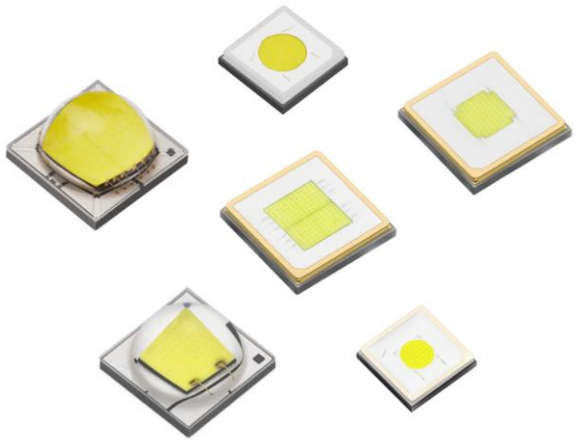
Overdriving Luminus LEDs



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Driving LEDs with currents higher than their rated maximum for short periods can yield significant benefits. For instance, some of Luminus' latest generation of high-power white LEDs can be overdriven at currents up to 10 times their nominal drive current. Overdriving LEDs is particularly useful in key applications like flashlights, search and rescue spotlights, bicycle and helmet lamps, weapon-mounted lights, and medical illumination such as endoscopy and task lighting.

In these applications, overdriving LEDs offers several advantages: enhanced visibility in low-light or high-contrast environments, increased light output for intense illumination, and extended beam throw distance. By overdriving LEDs and limiting the "on-time" to short periods, thermal heating is minimized. This reduction in heating allows for lower-cost solutions with smaller heat sinks and more compact designs. Importantly, LED lifespan can be maintained under these low duty factor drive conditions.

This application note provides comprehensive insights into the benefits and considerations of overdriving high-power LEDs. It covers survivability tests, lumen measurements at various injection levels, design guidelines for battery sizing, and discussions on thermal and optical performance considerations, with a focus on torch applications.

1. Introduction

This Application Note presents findings from survivability and performance testing conducted on Luminus LEDs to explore the benefits of short-duration overdriving—operating LEDs with currents exceeding their maximum rated values. The primary objective is to provide design engineers with data and guidelines to achieve significant performance enhancements in applications where short bursts of intense light are desired.

Overdriving LEDs is particularly advantageous in applications such as:

- Torches (handheld flashlights): To provide a momentary high-intensity beam for improved visibility.
- Bicycle and helmet lights: For increased rider safety through enhanced visibility.
- Weapon-mounted lights: To offer tactical advantages with powerful, short-duration illumination.
- Task lights: To deliver temporary high-output lighting for detailed work.
- Endoscopes and other medical illumination devices: To enhance visualization during medical procedures.

The High-Power White LEDs discussed in this Application Note are shown in Figure 1. Detailed datasheets for these products are available on the Luminus website at https://www.luminus.com/products/white.

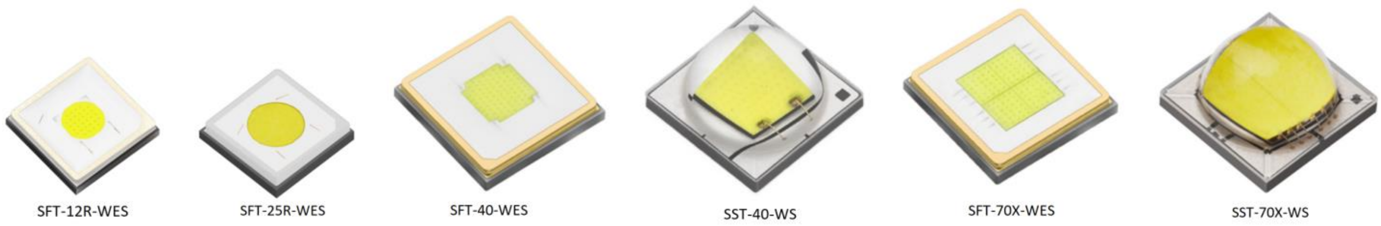

Figure 1. Luminus High Power White LEDs evaluated for overdrive performance.

This report covers four main categories:

- Domed (SST) vs. flat form factor (SFT) LED types.
- Round vs. square light-emitting surfaces.

