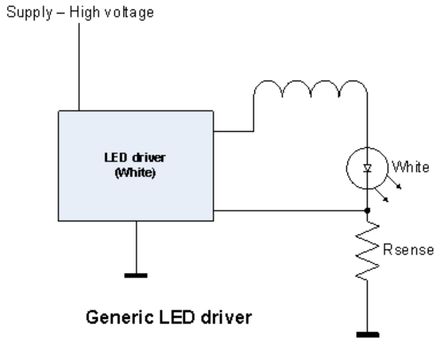
When the lumen output of the LED light is reduced, it is important to know if the LED output is reduced due to an over-temperature condition or because the LED is failing. This can be determined by utilizing an indicator that produces a reduction in lumens.

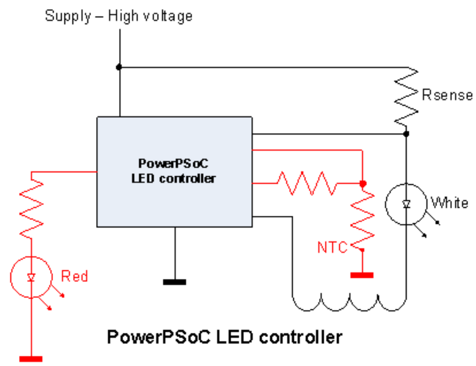


The lumen reduction indication in this system is a low-power red LED. When the system is operating at maximum lumens output, the red LED is off. As the temperature of the LED light increased, the lumens output will be reduced. As the lumens output is reduced, the red LED will begin to turn on. As the lumen output repeatedly reduces, the red LED intensity will be correspondingly increased. When the lumens output has been reduced to its minimum intensity, the red LED will have been fully turned on.

When the lumens is at minimum intensity and the temperature of the LED light is still high, the red indication LED has one additional function: it will act as an alarm to signify a serious problem. In alarm mode, the red LED will pulse on-off-on-off while the white LEDs are off.

The block diagram below shows a generic LED driver and an LED controller with a NTC and 'alarm' indicator. The generic LED light consists of an LED driver configured to provide a set current through the LED. The driver has no method to lower the lumens based upon temperature. Any temperature monitoring the drive provides is only to protect itself and completely shutdown when its temperature is very high.





The LED controller has all the control capabilities of the generic LED driver and adds intelligence for additional functions such as temperature monitor, communication, and dimming control. The LED controller in the diagram has the basic modules and components in blue. The components in red are not required for basic operation, but are shown for the NTC and alarm capabilities discussed in this article.

The addition of an NTC to the basic LED light provides a method for the light to shut down in a controlled sequence when the temperature reaches set limits. The two red components (resistor and NTC) on the right side of the LED controller are configured as detailed in method one under NTC operation. A precise voltage is provided from the controller to the resistor element. The voltage at the NTC node is measured by the controller for conversion to a relative system temperature.

The ‘alarm’ provides a method for the LED light to indicate that the temperature is increasing or has increased to a level where safety dictates the light be shut down. The two red components (resistor and LED) on the left side of the LED controller are a basic indicator LED configuration. The brightness of the LED is controlled by a PWM (Pulse Width Modulation) signal. The LED will be increase in brightness with an increase in the duty cycle of the PWM.

The intelligent LED light depicted above shows the ‘alarm’ as an additional LED. The LED ‘alarm’ is only one of many communication interfaces an intelligent LED light is capable of utilizing. Other communication interfaces include PLC (Power Line Communication), DMX (Digital Multiplexing), and DALI (Digital Addressable Lighting Interface) to list a few.

