Application Brief AB20-1

LUMILEDS

Using SuperFlux LEDs in Automotive Signal Lamps

Introduction

Lumileds Lighting SuperFlux LEDs are specifically designed for automotive signal lamp applications and are designed to operate at high DC forward currents reliably over the automotive temperature range. Each SuperFlux LED generates several lumens of luminous flux. In addition, SuperFlux LEDs have a low thermal resistance package, which reduces the temperature rise within the LED signal lamp. This allows for higher drive currents and reduces the loss in optical flux due to self-heating. SuperFlux LEDs allow the designer to significantly reduce the number of LEDs needed to provide the required light output.

The colors of SuperFlux LEDs are designed to be compatible with SAE and ECE color requirements. SuperFlux LEDs are available in an amber color with dominant wavelengths of 592 and 594 nm. Red-orange and red SuperFlux LEDs are available in three colors with dominant wavelengths of 618, 620, and 630 nm. The red-orange color is designed to match the color of filtered incandescent bulbs.

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SuperFlux LEDs are available in several different optical radiation patterns, which allow the designer to optimize his secondary optics for different signal lamp designs. Currently, SuperFlux LEDs are available with round and rectangular radiation patterns. The round radiation patterns are ideal for single and multiple row LED arrays (with the same pitch in x and y dimensions). The rectangular radiation pattern is ideal for CHMSL applications that require longer aspect ratios than can be obtained from LEDs with round radiation patterns. Please refer to the SuperFlux LED Data Sheet for a current list of available viewing angle options.

SuperFlux LEDs have a low-profile package, which is compatible with high-volume automatic insertion equipment. SuperFlux LEDs are categorized for luminous flux, dominant wavelength, and forward voltage, which improves the matching between LEDs within the signal lamp. SuperFlux LEDs are packaged in tubes with 60 matched LEDs per tube and shipped in bundles of 1200 matched LEDs, which simplify the assembly of LED signal lamps.

The Application Note series 1149 has been prepared in order to simplify the design process using SuperFlux LEDs in automotive signal lamps. This application note series has been subdivided into the following application notes:

AB20-1	*Using SuperFlux LEDs In Automotive Signal Lamps*
AB20-3	*Electrical Design Considerations for SuperFlux LEDs*
AB20-4	*Thermal Management Considerations for SuperFlux LEDs*
AB20-5	*Secondary Optics Design Considerations for SuperFlux LEDs*
AB20-6	*Reliability Considerations for SuperFlux LEDs*
AB20-7	*SuperFlux LED Categories and Labels*

These application notes are available from your local Lumileds Lighting or Agilent Technologies Field Sales Engineer or from the following URL: www.lumileds.com

Signal Lamp Design Process

The design of an LED signal lamp consists of four independent but interrelated designs: optical design, mechanical design, thermal design, and electrical design.

The optical design is needed in order to design the secondary optics elements, such as reflectors or lenses, which are mounted in front of the LED emitters. In addition, the outer pillow lens needs to be designed in order to generate the desired output beam pattern. The optical design of an LED signal lamp is not unlike that of an incandescent signal lamp, except that the LED emitters have a much smaller geometry and a different optical radiation pattern.

A mechanical design is needed in order to generate the desired mechanical drawings for the outer case, outer lens, and possibly internal secondary optics. The mechanical design would also include the selection of materials used for the signal lamp assembly. The mechanical design is not unlike the mechanical design of an incandescent signal lamp.

The purpose of the thermal design is to evaluate the heat flow from the LED emitters to the ambient air and to reduce the thermal resistance as much as possible. For best results, the LED signal lamp should be designed to minimize self-heating of the LED emitters. SuperFlux LEDs are limited to a maximum junction temperature of 125°C. In addition, all LEDs experience a reduction in light output at elevated temperatures. This phenomena is fully reversible, such that the light output returns to its original value when the in the temperature returns to its initial value. However, self-heating causes an undesirable reduction in the luminous flux output of the LEDs. The thermal design of an LED signal lamp differs from that of an incandescent design. For an incandescent design, the design focus is to choose plastic materials that can withstand the heat generated by the bulb. For the LED lamp design, the focus is to protect the LEDs from high temperatures and to optimize the optical performance.

The purpose of the electrical design is to choose the appropriate forward current through the LED emitters and ensure that this current stays within an acceptable range during worst-case operation at the extremes of ignition voltage and temperature. Also, the electrical circuit configuration determines the luminous intensity matching between the emitters within the LED signal lamp. In addition, the electrical design can also protect against EMC transients, and high-voltage and low-voltage transient conditions. In many cases, an electrical design is not needed for an incandescent signal lamp since the bulb can be driven directly from the ignition voltage.

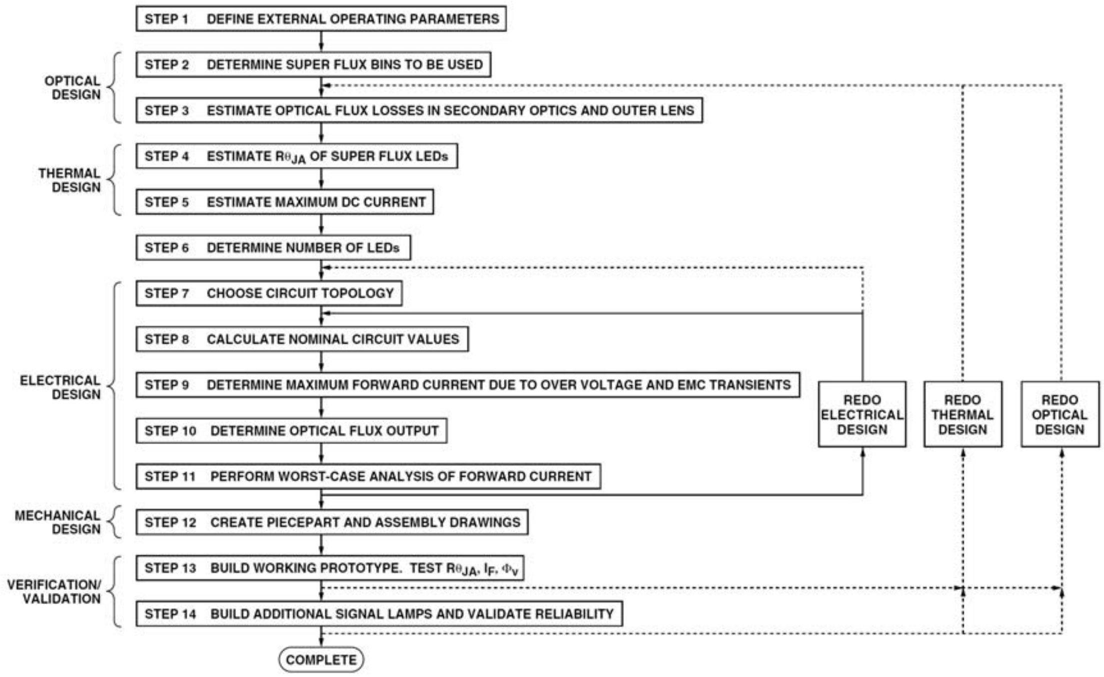
These four design processes are interrelated. For example, the mechanical drawings used to construct the signal lamp cannot be completed until the optical, thermal, and electrical designs are finished. Since these different design processes are interrelated, it is not uncommon to design the LED signal lamp using estimates for these different factors and to iterate the optical, mechanical, thermal, and electrical designs based on bench testing of prototype signal lamps.