Subsequent sections provide a detailed discussion of the advantages and disadvantages of each configuration.

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2. Test Procedures and Results

The tests aimed to determine the maximum current each LED can endure for short durations and to characterize lumen output at various drive current levels.

To determine survivability levels, five samples of each LED type were subjected to various overcurrent conditions. The maximum overdrive current was defined as the highest current level at which the LEDs did not exhibit rapid degradation, discoloration, or catastrophic failure. At each potential overdrive level, each LED underwent the sequence of tests listed in Table 1 where **n** is the multiplier of the LED datasheet binning current. Each sample was tested a total of 70 times for each potential overdrive current level.

Table 1. Survivability Test Conditions.

Test Duration (s)	Number of Repeats per LED	Overdrive Level (**n** * test current)
15	10	Overdrive test currents ranged from **n** = 4 to **n** = 12 depending on the LED type. Testing was terminated if a failure occurred and the previous test level was selected.
30	10	
60	10	
120	10	
300	10	
600	10	
1800	10	

A fresh sample of ten LEDs were used for lumen characterization scans up to the maximum survivable current. Droop was determined by plotting these lumen vs. current scans. Lumen "droop" describes the LED characteristic where, at higher drive currents, the light output increases less than proportionally to the current, resulting in reduced efficiency. This effect limits the maximum achievable light output. The fitted curves in Figure 2 below show extrapolations of droop in the fitted curves. The results in Table 2 represent data for the LEDs with the highest lumen output bin for each LED type. The binning current is 1.5 A for each of these devices and this value was used as the basis to calculate the current factor and lumen factor gains.

Lumen output (Table 2) is reported at three current levels:

- **Binning Current:** The test current used in the factory to assign lumen and voltage categories to LEDs. This is also called the nominal current.
- **Rated Maximum Current:** The highest current value listed in the datasheet that can be continuously applied to each LED type. This value is determined during device development and is based on device performance data and long-term reliability test results.
- **Overdrive Current:** The focus of this application note. The overdrive currents in Table 2 were selected considering two factors: 1) the LED's robust survivability at the applied overdrive current, and 2) the LED's optical output does not exhibit droop at the maximum survivable current level. If droop is present the recommended overdrive current is the current where the maximum optical output occurs.

Table 2. Test Results Ranked by the Rated Maximum Current Value (T_c = 85°C).

LED	If (A)	lm	Current Factor	Lumen Factor	Condition
SFT-12R-W65S (3535)	1.50	625	1.00	1.00	Binning Current
	3.00	1012	2.00	1.62	Rated Max Current
	6.00	**1324**	**4.00**	**2.12**	**Overdrive Current**
SST-70X-W65S	1.50	1618	1.00	1.00	Binning Current
	5.25	4409	3.50	2.73	Rated Max Current
	7.00	**5349**	**4.67**	**3.31**	**Overdrive Current**
SST-40-WDS	1.50	788	1.00	1.00	Binning Current
	6.00	2298	4.00	2.92	Rated Max Current
	9.00	**2927**	**6.00**	**3.72**	**Overdrive Current**
SFT-70X-W65S	1.50	1513	1.00	1.00	Binning Current
	7.00	4910	4.67	3.25	Rated Max Current
	10.50	**5900**	**7.00**	**3.90**	**Overdrive Current**
SFT-25R-W65S (3535)	1.50	740	1.00	1.00	Binning Current
	7.50	2396	5.00	3.24	Rated Max Current
	14.00	**3037**	**9.33**	**4.10**	**Overdrive Current**
SFT-40-WES	1.50	740	1.00	1.00	Binning Current
	8.00	2782	5.33	3.76	Rated Max Current
	17.00	**4040**	**11.33**	**5.46**	**Overdrive Current**

Figure 2 graphically illustrates these results, with drive conditions color-coded: black points represent the binning current, blue points represent the rated maximum currents, and red points represent the suggested overdrive currents. A quadratic fit to each data series is shown, with a projection past the overdrive current, to illustrate the curvature of the fit around the overdrive condition and to assess the droop threshold.