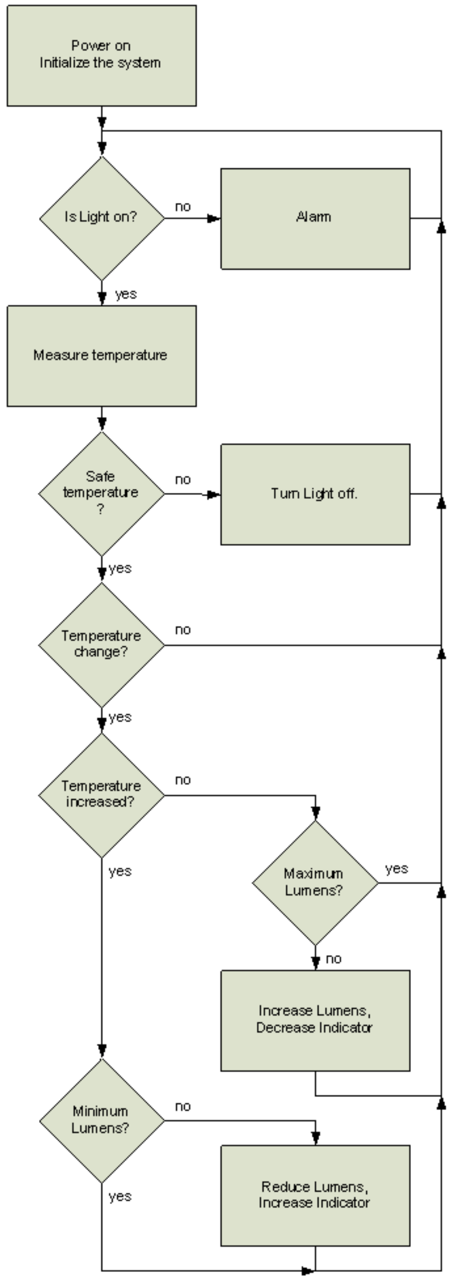
Adjusting the lumens

The flow chart below shows a simple algorithm to monitor the temperature of the LED light and adjust the lumens to a level where the temperature is within safe limits. The top block, ‘Power on – Initialize the system’, of the flow chart is the microcontroller initialization block. When the wall switch is turned on, power will be applied to the LED light and this block will configure the LED light for basic operation, lumens output, and temperature measurement.

The ‘Is Light on?’ block tests if the light has been turned off by an over-temperature condition. The test involved to determine if the light is on is a simple bit test. If the light on bit is set, the light is on, and if the light on bit is not set, the light is off. When power is first applied, the light will be on by default and the bit is set.

The ‘Alarm’ control block controls the on-off-on-off sequence when an extreme over-temperature condition is reached and the LED light has been turned off by the controller. The next block is the ‘Is Light on?’ block to start the test sequence again. The only method for exiting the alarm condition is to remove and reapply power using the wall switch.

The next block, ‘Measure temperature’, measures the voltage at the NTC node. As NTCs typically exhibit a non-linear change with temperature, the measured voltage can be compared against a look-up table for the associated temperature. This temperature will be used in the next two blocks.



The ‘Safe temperature’ block determines if the temperature of the LED light is within safe limits. If the temperature has reached its configured maximum value, the system will shut off the light. If the temperature is less than the maximum allowed value, the system will proceed to test for temperature stability.

The ‘Turn Light off’ block turn the light off when the LED light temperature is unsafe. The next block, ‘Is Light on?’, restarts the test sequence again.

The ‘Temperature change’ block determines if the temperature has changed a sufficient amount from the last lumens adjust cycle to warrant an increase or decrease in light output. The ‘Temperature increased’ block determines if the temperature has increased or decreased. These are the only two choices as the prior block determined the temperature had changed sufficiently from the prior lumens adjust cycle.

The ‘Maximum Lumens’ block determines if the LED light is set for maximum lumens output. If the lumens output is at maximum, the ‘Is Light on?’ block restarts the test sequence again.

The ‘Increase Lumens, Decrease Indicator’ block is triggered when the prior block determines that the lumens output is not its maximum. This block will increase the output by a step as configured during the initialization block. This block will also decrease the indicator LED by a step to match the lumens increase with indicator decrease, then restarts the test sequence.

The ‘Minimum Lumens’ block is triggered when the ‘Temperature increased’ block determines the temperature has increased. If the lumens is not at a defined minimum value, the flow is directed to the ‘Reduce Lumens, Increase Indicator’ block. If the Lumens output is at the defined minimum value, the ‘Is Light on?’ block restarts the test sequence again.

The ‘Reduce Lumens, Increase Indicator’ block decreases the output by a step as configured during the initialization block. This block will also increase the indicator LED by a step to match the lumens decrease with indicator increase, then restarts the test sequence.

This flow-chart diagrams a sequence where the LED light turns off and stays off until the input power is recycled. A small change in the flow can provide a sequence where after the light is turned off, the temperature can be monitored and, when reduced to a safe level, the LED light will be turned on again.

About the Author

Charles Pencil is an ‘Applications Eng, Sr. Staff’ for PowerPSoC and Off-line LED drivers at Cypress Semiconductor. He is focused on High-brightness LED operation, control, and application in LED-light systems operating in the 1W to 100W range.

Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709
Phone: 408-943-2600
Fax: 408-943-4730
http://www.cypress.com