Overcurrent Application Note

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INTRODUCTION TO OVERCURRENT TESTING

In certain applications, namely flashlights, signal lighting, strobe lighting, and entertainment lighting, the ability to drive an LED at a current higher than the rated maximum current for a short period of time is beneficial in maximizing lumen output, intensity, or minimizing cost. Generally, LED devices are characterized with a maximum rated forward current across the p-n junction, usually coupled with a maximum junction temperature above which the probability of catastrophic failure increases considerably. Balancing the tradeoffs between fixture size, weight, cost to build, optical output, operating temperature, and environmental conditions can lead to deciding to drive the LED devices harder than their respective rated conditions.

In this application note, the maximum current that a given LED device can repeatedly withstand (denoted as overcurrent) as a function of Tsp while providing the maximum lumens per emitting area will be explored across the Cree LED high-power device portfolio. Contrary to the high-frequency pulsed studies that several large LED manufacturers have begun publishing, this is the first dive into sustained overdrive current characterization of a major LED manufacturer's portfolio. A high lumen-output flashlight is provided as a test bed for understanding the fundamentals of how to use this overcurrent information. As the baseline for testing is the rated maximum current on the data sheet (with respect to each product), the overcurrent conditions discussed herein have the potential to cause immediate damage to the LED device. The data and details are provided to inform end users of the potential performance at overcurrent amperages and imply no warranty of the LED devices surviving these conditions once or indefinitely.

Definitions of commonly used words in this application note:

- Tsp is the temperature measured at the LED solder point in °C.
- LumFlux is a shorthand for luminous flux emitted from an LED.
- Relative LumFlux is the luminous flux emitted from an LED, expressed as a percentage of the luminous flux measured at the LED's binning condition.
- DTP refers to a metal-core PCB where the metal substrate makes direct contact with the thermal pad of the LED.

A PRIMER ON ELECTRONIC OVERSTRESS

Electrical Overstress (EOS) is a condition in which an electronic device, such as an LED, is exposed to voltage or current that exceeds its maximum operating limits. This can lead to immediate damage or long-term degradation of the device. In the context of LEDs, EOS can cause a reduction in light output, changes in color output, loss of diode I-V behavior, or complete device failure.

The causes of EOS in LED devices can be broadly categorized into external and internal causes.

External Causes

- Power Supply Fluctuations: Variations in the power supply can cause voltage spikes or surges that exceed the LED's maximum current or voltage rating. This can occur due to power grid instability, power supply design flaws, or sudden changes in load.
- Electrostatic Discharge (ESD): ESD events can generate high-voltage transients that can cause EOS. ESD can occur when a charged object or person comes into contact with the LED, causing a rapid discharge of electricity.
- Lightning Strikes: While not common, lightning strikes can induce high-voltage transients in electrical circuits, leading to EOS.

Internal Causes

- Design Errors: Errors in circuit design can lead to EOS. For example, if the LED is not properly matched to its power supply, it can be subjected to voltages or currents that exceed its specified limits.
- Component Failures: Failures of other components in the circuit, such as resistors or capacitors, can cause overcurrent or overvoltage conditions that lead to EOS.
- Thermal Stress: Excessive heat can cause thermal stress in the LED, leading to increased susceptibility to EOS. High temperatures can cause changes in the material properties of the LED, leading to increased current flow and potential EOS. Many Cree LED products are rated to a maximum junction temperature of 150 °C.

To protect LEDs from EOS, various strategies can be employed including the use of current-limiting resistors, voltage clamping devices, and ESD protection devices. Additionally, careful circuit design, including proper component selection and layout, can help to minimize the risk of EOS.

Catastrophic EOS events are more frequent as the drive current across an LED is increased, meaning it is imperative that circuit and driver design are optimized according to best practices.

THE OVERCURRENT TESTING PROCEDURE

The following procedure was followed to collect the data necessary to produce relationships between overcurrent values and Tsp/LumFlux for a given Cree LED device.

1. The LED under study (5700 K color space, top flux bin) was soldered onto a DTP MHE301 starboard, affixed to an Arroyo Series 286 thermoelectric cooler (TEC) plate, inside a 2-m integrating sphere

2. A pair of wire leads was soldered onto the electrodes of the starboard along with a thermocouple wire to measure the Tsp of the device.

3. Before each measurement, the thermocouple was checked against a known standard.

4. The LED is energized in incremental steps, starting at the rated maximum current from the Cree LED data sheet, and allowed to stabilize for 60 seconds at each condition, after which the optical data and Tsp was recorded.

5. Three individual samples were collected for each LED product family under test and the resultant data was averaged.

The triplicate average for each product is reported in two forms: 1) overcurrent as a function of Tsp and 2) the resultant relative LumFlux as a function of Tsp. The overcurrent values were de-rated as a function of power density where applicable, based on millions of device hours of internal reliability testing.

