BROADCOM®

Data Sheet

# HLMP-ELxx, HLMP-EHxx, HLMP-EJxx, HLMP-EGxx

## T-1¾ (5 mm) Precision Optical Performance AlInGaP LED Lamps

## Description

These Precision Optical Performance AlInGaP LEDs provide superior light output for excellent readability in sunlight and are extremely reliable. AlInGaP LED technology provides extremely stable light output over long periods of time. Precision Optical Performance lamps use the aluminum indium gallium phosphide (AlInGaP) technology.

These LED lamps are untinted, nondiffused, T-1¾ packages incorporating second-generation optics producing well defined spatial radiation patterns at specific viewing cone angles.

These lamps are made with an advanced optical grade epoxy, offering superior high temperature and high moisture resistance performance in outdoor signal and sign applications. The high maximum LED junction temperature limit of +130 °C enables high temperature operation in bright sunlight conditions. The package epoxy contains both uv-a and uv-b inhibitors to reduce the effects of long-term exposure to direct sunlight.

These lamps are available in two package options to give the designer flexibility with device mounting.

## Benefits

- Viewing angles match traffic management sign requirements
- Colors meet automotive and pedestrian signal specifications
- Superior performance in outdoor environments
- Suitable for autoinsertion onto PC boards

## Features

- Well-defined spatial radiation patterns
- Viewing angles: 8°, 15°, 23°, 30°
- High luminous output
- Colors:
  - 590 nm amber
  - 605 nm orange
  - 615 nm reddish-orange
  - 626 nm red
- High operating temperature: $T_J$LED = +130°C
- Superior resistance to moisture
- Package options:
  - With or without lead stand-offs

## Applications

- Traffic management:
  - Traffic signals
  - Pedestrian signals
  - Work zone warning lights
  - Variable message signs
- Commercial outdoor advertising:
  - Signs
  - Marquees
- Automotive:
  - Exterior and interior lights

# Device Selection Guide

**Table 1: Device Selection Guide, 8° Typical Viewing Angle**

| Typical Viewing Angle $2\theta_{1/2}$ (Deg)[a] | Color and Dominant Wavelength (nm), Typ.[b] | Lamps without Standoffs on Leads (Outline Drawing A) | Lamps with Standoffs on Leads (Outline Drawing B) | Luminous Intensity Iv (mcd)[c,d,e] at 20 mA | |
|---|---|---|---|---|---|
| | | | | Min. | Max. |
| 8° | Amber 590 | HLMP-EL08-T0000 | — | 2500 | — |
| | | HLMP-EL08-VY000 | HLMP-EL10-VY000 | 4200 | 12000 |
| | | HLMP-EL08-WZ000 | — | 5500 | 16000 |
| | | HLMP-EL08-X1K00 | HLMP-EL10-X1K00 | 7200 | 21000 |
| | | HLMP-EL08-X1000 | HLMP-EL10-X1000 | 7200 | 21000 |
| | Orange 605 | HLMP-EJ08-WZ000 | — | 5500 | 16000 |
| | | HLMP-EJ08-X1000 | — | 7200 | 21000 |
| | | HLMP-EJ08-Y2000 | — | 9300 | 27000 |
| | Red-Orange 615 | HLMP-EH08-UX000 | — | 3200 | 9300 |
| | | HLMP-EH08-WZ000 | HLMP-EH10-WZ000 | 5500 | 16000 |
| | | HLMP-EH08-Y2000 | HLMP-EH10-Y2000 | 9300 | 27000 |
| | Red 626 | HLMP-EG08-T0000 | — | 2500 | — |
| | | HLMP-EG08-VY000 | — | 4200 | 12000 |
| | | HLMP-EG08-WZ000 | HLMP-EG10-WZ000 | 5500 | 16000 |
| | | HLMP-EG08-X1000 | HLMP-EG10-X1000 | 7200 | 21000 |
| | | HLMP-EG08-YZ000 | — | 9300 | 16000 |
| | | HLMP-EG08-Y2000 | HLMP-EG10-Y2000 | 9300 | 27000 |

a. $\theta_{1/2}$ is the off-axis angle where the luminous intensity is half the on-axis intensity.

b. The dominant wavelength, $\lambda_d$, is derived from the CIE Chromaticity Diagram and represents the color of the lamp.

c. The luminous intensity is measured on the mechanical axis of the lamp package.

d. The optical axis is closely aligned with the package mechanical axis.

e. Tolerance for each intensity bin limit is ±15%.