A flow chart of the basic design process for an LED signal lamp is shown in Figure 1.1 and consists of the following steps:

1. Define external operating parameters for the signal lamp. These parameters are usually specified by the car manufacturer or defined in various automotive specifications. These parameters include:
   - Operating and storage temperature requirements for the signal lamp.
   - Photometric test conditions of the signal lamp (i.e., whether testing is done at initial turn-on at room temperature, after a 30 minute warm-up at room temperature, or over some operating temperature range).
   - Design voltage (the voltage at which the photometrics will be tested).
   - Operating voltage range (i.e., 9 V to 16 V).
   - Transient operating voltage range (i.e., 24 V for 1 minute).
   - EMC transients applied to the signal lamp (i.e., SAE J1113 pulses 1 through 7 and theamplitude and duration of each pulse).
   - Whether any additional photometric guard band is required above the minimum photometric requirements defined by the SAE or ECE standards.

   Please refer to AB20-6 for a summary of environmental strife tests that have been used to validate Super Flux LEDs as well as suggested assembly validation tests for automotive applications.

Figure 1.1 LED Signal Lamp Design Process.



2. Determine the SuperFlux LED luminous flux, and forward voltage categories to be used for the signal lamp. Category ranges for SuperFlux LEDs are discussed in AB20-7. Your local LumiLeds Lighting or Agilent Technologies Field Sales Engineer should be consulted to determine which category ranges should be used for a given model year design.

3. Complete the optical design of the outer lens and secondary optics (i.e., lens or reflectors mounted over each LED emitter). AB20-5 provides some useful guidelines on the different options available for secondary optic designs. Estimate the percentage of optical flux coupled through the secondary optics and pillow lens and the percentage of optical flux transmitted through the outer lens and any other optical surfaces. For a discussion of optical flux losses, please see the following section of this application note titled *Estimating the Number of SuperFlux LEDs Needed For a Signal Lamp*.

4. Complete the thermal design of the LED signal lamp and estimate the overall thermal resistance, $R_{\theta ja}$, of the signal lamp. Some useful thermal design guidelines and a thorough discussion of the measurement techniques and typical ranges for $R_{\theta ja}$ are provided in AB20-4.

5. Estimate the maximum DC forward current per SuperFlux LED based on the overall thermal resistance, $R_{\theta ja}$, of the LED signal lamp, and maximum ambient temperature, using Figure 4 on the SuperFlux LED Data Sheet.

6. Estimate the number of SuperFlux LED emitters needed for the signal lamp. This topic will be covered in the section titled *Estimating the Number of SuperFlux LEDs Needed For a Signal Lamp* contained in this application note.

7. Pick the circuit topology. Circuit topology refers to the electronic circuit schematic without the electronic component values. The key factors of circuit topology for an LED signal lamp include the following considerations:
   - Dimensions of the LED array (i.e., number of strings of SuperFlux LEDs and how many series-connected SuperFlux LEDs per string).
   - Interconnection scheme for the LED emitters within the LED array.
   - Current limiting method (i.e., resistive or active current limiting).
   - EMC transient protection circuit (if any).
   - Dimming circuit (such as for a Stop/Tail signal lamp). Please refer to AB20-3 for a detailed discussion of electrical design considerations.

8. Calculate the nominal values of circuit components [i.e., current limiting resistor(s)] using nominal values for the LED forward voltage. A simple linear model for the forward voltage of SuperFlux LEDs is given in AB20-3.

9. Estimate the effects of over-voltage and EMC transients on maximum forward current through the SuperFlux LEDs as desired. A discussion of EMC transient protection circuits is given in AB20-3.

10. Calculate expected values of luminous flux at 25°C and over operating temperature as desired. A discussion of how luminous flux varies over temperature is given in AB20-3 and AB20-4.

11. Complete the electrical design. Perform a worst-case circuit analysis using worst-case values for the LED forward voltage to ensure that the maximum forward current in Step 5 is not exceeded. Worst-case forward voltage ranges for SuperFlux LEDs are given in AB20-3. Note: If the worst-case circuit analysis indicates that the maximum allowable DC forward current calculated in Step 5 is exceeded, then Steps 7 through 10 should be repeated using different assumptions for circuit topology and nominal forward current.

12. Complete the mechanical design and fabricate LED signal lamp using prototype tooling.

13. Build working prototypes of the LED signal lamp to verify the electrical circuit design parameters. Prototypes should be built from different LED categories spanning the expected forward voltage and luminous flux distributions. Measure LED forward currents over the expected range of operating voltages. Measure overall LED signal lamp thermal resistance, $R_{\theta ja}$, using the test procedure outlined in AB20-4. Measure the photometric output of the LED signal lamp at each angular test point in order to verify the assumptions used in Steps 2 through 6. Optical measurements should use data-logged LEDs and the photometric results should be scaled to the luminous flux bin minimums given in AB20-7.