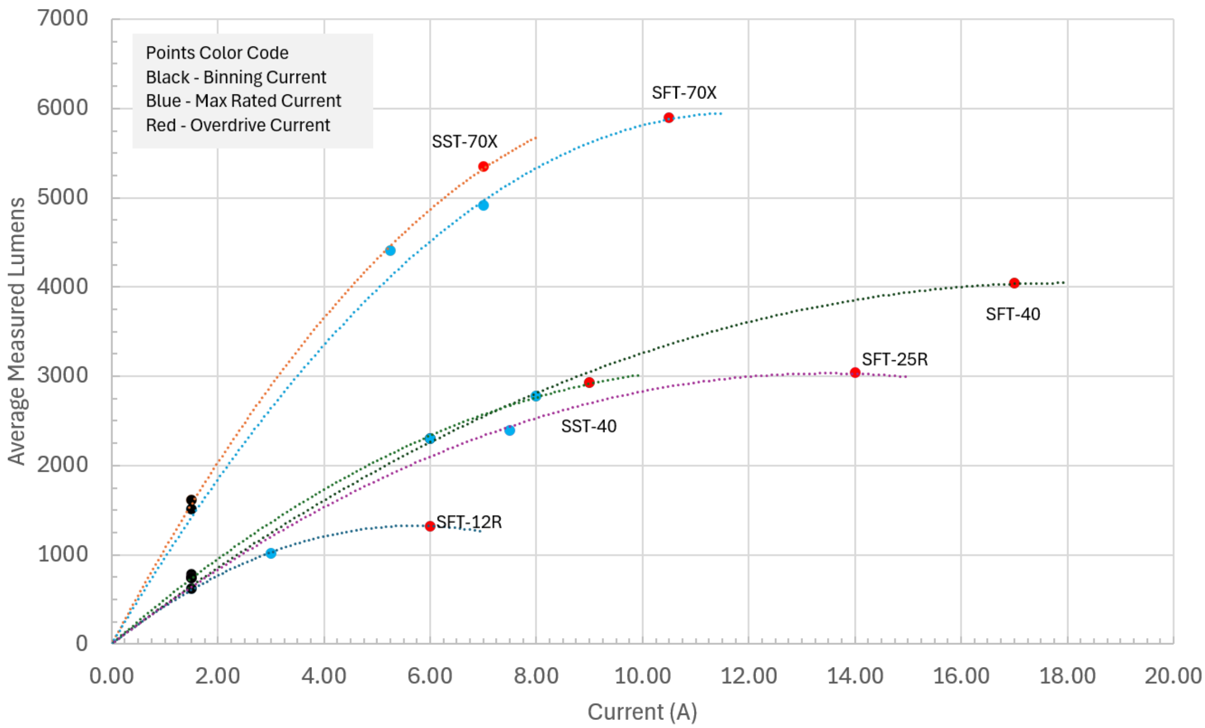


Figure 2. Lumen output vs. drive current for selected Luminus LEDs at T_c = 85 °C, showing binning, rated maximum, and overdrive currents. Quadratic fit lines are included to illustrate the trend in lumen output.

3. Design Considerations

3.1 Battery Design

Battery longevity is a critical design consideration for portable lighting devices such as torches. To optimize performance for various user needs, we have defined five distinct operational modes:

- **Eco Mode:** Prioritizes extended battery life by providing sufficient illumination at a lower power output.
- **Low Mode:** Offers increased light output with a moderate reduction in battery runtime.
- **Medium Mode:** Provides a balance between brightness and battery efficiency, offering a higher light output than Low Mode while conserving more energy than High Mode.
- **High Mode:** Delivers maximum rated steady-state LED current, resulting in significantly brighter steady state light at the expense of reduced battery life. It's important to note that the designer may choose to operate High Mode at a current level below the LED's absolute maximum rating, with Medium Mode catering to intermediate brightness requirements.
- **Turbo Mode:** Provides a brief, intense burst of light by utilizing the LED's overdrive current capabilities. This mode is intended for short-duration use.

To illustrate the impact of these modes on battery life, Table 3 presents simplified calculations based on data from commercially available Lithium-Ion batteries. These calculations are based on a single battery configuration. Each battery capacity category listed has a wide range of maximum output currents depending on the specific design of the battery structure. Battery packs, consisting of multiple cells, can be configured to meet a wide range of voltage and discharge current requirements to accommodate these variations. Furthermore, power control circuitry can be employed to regulate voltage output, enabling flexible power management.