SUMMARY OF OVERCURRENT LIMITS FOR SELECT WHITE LEDS

Table 1 summarizes the maximum overcurrent values (Tsp = 85 °C) and relative luminous flux scalars across the Cree LED line of high-power LED products. As a reminder, please refer to the "Overcurrent Precautions" section before implementing any circuit in which the LED is driven above its rated maximum current per the associated Cree LED data sheet. The Relative LumFlux column is a multiplier relative to the binning condition of the respective Cree LED, as described in the data sheet. This multiplier is valid for the LED only; any optical or electrical losses on a system level will continue to carry through (and may increase) as the drive current and system temperature are increased.

Table 1: Summary of maximum overcurrent values and relative luminous flux

White XLamp® LED	Overcurrent Maximum at Tsp = 85 °C (A)	Relative LumFlux
XHP35.2 High Density (12 V)	2.80	4.75
XHP35.2 High Intensity (12 V)	2.65	4.60
XP-G3	5.50	7.25
XP-G4 Standard	6.00	4.25
XP-L	8.80	4.30
XP-L2	10.00	4.80
XT-E	3.40	4.90
XM-L2	10.25	7.40
XM-L3	7.60	5.35
XHP50.3 High Density (12 V)	4.95	4.00
XHP50.3 High Intensity (12 V)	4.7	3.85
XHP70.3 High Density (12 V)	5.15	3.50
XHP70.3 High Intensity (12 V)	4.65	3.25

Data summaries for each of the above Cree LED products are available in the Appendix section of this application note.

AN IMPLEMENTATION EXAMPLE: TURBOCHARGE A FLASHLIGHT WITH A XHP35.2 HIGH DENSITY (HD) LED

Many medium-to-high end flashlights offer several modes, with mode names like Eco, Low, Medium, etc. For this reference case, we are going to explore a simple flashlight design that initially has three modes denoted as Eco, Low, and High. These modes refer to the relative power pushed through the LED via a button or switching interface on the flashlight housing. An inverse relationship exists between the flashlight's mode output power and allowable runtime, i.e., High mode will have the highest lumen output and shortest setting timer, which serves to protect the LED from excessive operating time above the maximum power rating. Figure 1 describes these modes graphically, with relative runtimes for each mode. In this test case, the model is limited to a total runtime of ten minutes, with a relatively simple thermal model added to adjust the lumen output as the runtime increases.

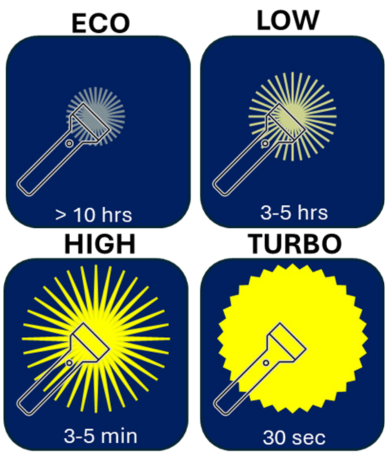

Figure 1: Graphical representation of a flashlight with four output modes along with relative runtimes for each mode.

This application note flashlight (Flashlight 1.0) has an optical efficiency of 84%, a beam angle of 15°, fixed optic, a 13.6-V lithium-ion battery, a simple mode switching circuit driven by a tactile button on the outside, and an aluminum body. A constant current driver system is employed with the following currents per mode: High – 1.500 A, Low – 0.350 A, Eco – 0.100 A. The XHP35.2 HD (E4 flux bin, 5700 K CCT) LED is mounted to a DTP starboard on an aluminum slug that is directly interfaced with the flashlight casing, with lead wires connecting the LED to the internal flashlight circuit. The modeled output of the flashlight in the three separate modes is shown below in Figure 2 and key output parameters are tabulated in Table 2 for reference. Relative lumen output is included to accommodate the usage of different LED flux bins as inputs.

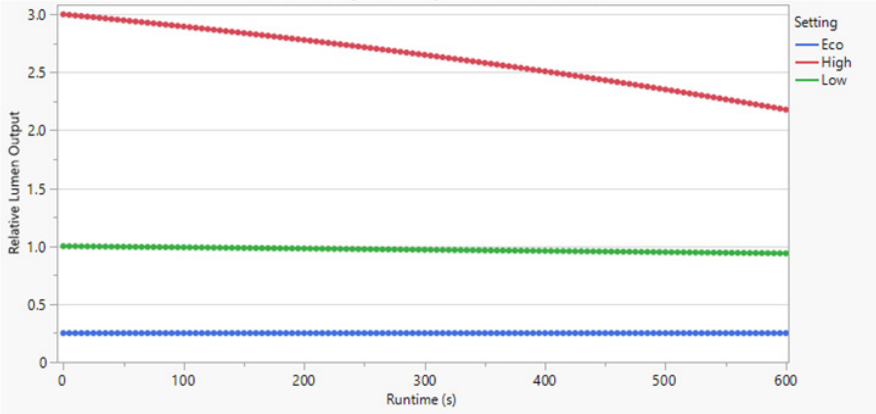

Figure 2: Flashlight 1.0 relative lumen output vs. runtime

Table 2: Output parameters for Figure 2

XHP35.2 HD Duration	High LumFlux (lm)	Low LumFlux (lm)	Eco LumFlux (lm)
Turn-on	1663	553	138
30 s	1645	551	138
60 s	1625	548	138
600 s	1207	518	138