    Based on the measurements of the prototypes, the electrical design may need to be further optimized. A thorough discussion of the effects of different circuit designs is provided in AB20-3.

    Based on the measurements of the prototypes, the thermal resistance of the signal lamp may need to be further optimized. A thorough discussion of the thermal design factors is provided in AB20-4.

    Based on the measurements of the prototypes, the optical design may need to be further optimized. A thorough discussion of the optical design of the LED signal lamps is provided in AB20-5.

    Note: If measurements of the prototype LED signal lamps indicate that the assumptions for LED forward voltage, $R_{\theta ja}$, and luminous flux utilization are wrong, then Steps 2 through 12 should be repeated using measured values or new assumptions based on revised electrical, thermal, or optical designs.

14. Build additional LED signal lamps using the final electrical, thermal, and optical design. Perform additional testing to verify the expected ranges for forward current, thermal resistance, and photometric output. Validate reliability of final design using automotive reliability tests such as those given in SAE J575, SAE J1889, corresponding ECE or other regulations, or AB20-6.

Estimating the Number of SuperFlux LEDs Needed For a Signal Lamp

The number of SuperFlux LEDs needed for a signal lamp can be easily estimated. This is done by calculating the minimum luminous flux needed to meet the regulated photometric minimums, dividing this by the minimum luminous flux emitted by each SuperFlux LED, and then accounting for all luminous flux losses in the signal lamp. This process is summarized in a Microsoft Excel spreadsheet program that is available from Lumileds. The general calculations that are used within the spreadsheet are discussed in this section. These general calculations use a numerical method called zonal constant integration.

In general, the minimum luminous flux emitted by any LED can be estimated from the on-axis luminous intensity category and the viewing angle. For the SuperFlux LED family, the luminous flux is 100% tested and the LEDs are sorted into well-defined luminous flux categories. These categories are defined in AB20-7.

It is also important to consider luminous flux losses within the LED signal lamp. From experience, these luminous flux losses are quite large—although not as large as those for an incandescent signal lamp. The net effect of these luminous flux losses is that a total of 4 to 10 times more luminous flux is needed from the SuperFlux LED array than would be required if the optical system were completely loss-less.

The *zonal constant integration technique* can be used to calculate the minimum luminous flux emitted for a given type of signal lamp. The zonal constant integration technique is a numerical method where the total luminous flux emitted by the signal lamp is calculated by summing the amounts of incremental luminous flux emitted by the signal lamp at discrete angular positions at all angles where the luminous intensities are greater than zero. The amount of luminous flux emitted by each incremental angular position is equal to the average luminous intensity of each incremental emitting area multiplied by the solid angle subtended between the specified incremental emitting area and the adjacent emitting areas, such as shown in Figure 1.2.

For sake of convenience, the radiation pattern of the signal lamp can be considered to consist of a number of horizontal bands (i.e., H, 5U, 5D, 10U, 10D, etc.).

Then the amount of luminous flux emitted by the signal lamp into each horizontal band is equal to the summation of the non-zero luminous intensities of all points in the horizontal band multiplied by a constant, CZ, called the zonal constant. The total luminous flux emitted by the signal lamp is equal to the summation of the amounts of luminous flux emitted by all of the horizontal bands. Written mathematically, the luminous flux is equal to:

$$\phi_v \cong \sum_{\substack{\text{all } \delta \text{ horizontal} \\ \text{bands with } I_V > 0}}^{m/2} \left[C_Z(\delta) \sum_{\substack{\text{all } \theta \text{ within} \\ \text{horizontal band}}}^{n} I_V(\theta,\delta) \right]$$

$$C_Z(\delta) \cong \frac{4\pi^2}{nm} \cos(\delta)$$

Where:

Φ_V = total luminous flux emitted by the light source

$I_V(\theta,\delta)$ = luminous intensity emitted at angular position θ degrees left/right and δ degrees up/down.

n = number of horizontal divisions that an imaginary sphere surrounding the signal lamp is subdivided into. For example, for 5° increments, n = 360°/5° = 72.

m = number of vertical divisions that an imaginary sphere surrounding the signal lamp is subdivided into. For example, for 5° increments, m = 360°/5° = 72.

δ = vertical angle of midpoint of horizontal band. For example, for 5° horizontal bands (i.e., m = 72), the midpoint of the horizontal band covering angles from –2.5° to 2.5° would have a value of δ = 0° and the midpoint of the horizontal band covering angles from 2.5° to 7.5° would have a value of δ = 5°.

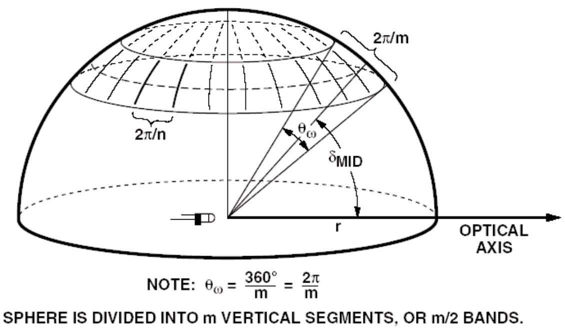
Since most photometric specifications are specified in horizontal and vertical increments of 5°, the zonal constant is equal to:

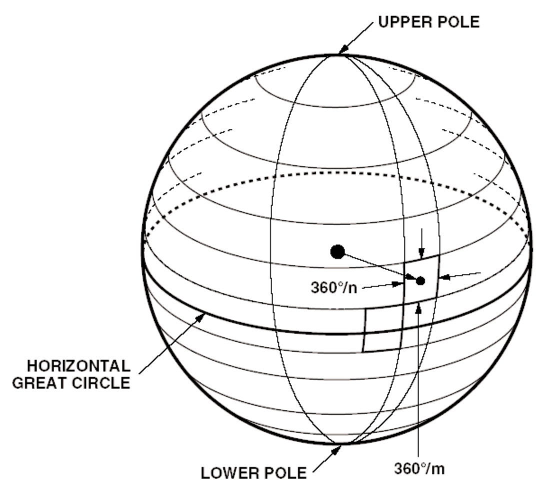
$$C_Z(\delta) = \frac{4\pi^2}{72^2} \cos(|\delta|, \text{in increments of } 5°)$$
$$= 0.007615 \cos(|\delta|)$$

Tip: Since most automotive signal lamps are only specified over a narrow range of up and down angles, typically 15U to 15D, in increments of 5 degrees left and right, then the zonal constant, $C_Z(\delta)$, is approximately equal to 0.0076.