Regarding Turbo Mode, we anticipate typical usage to be limited to 30 seconds or less. For instance, considering the 1050 mAh Lithium-Ion battery referenced in Table 3, a 30-second Turbo Mode pulse would deplete the battery after approximately 18 pulses. Conversely, the 6200 mAh battery would support approximately 106 such pulses. (Table 3 presents the data of those two example batteries, and the calculations for all modes).

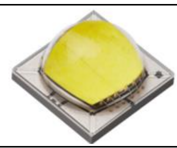
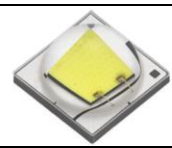
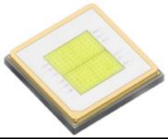
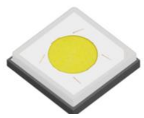
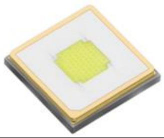
Table 3. Battery Lifetime Scenarios for the SST-70X.

Battery datasheet parameters			SST-70X Service time for one battery (minutes)				
Battery Capacity (mAh)	Nominal Voltage (V)	Max Output Current (A)	ECO (0.1 A)	Low (1 A)	Med (2.5A)	High (5.25 A)	Turbo (7 A)
1050	3.7	2.0	630	63	25	12	9
1100	3.7	10.0	660	66	26	13	9
1250	3.7	3.0	750	75	30	14	11
2000	3.7	2.0	1200	120	48	23	17
2040	3.7	3.8	1224	122	49	23	17
2600	3.7	3.9	1560	156	62	30	22
3200	3.7	2.0	1920	192	77	37	27
3500	3.7	10.0	2100	210	84	40	30
4800	3.7	5.5	2880	288	115	55	41
5000	3.7	60.0	3000	300	120	57	43
5600	3.7	12.5	3360	336	134	64	48
6200	3.7	15.0	3720	372	149	71	53

3.2 Thermal Design

Effective thermal management is crucial for optimal performance to prevent overheating the LED, which can lead to reduced light output, decreased efficiency, color shifts, and accelerated degradation of the LED, ultimately resulting in premature failure. Table 4 details the electrical power consumption under maximum overdrive conditions and the corresponding expected LED junction temperature rise. Given that these LEDs have a maximum rated junction temperture of 150˚C, the thermal extraction system must be engineered to maintain temperatures below this threshold. Incorporating adequate thermal mass and optimized thermal coupling within the system helps to mitigate rapid temperature increases in the heat sink near t=0. This enhances lumen maintenance ensuring a more visually stable high output.

Table 4. LED Package Temperature Rise for 30 Second Overdrive Conditions.

Parameter						
Datasheet	SFT-12R-WES	SST-70X-WS	SST-40-WS	SFT-70X-WES	SFT-25R-WES	SFT-40-WES
Overdrive Current (A)	6.0	7.0	9.0	10.5	14.0	17.0
Overdrive Voltage (V)	4.5	7.24	3.71	8.34	4.02	4.44
Overdrive Power (W)	27.0	50.7	33.4	87.6	56.3	75.5
$R_{thjs-EL}$ (˚C/W)*	2.0	0.6	0.8	0.6	0.8	0.6
LED Package Temperature Rise (˚C)	54	30	27	53	45	45

* $R_{thjs-EL}$ is the electrical thermal resistance of the LED package between the p-n junction and the solder point at the bottom of the package.

The LED package temperature rise values in Table 4 represent the increase in temperature from the LED's solder point to its junction when operating at the specified overdrive conditions. To ensure the LED junction temperature remains below the maximum rating of 150˚C, the thermal designer must select a heat sink and system design that effectively dissipates this heat. The required heat sink thermal resistance can be calculated based on the maximum ambient temperature of the application. LEDs with lower $R_{thjs-EL}$ values offer more efficient heat transfer from the junction to the solder point, simplifying the thermal management challenge. This is evident when comparing the SFT-12R-WES and SST-70X-WS. The SST-70X-WS, with a lower $R_{thjs-EL}$, exhibits a lower temperature rise despite a higher overdrive power. The LED package temperature rise is only one component of the overall thermal path. The total thermal resistance from the LED junction to the ambient environment includes the LED's internal resistance ($R_{thjs-EL}$), the thermal interface material resistance, the heat sink resistance, and any other thermal path resistances in the system.