In a constantly evolving market, flashlight manufacturers must constantly offer a fresh mix of innovative products and upgrades, usually increased performance at a lower cost, to their current lineup to stay competitive. One relatively straightforward way to upgrade a three-mode flashlight is to add a fourth mode, referred to as Turbo herein, without adding additional LEDs to achieve a higher lumen output. There are a few prerequisites to this design change: a thermal system that can handle the increased thermal load, a slightly more complicated switching circuit, and (most importantly) an LED that can be overdriven for a short period of time. Based on the results presented above, the XHP35.2 LED is an ideal candidate for a four-mode flashlight system, with a maximum effective overcurrent of 2.85 A (at 12 V) resulting in a LumFlux multiplier of 4.70 vs. the binning condition flux output. The modeled output curves of this new Flashlight 2.0 are presented in Figure 3 and tabulated in Table 3, similar to the Flashlight 1.0 case above.

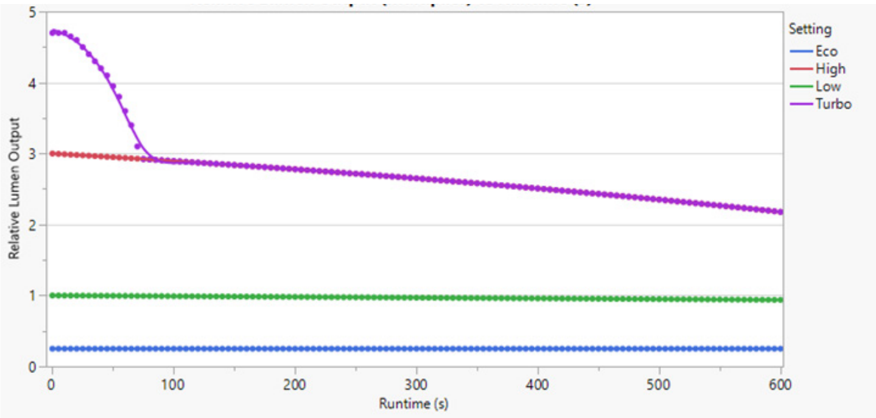

Figure 3: Flashlght 2.0 relative lumen output vs. runtime

Table 3: Output parameters for Figure 3

XHP35.2 HD Duration	Turbo LumFlux (lm)	High LumFlux (lm)	Low LumFlux (lm)	Eco LumFlux (lm)
Turn-on	2605	1663	553	138
30 s	2436	1645	551	138
60 s	1920	1625	548	138
600 s	1207	1207	518	138

A simple design feature of the Turbo mode above is a relatively slow current decay down to the output of the High setting, serving multiple purposes: preserving the life of the LED, preserving battery life, and keeping the temperature within regulatory guidelines based on the total thermal envelope of the system. Depending on the intricacies of the heat sink, especially in larger and more complex flashlights that include liquid or other exotic forms of cooling, the Turbo mode current decay can be modulated or even removed.

Per usual, as a designer of a flashlight product, the model above is just a starting point for reality. Care needs to be taken to specifically model the actual flashlight being designed and developed from a thermal and optical standpoint.

OVERCURRENT PRECAUTIONS

As the overcurrent values are substantially higher than the rated maximum currents for any of the LEDs described in this document, there is no warranty of optical performance, longevity, or cyclability, or any other metric related to the LED device at any condition greater than the maximum rated condition on the data sheet.

The following general precautions should be taken when implementing the information contained in this application note into a real-world system

- This application note is a guide for designing products using the selected LEDs and driving those LEDs above the maximum rated condition. It provides overcurrent limits as a function of Tsp, which were generated in a very controlled system setup that included active cooling. Use this information with engineering caution.
- Proper heat sinking is paramount and Tsp values must be measured at the solder point, directly connected with the thermal pad of the LED device.
- The drive current for an LED at a given Tsp must never exceed the overcurrent value for that Tsp. The probability of immediate catastrophic failure of the LED device increases exponentially as the drive current increases above the overcurrent for a given Tsp.
- The LED device should never be driven continuously for more than 30 seconds at the maximum overdrive current, and a proper cool-down period, dependent on thermal load and heat sinking of the fixture, must be implemented to preserve device longevity.
- DTP Cu MCPCB technology is recommended for all applications where currents greater than the maximum rated current are used.
- Implementation of an integrated thermal feedback circuit, or at a minimum a thermal cutoff circuit, is necessary in all overcurrent applications.

For any questions related to usage of any of the products in the Cree LED portfolio, please contact your local sales representative or visit the Cree LED website.