For a detailed derivation of the *zonal constant integration technique*, please see G. B. Stringfellow and M. George Craford, *High Brightness Light Emitting Diodes*, pp. 233—246.1

As an example of the *zonal constant integration technique*, consider the total luminous flux emitted by an automotive amber rear turn signal (a similar example for an automotive rear brake lamp is given in Stringfellow, HBLED, pp 246—247). The U.S. requirements for the rear amber turn signal are contained in SAE J588 titled *Turn Signal Lamps For Use On Motor Vehicles Less Than 2032 mm In Overall Width*. The minimum photometric design guidelines are shown in Table 1.1. Note that the minimum luminous intensities are specified over a range of 10 degrees up and down and 20 degrees left and right.





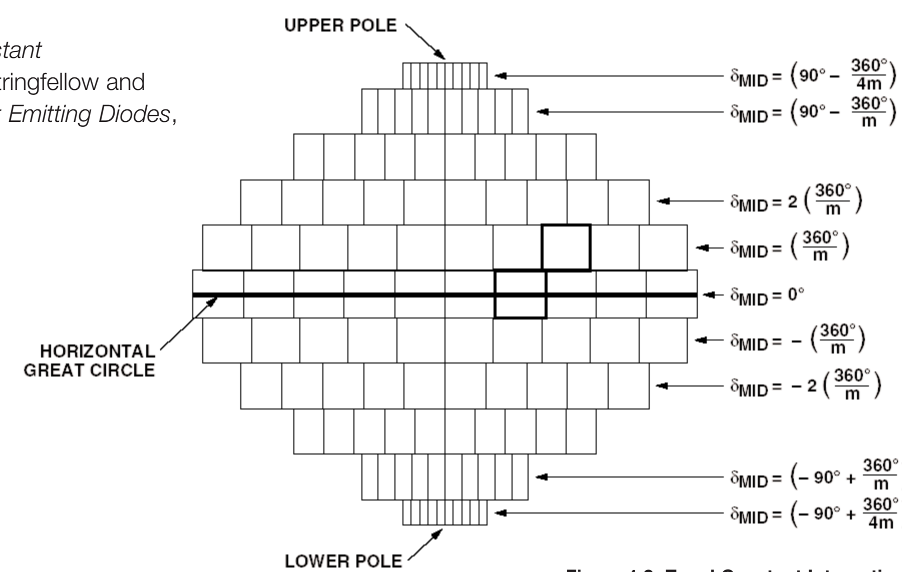


Figure 1.2 Zonal Constant Integration.

Note that not all luminous intensity points in Table 1.1 are specified. Therefore, the first step in calculating the minimum luminous flux is to estimate the luminous intensity values for the unspecified coordinates (e.g., 5L, 5U and 15L, 10U). A reasonable assumption is that the luminous intensities of the unspecified points are equal to the average values of the luminous intensities of the four adjacent points. Using these assumptions, the minimum luminous intensities of all of the unspecified points are shown in Table 1.2. Next the zonal constant integration is calculated by adding the luminous intensity values in each horizontal band (e.g., 10U, 5U, etc.) and multiplying by the zonal constant. Finally, the total luminous flux of the signal lamp is simply equal to the sum of the luminous flux values for each horizontal band. For example, referring to the 10U row of Table 1.2, the luminous flux emitted within the horizontal band (from 7.5° to 12.5°) is equal to:

$$\Phi_v \cong (1+10+17+24+26+42+26+24+17+10+1)\left(\frac{4\pi^2}{72^2}\right)\cos(10°)$$

$$\Phi_v \cong (1+10+17+24+26+42+26+24+17+10+1)(0.00750)$$

$$\Phi_v \cong (198)(0.00750) \cong 1.48\,\mathrm{lm}$$

Table 1.1 Minimum photometric design guidelines for a single compartment amber rear turn signal. All values in the table are in candela (cd). Note: Maximum luminous intensity at any point is 750 cd.

	20L	10L	5L	V	5R	10R	20R
10U			26		26		
5U	15	50		110		50	15
H		65	130	130	130	65	
5D	15	50		110		50	15
10D			26		26		

Table 1.2 Zonal constant integration of minimum photometric design guidelines for a single compartment amber rear turn signal. Note: Parentheses indicate estimated minimum luminous intensity of unspecified points.

	25L	20L	15L	10L	5L	V	5R	10R	15R	20R	25R	Sum	Zonal Constant	Flux lm
15U		(1)	(2)	(2)	(3)	(4)	(3)	(2)	(2)	(1)		20	7.36e-3	0.15
10U	(1)	(10)	(17)	(24)	26	(42)	26	(24)	(17)	(10)	(1)	198	7.50e-3	1.48
5U	(1)	15	(30)	50	(79)	110	(79)	50	(30)	15	(1)	460	7.59e-3	3.49
H	(2)	(20)	(39)	65	130	130	130	65	(39)	(20)	(2)	642	7.62e-3	4.89
5D	(1)	15	(30)	50	(79)	110	(79)	50	(30)	15	(1)	460	7.59e-3	3.49
10D	(1)	(10)	(17)	(24)	26	(42)	26	(24)	(17)	(10)	(1)	198	7.50e-3	1.48
15D		(1)	(2)	(2)	(3)	(4)	(3)	(2)	(2)	(1)		20	7.36e-3	0.15
													Total, lm	15.13

Using a similar approach, zonal constant integrations for most commonly used automotive signal lamps were calculated and are shown in Tables 1.3 and 1.4. The minimum luminous flux requirements for U.S. signal lamps are shown in Table 1.3. The minimum luminous flux requirements for European signal lamps are shown in Table 1.4. The values shown are based on the minimum photometric guidelines for single compartment lamps.