This is illustrated in Figure 3 and Figure 4, which present lumen maintenance measurements for two distinct scenarios. Figure 3 depicts an idealized scenario where the LED is mounted on a temperature-controlled plate, providing excellent heat sinking. This setup demonstrates the LED's intrinsic lumen maintenance capabilities, resulting in a 98% lumen maintenance after 30 seconds of overdrive. The data in Figure 3 aligns with the data in Table 2.

In contrast, Figure 4 shows the LED's performance in a real-world application, using the same LED integrated into a commercially available torch designed for turbo mode operation, where the thermal management is less ideal. In this configuration, an 88% lumen maintenance is achieved following 30 seconds of overdrive.

The difference in lumen maintenance between the two figures highlights the importance of effective thermal design in achieving optimal performance.

Specifically, the lumen output drop due to startup LED heating is only 2.1% after 30 seconds in the temperature-controlled stage test (Figure 3), but drops by 12% in the commercial torch (Figure 4). Thermal design and verification is therefore a critical requirement to enable the highest possible lumen output.

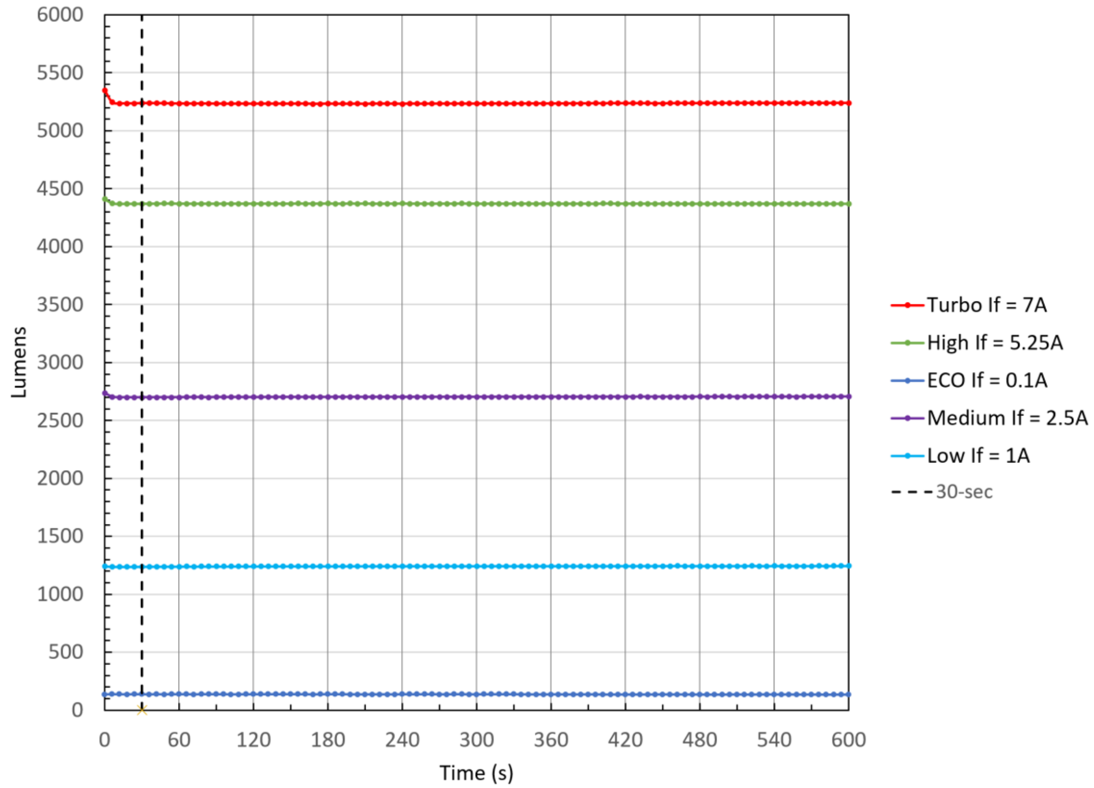


Figure 3. Lumen Maintenance of SST-70X LED mounted on a temperature-controlled plate at 85 °C. Here all lumen output is stable after a small intial drop.