APPENDIX - OVERCURRENT LIMITS FOR SELECT WHITE LEDS

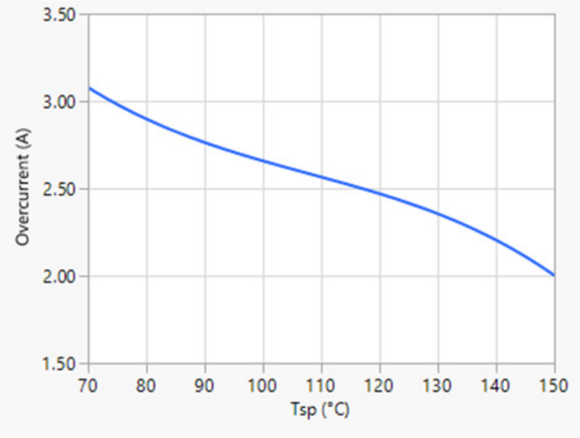

Figure 4: XHP35.2 HD (12 V) Overcurrent vs. Tsp

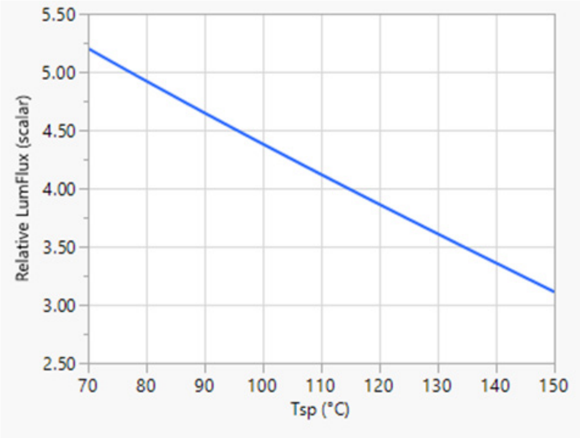

Figure 5: XHP35.2 HD (12 V) Relative LumFlux vs. Tsp

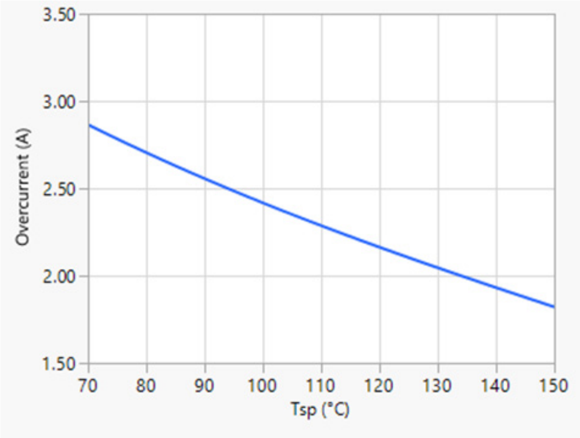

Figure 6: XHP35.2 HI (12 V) Overcurrent vs. Tsp

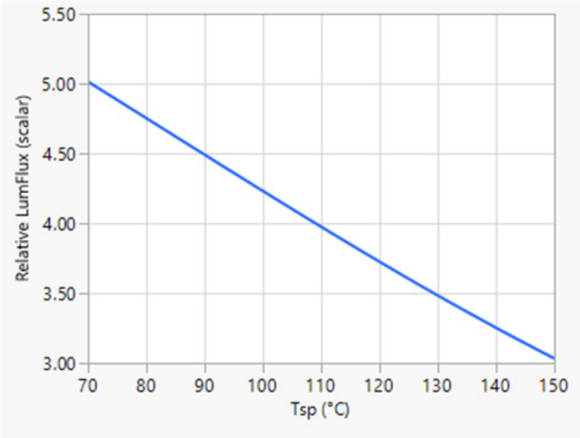

Figure 7: XHP35.2 HI (12 V) Relative LumFlux vs. Tsp

APPENDIX - OVERCURRENT LIMITS FOR SELECT WHITE LEDS (CONTINUED)