The specifications for U.S. motor vehicle signal lamps are written by the Society of Automotive Engineers (SAE). These publications are published in SAE publication HS-34 titled *SAE Ground Vehicle Lighting Standards Manual*, which is updated annually. The primary signal lamp specifications for passenger cars are as follows:

- SAE J222 *Parking Lamps (Front Position Lamps)*
- SAE J585 *Tail Lamps (Rear Position Lamps) For Use on Motor Vehicles Less Than 2032 mm in Overall Width*
- SAE J586 *Stop Lamps for Use on Motor Vehicles Less Than 2032 mm in Overall Width*
- SAE J588 *Turn Signal Lamps for Use on Motor Vehicles Less Than 2032 mm in Overall Width*
- SAE J592 *Clearance, Side Marker, and Identification Lamps*
- SAE J914 *Side Turn Signal Lamps for Vehicles Less Than 12 m in Length*
- SAE J1319 *Fog Tail Lamp (Rear Fog Light) Systems*
- SAE J1957 *Center High Mounted Stop Lamp Standard for Vehicles Less Than 2032 mm in Overall Width*
- SAE J2087 *Daytime Running Lamps For Use on Motor Vehicles*

Table 1.3 Minimum luminous flux requirements based on the zonal constant integration of different single compartment U.S. automotive signal lamps.

Function	Signal	U.S. Spec	Color	Lit Area (cm^2)	Max I_V [H, V] (cd)	Min I_V [H, V] (cd)	Min Φ_V (lm)	Notes
Front Turn/Park Lamp	Turn	SAE J588	Amber	≥ 22	—	200	23.3	Note 1, 2
						300	33.7	Note 1, 2
						400	44.2	Note 1, 2
						500	54.7	Note 1, 2
	Position	Not defined						
	Park	SAE J222	White, Amber	—	—	4	0.40	Note 2
Side Turn Lamp	Turn	SAE J914	Amber	—	200	0.6	0.21	Note 3
	Park	Not defined						
Rear Combination	Turn	SAE J588	Red	≥ 37.5	300	80	9.5	
			Amber	≥ 37.5	750	130	15.1	
	Stop	SAE J586	Red	≥ 37.5	300	80	9.4	Note 4
	Position	SAE J585	Red	—	18	2	0.28	Note 4
	Reverse	SAE J593	White	—	500	80	15.2	
	Rear Fog	SAE J1319	Red	—	300	80	9.0	Note 5
	Park	Not defined						
CHMSL	Stop	SAE J1957	Red	≥ 29	130	25	3.1	
Daytime Running Lamp	Day	SAE J2087	White, Sel Yellow, Amber	≥ 40	7000	500	39.3	
Side Marker Lamp	Front	SAE J592	Amber	—	—	0.62	0.47	
	Rear	SAE J592	Red	—	18	0.25	0.19	
End Outline Marker Lamp	Front	SAE J592	Amber	—	—	0.62	0.47	
	Rear	SAE J592	Red	—	18	0.25	0.19	

Note 1: Minimum luminous intensity requirement is increased if the Front Turn signal (FTS) is mounted in close proximity to Low Beam headlamp (LB). If spacing from center of the FTS is less than 100 mm from the lit edge of the low beam headlamp, increase minimum IV as follows:

Spacing Between FTS and LB Headlamp	Multiplier
75 mm ≤ spacing < 100 mm	1.5
60 mm ≤ spacing < 75 mm	2.0
Spacing < 60 mm	2.5

Note 2: If the Park signal is combined with the Front Turn signal, at (H, V) the luminous intensity of the Front Turn should be ≥ 5x luminous intensity of the Park signal.

Note 3: Supplemental to Front Turn signal.

Note 4: If the Rear Position signal is combined with the Stop or Turn signal, at (H, V) the luminous intensity of the Stop/Turn signal should be ≥ 5x luminous intensity of the Rear Position signal.

Note 5: Installation allows either one Rear Fog lamp on the vehicle centerline or to the left of centerline or two lamps symmetrically placed on either side of centerline.

The specifications for European motor vehicle signal lamps are written by the Economic Commission of Europe (ECE). Within these regulations, the different signal lamps are further subdivided into different categories. The primary specifications and categories for passenger cars are as follows:

ECE Regulation 6 *Uniform Provisions Concerning the Approval of Direction Indicators for Motor Vehicles and Their Trailers*

- Cat 1: *Front Turn signal mounted greater than 40 mm from the headlamp.*
- Cat 1a: *Front Turn signal mounted greater than 20 mm but less than 40 mm from the headlamp.*
- Cat 1b: *Front Turn signal mounted less than 20 mm from the headlamp.*
- Cat 2a: *Rear Turn signal with single level of intensity.*
- Cat 2b: *Rear Turn signal with two levels of intensity (day and night operation).*
- Cat 3: *Side Turn signal for vehicles without Front and Rear Turn signals.*
- Cat 4: *Front/Side Turn signal that replaces Front Turn and is supplemental to the Rear Turn signal.*
- Cat 5/6: *Supplementary Side Turn signal for vehicles that also have Front and Rear Turn signals.*

ECE Regulation 7 *Uniform Provisions Concerning the Approval of Front and Rear Position (Side) Lamps, Stop-Lamps and End-Outline Marker Lamps for Motor Vehicles (Except Motor Cycles) and Their Trailers*

- Cat S1: *Stop lamp with one level of intensity.*
- Cat S2: *Stop lamp with two levels of intensity (day and night operation).*
- Cat S3: *Center High Mount Stop lamp*

ECE Regulation 23 *Uniform Provisions Concerning the Approval of Reversing Lamps for Power-Driven Vehicles and Their Trailers*

ECE Regulation 38 *Uniform Provisions Concerning the Approval of Rear Fog Lights for Power-Driven Vehicles and Their Trailers*

ECE Regulation 48 *Uniform Provisions Concerning the Approval of Vehicles with Regard to the Installation of Lighting and Light-Signaling Devices*

ECE Regulation 77 *Uniform Provisions Concerning the Approval of Parking Lamps for Power-Driven Vehicles*

ECE Regulation 87 *Uniform Provisions Concerning the Approval of Daytime Running Lamps for Power-Driven Vehicles*

ECE Regulation 91 *Uniform Provisions Concerning the Approval of Side-Marker Lamps for Motor Vehicles and Their Trailers*

Table 1.4 Minimum luminous flux requirements based on the zonal constant integration of different single compartment ECE. automotive signal lamps..