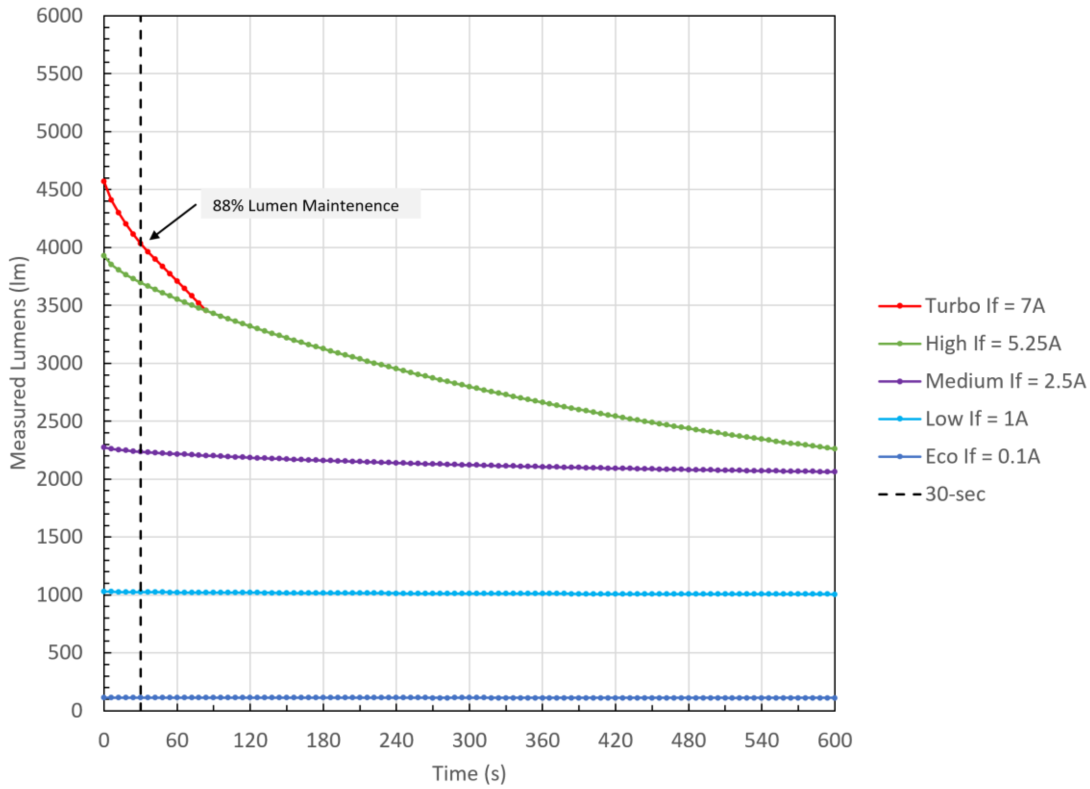


Figure 4. Lumen Maintenance of SST-70X LED in a commercial torch designed for Turbo Mode. Here the designer might select a "High" current level closer to the medium mode displayed so that the continuous output is stabilized.

Important Notes:
Using a standard torch with a thermal management system not designed for turbo mode will result in significantly poorer lumen maintenance. Commercially available torches not engineered for turbo mode operation often have thermal extraction systems inadequate for handling the increased heat generated during overdrive operation. Consequently, using a standard torch in turbo mode can lead to substantially reduced lumen maintenance and potential damage to the LED.

To mitigate these issues, incorporating electronic controls to limit both the turbo pulse duration and the repetition delay time is highly advisable. These controls allow the LED to cool down between pulses, preventing thermal accumulation and the resulting increase in LED junction temperatures that occur with excessively frequent or prolonged pulses. Measuring the temperature directly at the solder point on the LED's thermal pad to provide feedback is advised[1].

Furthermore, it is essential to avoid:

- Exceeding the maximum overdrive current for short periods, as this can cause immediate damage to the LED.
- Driving LEDs at overdrive currents for extended periods, as this can lead to gradual degradation, color shift, and reduced light output.
- Inadequate cooling, as this can trigger thermal runaway. Thermal runaway is a destructive process where rising temperature leads to further increases in temperature and current, ultimately resulting in catastrophic failure. Thermal runaway can be prevented by thermal design optimization and temperature feedback elements.