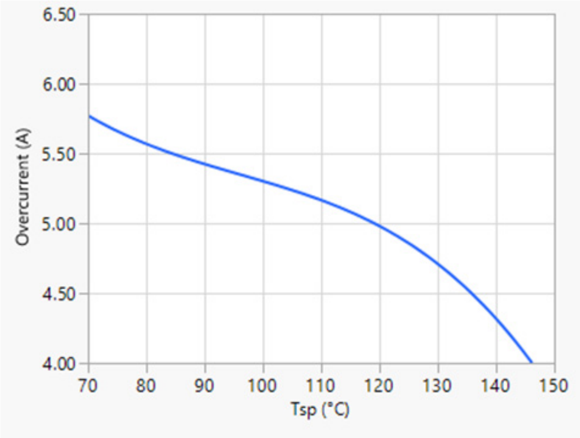

Figure 8: XP-G3 White Overcurrent vs. Tsp

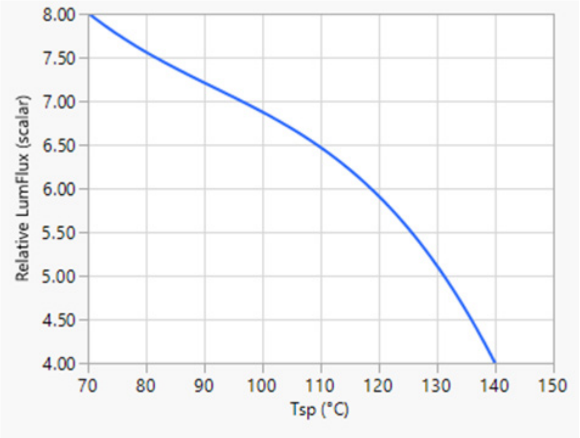

Figure 9: XP-G3 White Relative LumFlux vs. Tsp

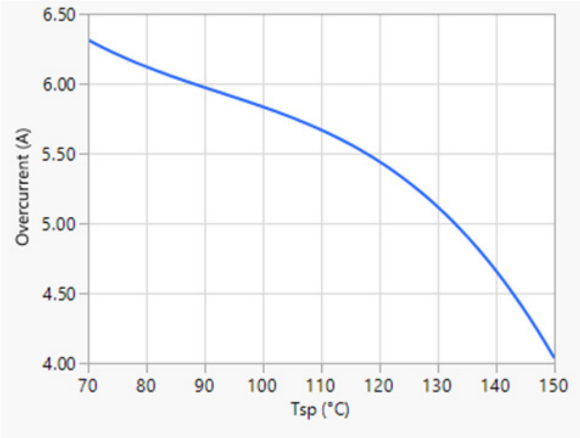

Figure 10: XP-G4 Standard White Overcurrent vs. Tsp

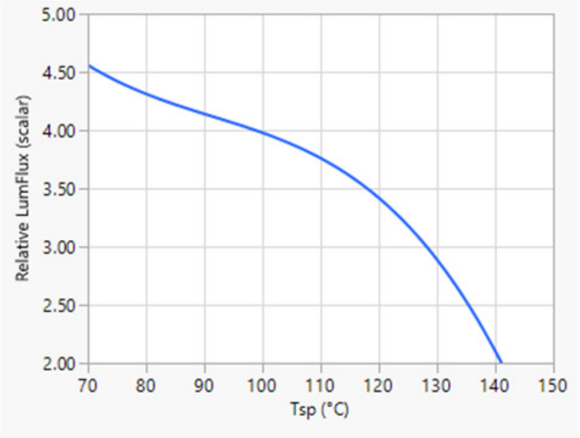

Figure 11: XP-G4 Standard White Relative LumFlux vs. Tsp

APPENDIX - OVERCURRENT LIMITS FOR SELECT WHITE LEDS (CONTINUED)