Function	Signal	ECE Spec	Color	Lit Area (cm^2)	Max I_V [H, V] (cd)	Min I_V [H, V] (cd)	Min Φ_V (lm)	Notes
Front Turn/Park Lamp	Turn	Reg 6, Cat 1	Amber	—	700	175	15.9	Note 1
		Reg 6, Cat 1a	Amber	—	600	250	22.6	Note 1
		Reg 6, Cat 1b	Amber	—	860	400	36.3	Note 1
	Position	Reg 7	White	—	60	4	0.41	
	Park	Reg 77	White	—	60	2	0.13	Note 2
Side Turn/Park Lamp	Turn	Reg 6, Cat 3	Amber	—	700 (front)	175 (front)	13.3	
		Reg 6, Cat 3	Amber	—	200 (rear)	50 (rear)	3.9	
		Reg 6, Cat 4	Amber	—	700 (front)	175 (front)	14.4	
		Reg 6, Cat 4	Amber	—	200 (rear)	0.6 (rear)	0.39	
		Reg 6, Cat 5	Amber	—	200	0.6	0.39	
		Reg 6, Cat 6	Amber	—	200	50	10.3	
	Park	Reg 77	Amber	—	60 (front)	2	0.13	Note 2
				—	30 (rear)	2	0.13	Note 2
Rear Combination Lamp	Turn	Reg 6, Cat 2a	Amber	—	350	50	4.7	
		Reg 6, Cat 2b	Amber	—	700 (day)	175 (day)	15.9 (day)	
	Stop	Reg 7, Cat S1	Red	—	185	60	5.5	
		Reg 7, Cat S2	Red	—	520 (day)	130 (day)	11.8 (day)	
	Position	Reg 7	Red	—	12	4	0.41	Note 3
	Reverse	Reg 23	White	—	300 (up), 600 (down)	80	15.2	
	Rear Fog	Reg 38	Red	≤ 140 cm^2	300	150	12.4	
	Park	Reg 77	Red	—	30	2	0.13	Note 2
CHMSL	Stop	Reg 7, Cat S3	Red	—	80	25	3.1	
Daytime Running Lamp		Reg 87	White	≥ 40 cm^2	800	400	37.8	
Side Marker Lamp	Front	Reg 91, Cat SM1	Amber	—	25	4	0.54	
		Reg 91, Cat SM2	Amber	—	25	0.6	0.32	
	Rear	Reg 91, Cat SM1	Red, Amber	—	25	4	0.54	Note 4
		Reg 91, Cat SM2	Red, Amber	—	25	0.6	0.32	Note 4
End Outline Marker Lamp	Front	Reg 7	White	—	60	4	0.41	
	Rear	Reg 7	Red	—	12	4	0.41	

Note 1: Minimum luminous intensity requirement is increased if the Front Turn signal (FTS) is mounted in close proximity to Low Beam headlamp (LB).

ECE Reg 6 Front Direction Indicator	Spacing Between FTS and LB Headlamp
Category 1	spacing ≥ 40 mm
Category 1a	20 mm < spacing < 40 mm
Category 1b	spacing ≤ 20 mm

Note 2: Vehicles should either have two Front Parking lamps and two Rear Parking lamps or one Side Parking lamp on either side. The Front Park is normally white. The Rear Park is normally red. However, Parking Lamps can be amber if reciprocally combined with the Side Turn lamps or Side Marker lamps.

Note 3: In the case where a Rear Position lamp is reciprocally combined with a Category S1 Stop lamp, the ratio of luminous intensities (both ON divided by Rear ON only) should be greater than 5:1. In the case where Rear Position lamp is reciprocally combined with a Category S2 Stop lamp, the ratio of luminous intensities (night-time S2 Stop ON plus Rear ON, divided by Rear ON only) should be greater than 5:1.

Note 4: The rear Side Markers should emit amber light. However, it can emit red light if reciprocally combined with the Rear Position lamp, End Outline lamp, Rear Fog lamp or Stop lamp. Rear Side Markers should be amber if they flash with the Rear Turn lamp.

In order to estimate the number of SuperFlux LED emitters needed to realize an LED signal lamp, it is important to account for wasted luminous flux. In addition, the useful amount of luminous flux emitted by each SuperFlux LED may be somewhat lower than the luminous flux categories would indicate. As previously described, these losses may require the LED array to generate substantially more luminous flux than indicated by the values in Tables 1.3 and 1.4. For simplicity, it is possible to create two equations that estimate the overall flux utilization. The first equation accounts for luminous flux losses in the outer lens, exterior surfaces (i.e., a behind-theglass CHMSL), and inaccuracies in the output radiation pattern. The second equation adjusts the amount of luminous flux emitted by the SuperFlux LEDs. This equation accounts for self-heating within the LED array and luminous flux collection and transmission losses in the secondary optics.

There are several causes for wasted luminous flux associated with the outer lens. For example, the radiation pattern achieved may exceed the minimum luminous intensity values at some of the points. Or perhaps, the luminous intensity is greater than zero at points outside the specified range of angles. Furthermore, the luminous flux values given in Tables 1.3 and 1.4 do not include transmission losses of the outer lens and transmission losses of the glass window (for a behind-the-glass CHMSL). The optical transmission through a glass window can be as high as 93%. However, if the rake angle of the rear window is small, then the Fresnel losses can be significantly higher. For example, for a rake angle of 20°, the overall transmission through the rear window is about 65%. Additional transmission losses would occur for a tinted window. The combined effect of these losses could result in the minimum lumious flux requirement of a behind-the-glass CHMSL being twice the luminous flux requirement of an exterior-mounted CHMSL. In addition, the car manufacturer may require a guard-band of the minimum luminous intensity values at each angular test point beyond that which is required to meet the government specification. For these reasons, the luminous flux needed from the light source is somewhat higher than the values given in Tables 1.3 and 1.4. The following equations can be used to estimate more realistic minimum luminous flux values:

$$\Phi_{V\ realistic} = \left(\frac{\Phi_{V\ spec}}{T_{signal}}\right) F_{guard}$$

$$T_{signal} = (T_{filler})(T_{glass})(1 - L_{pattern})$$

Where:

$\Phi_{V\ realistic}$ = realistic luminous flux requirement.