3.3 Optical Design

LEDs generally exhibit a Lambertian emission pattern with a beam angle of approximately 120°. To create a focused, narrow beam, secondary optics are employed.

In a related Luminus white paper[2], we detail that achieving optimal performance for High Lumen Directional Lighting (HLDL) requires LED manufacturers to carefully address all aspects of optical design, including the geometry of the LED and primary optics, as well as the design of secondary optics. Key considerations include:

- **Flat Optics:** LEDs with flat optical elements enhance beam intensity and distance by providing a more uniform emission pattern that is easier to collimate with secondary optics, improving HLDL performance. Secondary optics tailored for flat LEDs result in reduced spill light and extended throw distances compared to dome LEDs.
- **Small Light Emitting Surface (LES):** Smaller LED chips deliver superior performance in HLDL applications. This is because the smaller LES allows for more precise control of the light and tighter beam angles. In contrast, larger LED chips with a larger LES necessitate secondary optics with greater diameters to achieve comparable beam angles, limiting their suitability for compact devices like flashlights due to size constraints.
- **Shape:** While many LED chips have square geometries, round chips are better suited to meet the requirements of HLDL applications.
- **High-Performance Metrics:**
  - High luminous flux (lm)
  - High lumen density (lm/mm^2)
  - High on-axis intensity (cd)
  - High K Factor (cd/lm)*
  - High luminance (cd/m^2)
- **Secondary Optics:** Secondary optics, such as reflectors, total internal reflectors (TIRs), and lenses, are designed to collimate light for controlled output patterns and improved beam uniformity.

Figure 5 visually defines photometric concepts like luminous flux, luminous intensity, luminance, and illuminance. In the context of overdriven LEDs, maximizing luminous intensity and luminance is often a primary goal to achieve a high-quality beam profile with increased throw distance. These parameters serve as critical inputs for the design of secondary optics.

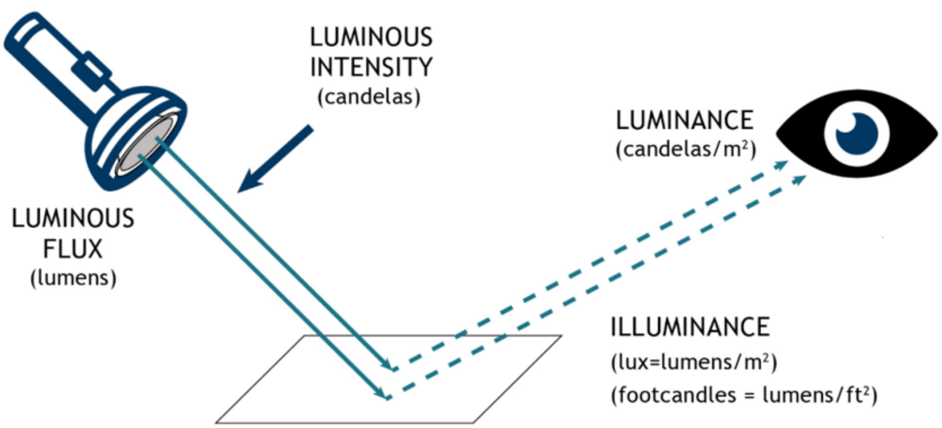
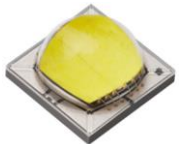
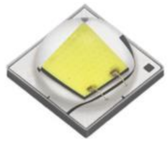
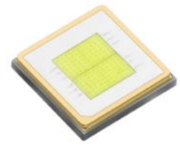
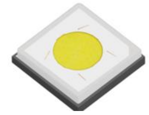
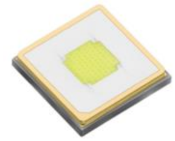


Figure 5: Illustration of the photometric concepts discussed in this section.

* When discussing HLDL "K Factor" in units of candela per lumen (cd/lm) refers to the lens efficiency factor. In this context, K Factor is not the same as the K metric used to characterize light source color, where K is Kelvin.

In Table 5, measured lumens under overdrive conditions are compiled alongside other parameters for various LEDs. This data serves as a reference to help designers select LEDs that best meet their performance and application needs. All of these LEDs can be used for sucessful designs.