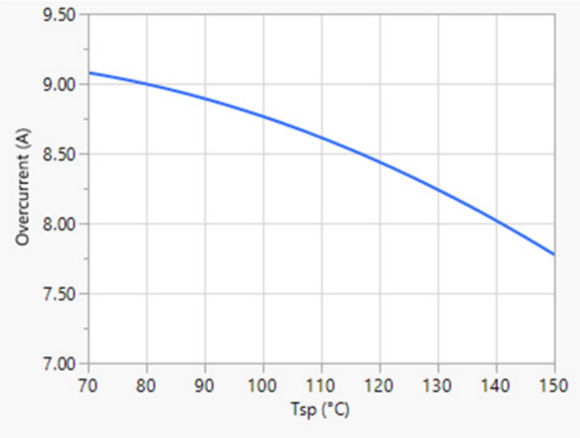

Figure 12: XP-L White Overcurrent vs. Tsp

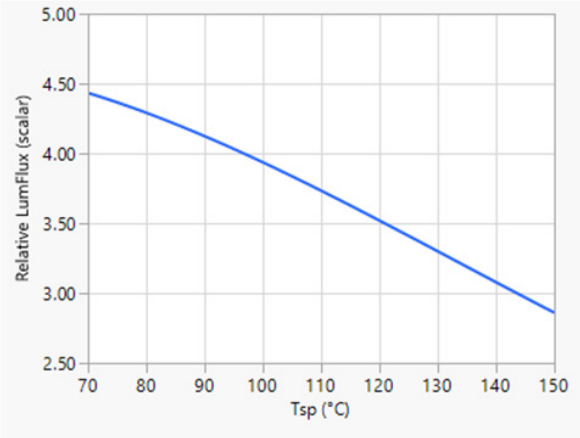

Figure 13: XP-L White Relative LumFlux vs. Tsp

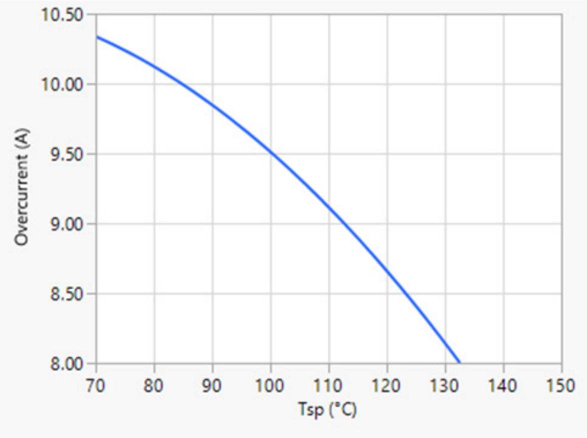

Figure 14: XP-L2 White Overcurrent vs. Tsp

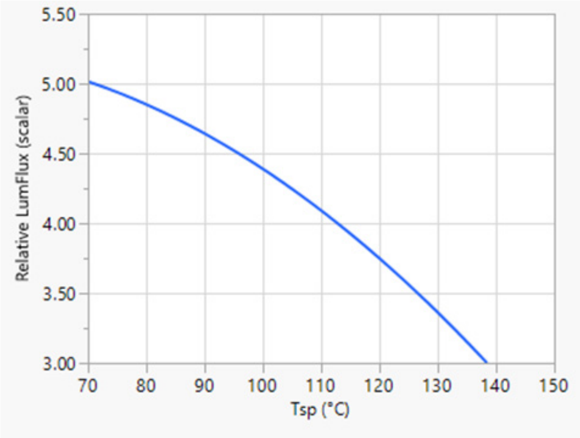

Figure 15: XP-L2 White Relative LumFlux vs. Tsp

APPENDIX - OVERCURRENT LIMITS FOR SELECT WHITE LEDS (CONTINUED)

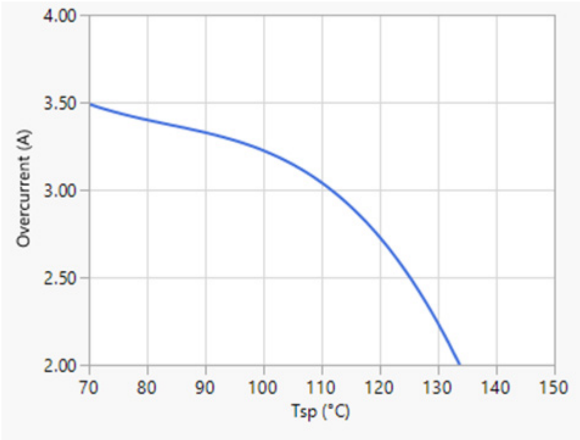

Figure 16: XT-E White Overcurrent vs. Tsp

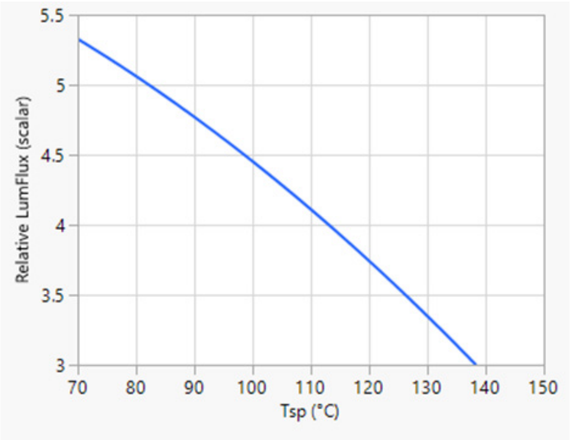

Figure 17: XT-E White Relative LumFlux vs. Tsp

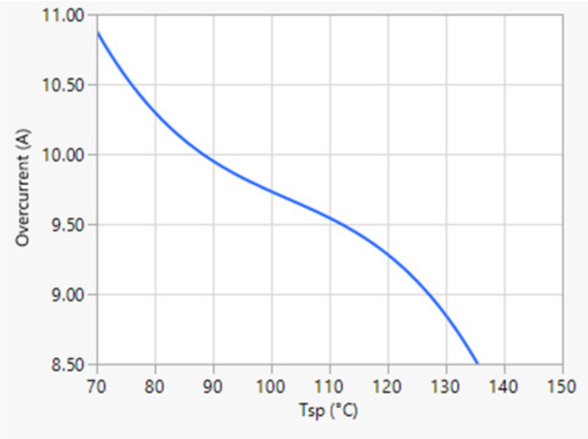

Figure 18: XM-L2 White Overcurrent vs. Tsp

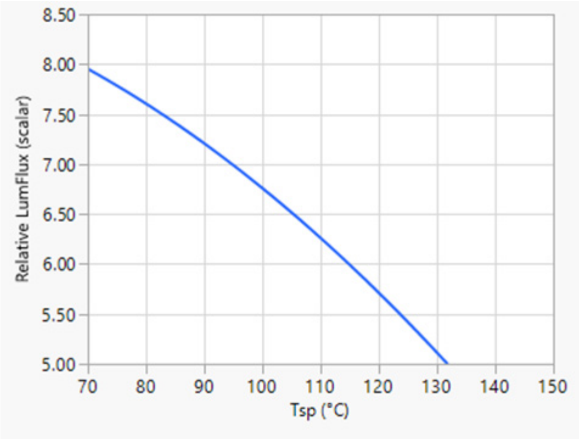

Figure 19: XM-L2 White Relative LumFlux vs. Tsp

APPENDIX - OVERCURRENT LIMITS FOR SELECT WHITE LEDS (CONTINUED)