$\Phi_{V\ spec}$ = minimum luminous flux requirement per Tables 1.3 or 1.4

F_{guard} = optional photometric guard-band. Note: $F_{guard} \geq 1$

T_{signal} = total luminous flux transmission losses associated with the output radiation pattern and outer lens surfaces. Note: $0 \leq T_{signal} \leq 1$

T_{filler} = optical transmission of the plastic outer lens.

T_{glass} = optical transmission of the glass window for behind-the-glass CHMSL.

$L_{pattern}$ = luminous flux losses due to radiation pattern inaccuracy.

The amount of useful luminous flux available from SuperFlux LEDs may be less than that indicated by the luminous flux categories. This is because the actual drive current may be less than the test current used to initially categorize the LEDs, and the system thermal resistance may also be higher than the test conditions. SuperFlux LEDs are tested at 70 mA with a system thermal resistance, $R_{\theta ja}$, of 200 ºC/W. With a higher thermal resistance, some luminous flux will be lost due to self-heating. Furthermore, most applications cannot be driven at 70 mA due to the requirements for operation over a range of ignition voltages and at elevated ambient temperatures. In addition, the secondary optics may not collect all of the luminous flux generated by the SuperFlux LEDs. The secondary optics can have transmission losses as well as limitations on collecting luminous flux at wider off-axis angles. The following equations can be used to estimate how much useful luminous flux will be emitted by the SuperFlux LEDs and collected by the secondary optics as compared to the published luminous flux category limits:

$$\Phi_{LED} = (\Phi_{cat})(T_{LED+optics})$$

$$T_{LED+optics} = \left(\frac{\Delta\Phi}{\Delta T_a}\right)\left[\Phi(I_f, \theta_{ja})\right](\Phi_{collected})(T_{optics})$$

$$\frac{\Delta\Phi}{\Delta T_a} = e^{-k(T_a - 25°C)}$$

Where:

Φ_{LED} = useful luminous flux emitted by the SuperFlux LED.

Φ_{cat} = minimum luminous flux emitted per SuperFlux LED emitter luminous flux category

$T_{LED + optics}$ = total luminous flux transmission losses associated with the emitter as well as collection and transmission losses for the secondary optics. Note: $0 \leq T_{LED + optics} \leq 1$

$\Delta\Phi / \Delta T_a$ = reduction in luminous flux if specification must be met at elevated temperature.

$\Phi(I_f, \theta_{ja})$ = normalized luminous flux versus forward current and thermal resistance per Figure 3 of the SuperFlux LED Data Sheet.

$\Phi_{collected}$ = percentage of luminous flux collected by secondary optics based on maximum collection angle of the secondary optics and Figure 6 of the SuperFlux LED Data Sheet.

T_{optics} = optical transmission of secondary optics.

k = temperature coefficient: k = 0.00952 for HPWx-xH00 SuperFlux LEDs and 0.0111 for HPWA-xL00 SuperFlux LEDs. See AB20-3 and AB20-4 for more information.

Thus, the number of LEDs, N, needed to generate sufficient luminous flux required to meet the required photometric lighting specification is equal to:

$$N = \left(\frac{\Phi_{v\ realistic}}{\Phi_{LED}} \right) = \left(\frac{\Phi_{v\ spec}}{\Phi_{cat}} \right) \left(\frac{F_{guard}}{(T_{signal})(T_{LED+optics})} \right)$$

The approximate numbers of SuperFlux LEDs needed to meet the SAE and ECE signal lamp requirements are shown in Tables 1.5 and 1.6. These tables are based on the factor shown below:

$$4 \le \left(\frac{F_{guard}}{(T_{signal})(T_{LED+optics})} \right) \le 8$$

Note that for the assumptions used to estimate the number of SuperFlux LEDs requires that the designer first complete Steps 1 through 5 of the design process outlined in the section *Signal Lamp Design Process* of this application note. The calculation for the minimum number of SuperFlux LEDs shown in the sidebar example titled *Calculating the Minimum Number of LEDs Required* is Step 6 of this design process. Once the minimum number of SuperFlux LEDs has been established, it is possible to complete Step 7 of the design process—evaluating the circuit topology of the LED signal lamp.

Calculating the Minimum Number of LEDs Required

Suppose that an LED Rear Stop/Turn signal lamp will be constructed with 3.0 lumen (Category F) HPWT-MH00 and 1.5 lumen (Category C) HPWT-ML00 SuperFlux LEDs. What is the minimum number of LED emitters needed?

The minimum luminous flux requirements shown in Table 1.3 are 9.4 lumens for the red Stop lamp and 15.1 lumens for the amber Rear Turn Signal. Let's suppose that the signal lamp needs to operate at 55 ºC and has a system thermal resistance of 500 ºC/W. Then, for the assumptions listed below T_{signal} and (Φ_V realistic / $\Phi_{V\ spec}$) are equal to:

T_{filler} = 0.9 (red)

T_{filler} = 0.8 (amber)

T_{glass} = 1.00 (this application is not a behind-the-glass CHMSL).

$L_{pattern}$ = 0.3

F_{guard} = 1.25

T_{signal} = $(T_{filler})\ (T_{glass})\ (1 - L_{pattern})$
= (0.9 for red, 0.8 for amber)(1.00)(1- 0.3)

T_{signal} = 0.63 for red, 0.56 for amber

$$\frac{\Phi_{V\ realistic}}{\Phi_{V\ spec}} = \left(\frac{F_{guard}}{T_{signal}}\right)$$

$$= \left(\frac{1.25}{0.63 \text{ for red}, 0.56 \text{ for amber}}\right)$$

$$= 2.0 \text{ for red}, 2.2 \text{ for amber}$$

According to Figure 4b of the SuperFlux LED Data Sheet, the maximum DC forward current at 55°C, 500°C/W is 50 mA. Thus, $\Phi(I_f, \theta_{ja})$ from Figure 3 of the SuperFlux LED Data Sheet is equal to 0.56. Further, suppose that the signal lamp needs to meet the SAE J1889 requirement for a 30-minute warm-up prior to taking photometric values. Since Figure 3 of the SuperFlux LED Data Sheet represents the luminous flux after thermal equilibrium, the 30-minute warm-up effects are included in the 0.56 factor. If the signal lamp does not need to meet photometrics at an elevated temperature, then $\Delta\Phi / \Delta T_a$ is equal to 1.00. Finally, suppose the maximum off-axis angle collected by the secondary optics is 40º. Then, from Figure 6a of the SuperFlux LED Data Sheet, 75% of the total luminous flux emitted by the HPWT-MH00 will be collected. Finally, let's assume that the optical transmission of the secondary optics is 80%. Then the equations for $T_{LED+optics}$ and (Φ_{LED}/Φ_{cat}) are equal to:

$$T_{LED+optics} = (\Delta\Phi / \Delta T_a)[\Phi(I_f, \theta_{ja})](\Phi_{collected})(T_{optics})$$

$$= (1.00)(0.56)(0.75)(0.80) = 0.34$$

$$\frac{\Phi_{LED}}{\Phi_{CAL}} = (T_{LED+optics}) = 0.34$$

Thus, the minimum number of LED emitters needed for the Stop lamp is equal to:

$$N = \left(\frac{\Phi_{V\,realistic}}{\Phi_{LED}}\right) = \left(\frac{\Phi_{V\,spec}}{\Phi_{cat}}\right)\left(\frac{F_{guard}}{(T_{signal})(T_{LED+optics})}\right)$$

$$= \left(\frac{\Phi_{V\,spec}}{\Phi_{cat}}\right)\left(\frac{2.0}{0.34}\right)$$

$$N = \left(\frac{9.4}{3.0}\right)(5.9) = 19$$

Thus, the minimum number of LED emitters needed for the amber Rear Turn signal is equal to:

$$N = \left(\frac{\Phi_{V\,realistic}}{\Phi_{LED}}\right) = \left(\frac{\Phi_{V\,spec}}{\Phi_{cat}}\right)\left(\frac{F_{guard}}{(T_{signal})(T_{LED+optics})}\right)$$

$$= \left(\frac{\Phi_{V\,spec}}{\Phi_{cat}}\right)\left(\frac{2.2}{0.34}\right)$$

$$N = \left(\frac{15.1}{1.5}\right)(6.5) = 65$$

Table 1.5 Approximate number of SuperFlux LEDs for several SAE automotive signal lamps using assumptions from this example.

LED P/N	Φ_{cat}, lm	Signal SAE Amber Front Turn Φ_{spec} = 23.3 lm	Signal SAE Amber Rear Turn Φ_{spec} = 15.1 lm	Signal SAE Red Rear Turn Φ_{spec} = 9.5 lm	Signal SAE Stop Φ_{spec} = 9.4 lm	Signal SAE CHMSL Φ_{spec} = 3.1 lm
HLMP-C100	≈ 0.375			100 to 200	100 to 200	36 to 72
HPWA-M/DH	C, 1.5			26 to 52	26 to 52	9 to 18
	D, 2.0			20 to 40	20 to 40	7 to 14
HPWT-M/DH	E, 2.5			16 to 32	16 to 32	5 to 10
	F, 3.0			14 to 26	14 to 26	4 to 8
	G, 3.5			12 to 24	12 to 24	4 to 8
	H, 4.0			10 to 20	10 to 20	3 to 6
	J, 5.0			8 to 16	8 to 16	3 to 6
HLMP-DL00	≈ 0.375	248 to 504	160 to 320			
HPWA-M/DL	A, 0.62	152 to 304	98 to 196			
	B, 1.0	96 to 192	60 to 120			
HPWT-M/DL	C, 1.5	64 to 128	40 to 80			
	D, 2.0	48 to 96	30 to 60			
	E, 2.5	40 to 76	24 to 48			
	F, 3.0	32 to 64	20 to 40			

Table 1.6 Approximate number of SuperFlux LEDs for several SAE automotive signal lamps using assumptions from this example.

LED P/N	Φ_{cat}, lm	Signal ECE Cat 1 Front Turn Φ_{spec} = 15.9 lm	Signal ECE Cat 2a Rear Turn Φ_{spec} = 4.7 lm	Signal ECE Cat S1 Stop Φ_{spec} = 5.5 lm	Signal ECE Rear Fog Φ_{spec} = 12.4 lm	Signal ECE Cat S3 CHMSL Φ_{spec} = 3.1 lm
HLMP-C100	≈ 0.375			60 to 120	132 to 264	36 to 72
HPWA-M/DH	C, 1.5			15 to 30	33 to 66	9 to 18
	D, 2.0			12 to 24	25 to 50	7 to 14
HPWT-M/DH	E, 2.5			9 to 18	20 to 40	5 to 10
	F, 3.0			8 to 16	17 to 34	4 to 8
	G, 3.5			7 to 14	14 to 28	4 to 8
	H, 4.0			6 to 12	13 to 26	3 to 6
	J, 5.0			5 to 10	10 to 20	3 to 6
HLMP-DL00	≈ 0.375	170 to 340	50 to 100			
HPWA-M/DL	A, 0.62	104 to 208	30 to 60			
	B, 1.0	64 to 128	20 to 40			
HPWT-M/DL	C, 1.5	42 to 84	14 to 28			
	D, 2.0	32 to 64	10 to 20			
	E, 2.5	26 to 52	8 to 16			
	F, 3.0	22 to 44	7 to 14			

References

G.B. Stringfellow and M. George Craford, *High Brightness Light Emitting Diodes*, Semiconductors and Semimetals, Volume 48, (San Diego, CA: Academic Press, 1997).

LUMILEDS

Company Information

Lumileds is a world-class supplier of Light Emitting Diodes (LEDs) producing billions of LEDs annually. Lumileds is a fully integrated supplier, producing core LED material in all three base colors (Red, Green, Blue) and White. Lumileds has R&D development centers in San Jose, California and Best, The Netherlands. Production capabilities in San Jose, California and Malaysia.

Lumileds is pioneering the high-flux LED technology and bridging the gap between solid state LED technology and the lighting world. Lumileds is absolutely dedicated to bringing the best and brightest LED technology to enable new applications and markets in the lighting world.

Lumileds may make process or materials changes affecting the performance or other characteristics of our products. These products supplied after such changes will continue to meet published specifications, but may not be identical to products supplied as samples or under prior orders.

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