Table 5. LED Optical Figures of Merit for Overdrive Conditions.

Parameter						
LED Datasheet	SFT-12R-WES	SST-70X-WS	SST-40-WS	SFT-70X-WES	SFT-25R-WES	SFT-40-WES
LED LES Area (mm^2)	1.2	7.0	4.0	7.0	2.5	4.0
Overdrive Current (A)	6	7	9	10.5	14	17
LED Overdrive Lumens (lm)	1324	5349	2927	5900	3037	4040
LED Lumen Density (lm/mm^2)	1103	764	732	843	1215	1010
LED Beam Angle (°)	119.4	132.5	126.3	119.5	118.6	119.4
Overdrive LED Candela (cd*)	425	1425	850	1892	988	1298
LED K Factor (cd/lm)	0.321	0.266	0.290	0.321	0.325	0.321
LED Luminance** cd/m^2	3.54E+08	2.04E+08	2.13E+08	2.70E+08	3.95E+08	3.25E+08

* cd is lm/Sr
** cd/m^2 is also called nits

Key Observations from Table 5:

- LES area ranges from 1.2 mm^2 (smallest) to 7.0 mm^2 (largest). Smaller LES areas enable secondary optics with smaller diameters for the same beam angle, enabling more compact optical designs.
- LEDs with larger LES, such as the SFT/SST-70X, produce higher lumen outputs. These differences are illustrated in Figure 2 (Section 2), demonstrating the trade-off between LED size and light output.
- The SFT-12R and SFT-40 achieve the highest surface brightness (luminance), while the SST-40 has the lowest. Higher luminance LEDs are beneficial for applications requiring a high-intensity beam.
- Beam angles and K Factors are relatively consistent, though SST LEDs with dome lenses exhibit slightly wider beam angles, whereas flat-profile SFT LEDs align more closely with ideal Lambertian emission. This indicates that flat LEDs provide a more predictable beam pattern.
- Luminance varies by a factor of 2 under overdrive conditions.

The choice of LED ultimately depends on design preferences, such as the desired balance between beam intensity and the overall size of the lighting system. For long-range beam spot applications, smaller round LEDs are expected to outperform larger square LEDs due to their higher luminance and compatibility with smaller secondary optics.

4. Conclusion

This Application Note provides information and crucial considerations to assist designers in optimizing lighting applications that benefit from overdriving LEDs, including battery design, thermal management, and optical design. It presents findings from survivability and performance testing on Luminus LEDs when subjected to overdrive currents exceeding the maximum rated values. It also details the maximum current levels these LEDs can withstand for short durations and provides lumen output data across various current levels.

Key takeaways include:

- Overdriving LEDs can significantly enhance light output and extend beam throw distance in applications like flashlights, search and rescue spotlights, and medical illumination.
- Limiting the "on-time" during overdrive minimizes thermal heating, enabling smaller heat sinks and more compact designs.
- Careful battery design is crucial to balance performance and battery life in devices utilizing overdrive.
- Effective thermal management is essential to prevent overheating and maintain LED performance and longevity.

Additionally, this Application Note shows the upper bounds of overdriving. Thermal design quality will determine how close designers can get to this best case in your specific applications. Thermal design and verification are critical requirements to enable the highest possible lumen output.

5. References

The following resources provide further information relevant to LED system design:

[1] Luminus White Paper: "Using LEDs with Onboard Thermistors" (thermal sensor integration)
[2] Luminus White Paper: "High-Luminance LEDs for Directional Lighting Applications" (optical design for HLDL)

Luminus Ecosystem: Balance of system components and supplier information
Luminus Design Files: Ray files, 3D step files, and PCB footprints
Luminus Help Center: Technical articles on LED applications

The overdrive conditions reported here push these LEDs beyond their maximum rated currents. As such, no guarantees are made regarding performance, lifespan, thermal behavior, or other characteristics beyond the maximum ratings in the datasheet. When using this information, please consider the following:

- This data is intended to guide engineers designing with these LEDs, especially when operating them beyond their rated maximum current.
- The overcurrent limits were determined under controlled test conditions. Always use engineering judgment when applying this data to real-world applications.