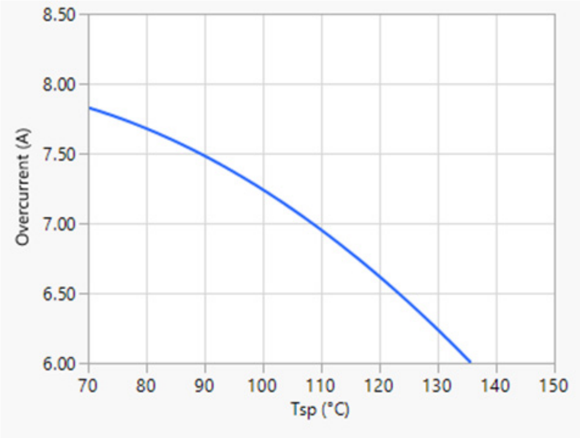

Figure 20: XM-L3 White Overcurrent vs. Tsp

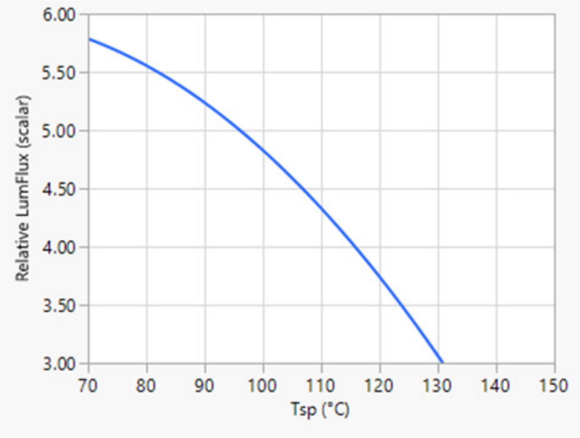

Figure 21: XM-L3 White Relative LumFlux vs. Tsp

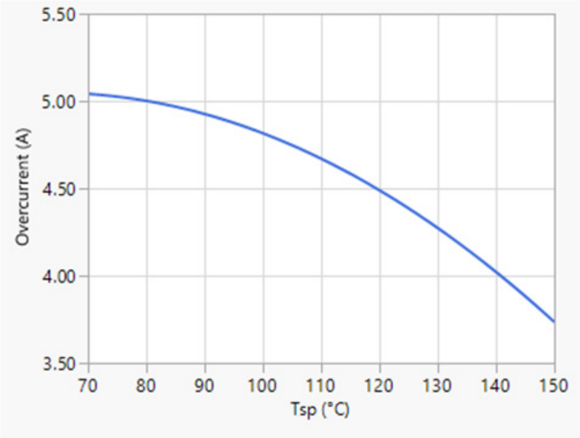

Figure 22: XHP50.3 HD (12 V) Overcurrent vs. Tsp

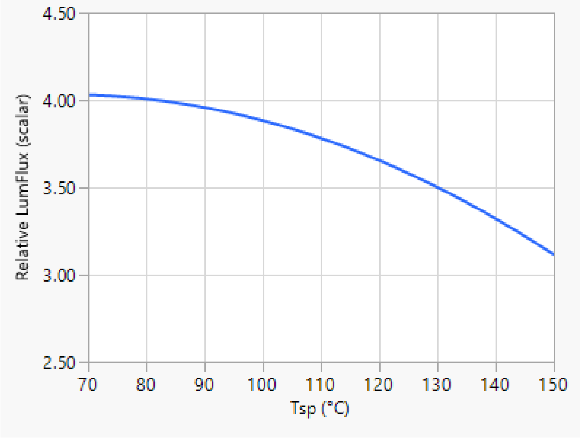

Figure 23: XHP50.3 HD (12 V) Relative LumFlux vs. Tsp

APPENDIX - OVERCURRENT LIMITS FOR SELECT WHITE LEDS (CONTINUED)

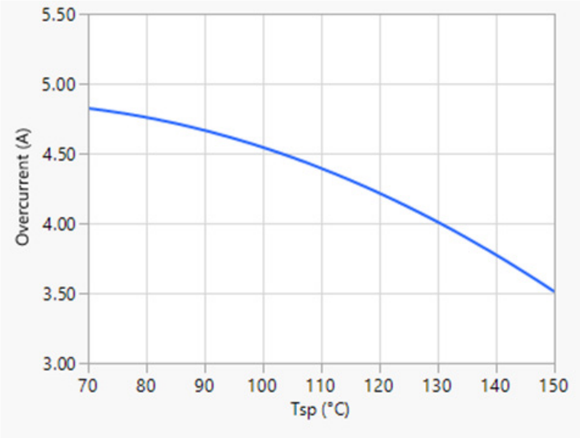

Figure 24: XHP50.3 HI (12 V) Overcurrent vs. Tsp

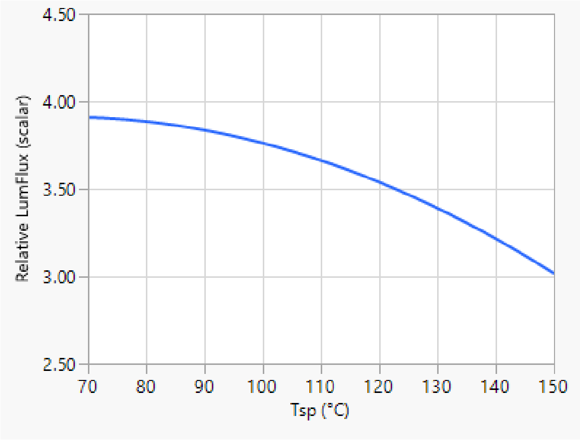

Figure 25: XHP50.3 HI (12 V) Relative LumFlux vs. Tsp

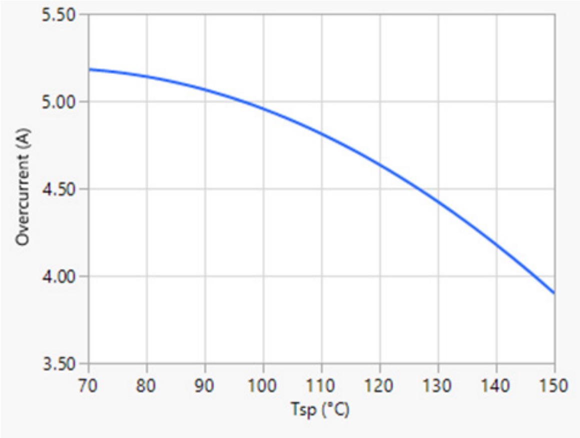

Figure 26: XHP70.3 HD (12 V) Overcurrent vs. Tsp

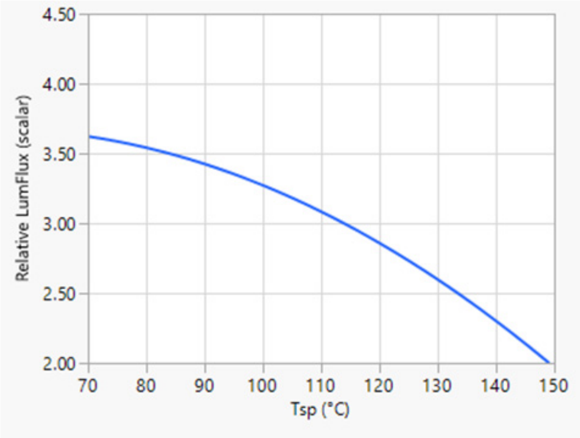

Figure 27: XHP70.3 HD (12 V) Relative LumFlux vs. Tsp

APPENDIX - OVERCURRENT LIMITS FOR SELECT WHITE LEDS (CONTINUED)

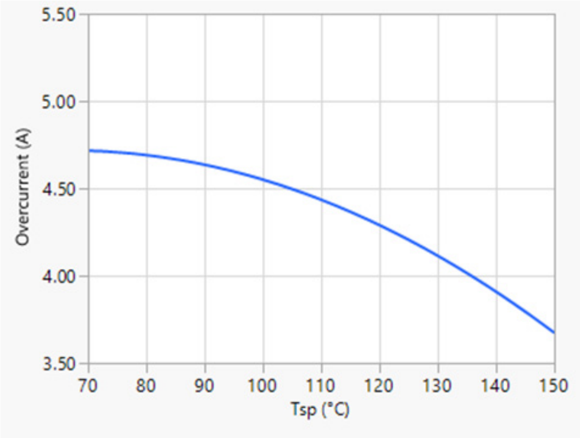

Figure 28: XHP70.3 HI (12 V) Overcurrent vs. Tsp

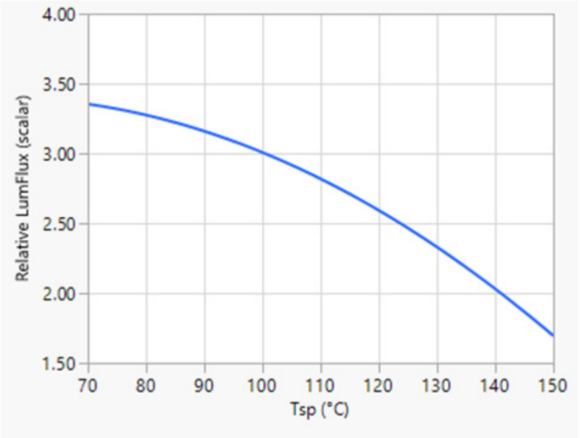

Figure 29: XHP70.3 HI (12 V) Relative LumFlux vs. Tsp