**Table 2: Device Selection Guide, 15° Typical Viewing Angle**

| Typical Viewing Angle $2\theta\frac{1}{2}$ (Deg)[a] | Color and Dominant Wavelength (nm), Typ[b] | Lamps without Standoffs on Leads (Outline Drawing A) | Lamps with Standoffs on Leads (Outline Drawing B) | Luminous Intensity Iv (mcd)[c,d,e] at 20 mA | |
|---|---|---|---|---|---|
| | | | | Min. | Max. |
| 15° | Amber 590 | HLMP-EL15-PS000 | — | 880 | 2500 |
| | | HLMP-EL15-QT000 | — | 1150 | 3200 |
| | | HLMP-EL15-UX000 | — | 3200 | 9300 |
| | | HLMP-EL15-VY000 | HLMP-EL17-VY000 | 4200 | 12000 |
| | | HLMP-EL15-VYK00 | — | 4200 | 12000 |
| | Orange 605 | HLMP-EJ15-PS000 | — | 880 | 2500 |
| | | HLMP-EJ15-SV000 | HLMP-EJ17-SV000 | 1900 | 5500 |
| | Red-Orange 615 | HLMP-EH15-RU000 | — | 1500 | 4200 |
| | | HLMP-EH15-TW000 | — | 2500 | 7200 |
| | Red 626 | HLMP-EG15-PS000 | — | 880 | 2500 |
| | | HLMP-EG15-QT000 | — | 1150 | 3200 |
| | | HLMP-EG15-RU000 | — | 1500 | 4200 |
| | | HLMP-EG15-UX000 | HLMP-EG17-UX000 | 3200 | 9300 |
| | | HLMP-EG15-TW000 | — | 2500 | 7200 |

a. $\theta\frac{1}{2}$ is the off-axis angle where the luminous intensity is half the on-axis intensity.

b. The dominant wavelength, $\lambda_d$, is derived from the CIE Chromaticity Diagram and represents the color of the lamp.

c. The luminous intensity is measured on the mechanical axis of the lamp package.

d. The optical axis is closely aligned with the package mechanical axis.

e. Tolerance for each intensity bin limit is ±15%.

**Table 3: Device Selection Guide, 23° Typical Viewing Angle**

| Typical Viewing Angle $2\theta_{1/2}$ (Deg)[a] | Color and Dominant Wavelength (nm), Typ[b] | Lamps without Standoffs on Leads (Outline Drawing A) | Lamps with Standoffs on Leads (Outline Drawing B) | Luminous Intensity Iv (mcd)[c,d,e] at 20 mA | |
|---|---|---|---|---|---|
| | | | | Min. | Max. |
| 23° | Amber 590 | HLMP-EL24-PS000 | HLMP-EL26-PS000 | 880 | 2500 |
| | | HLMP-EL24-QT000 | HLMP-EL26-QT000 | 1150 | 3200 |
| | | HLMP-EL24-SU400 | — | 1900 | 4200 |
| | | HLMP-EL24-TW000 | — | 2500 | 7200 |
| | Orange 605 | HLMP-EJ24-QT000 | — | 1150 | 3200 |
| | Red-Orange 615 | HLMP-EH24-PS000 | HLMP-EH26-PS000 | 880 | 2500 |
| | | HLMP-EH24-QT000 | — | 1150 | 3200 |
| | Red 626 | HLMP-EG24-PS000 | HLMP-EG26-PS000 | 880 | 2500 |
| | | HLMP-EG24-QT000 | — | 1150 | 4200 |
| | | HLMP-EG24-RU000 | — | 1500 | 4200 |

a. $\theta_{1/2}$ is the off-axis angle where the luminous intensity is half the on-axis intensity.

b. The dominant wavelength, $\lambda_d$, is derived from the CIE Chromaticity Diagram and represents the color of the lamp.

c. The luminous intensity is measured on the mechanical axis of the lamp package.

d. The optical axis is closely aligned with the package mechanical axis.

e. Tolerance for each intensity bin limit is ±15%.

**Table 4: Device Selection Guide, 30° Typical Viewing Angle**

| Typical Viewing Angle 2θ½ (Deg)[a] | Color and Dominant Wavelength (nm), Typ[b] | Lamps without Standoffs on Leads (Outline Drawing A) | Lamps with Standoffs on Leads (Outline Drawing B) | Luminous Intensity Iv (mcd)[c,d,e] at 20 mA | |
|---|---|---|---|---|---|
| | | | | Min. | Max. |
| 30° | Amber 590 | HLMP-EL30-MQ000 | — | 520 | 1500 |
| | | HLMP-EL30-PQ000 | — | 880 | 1500 |
| | | HLMP-EL30-PR400 | — | 880 | 1900 |
| | | HLMP-EL30-PS000 | HLMP-EL32-PS000 | 880 | 2500 |
| | | HLMP-EL30-PSK00 | — | 880 | 2500 |
| | | HLMP-EL30-QT000 | — | 1150 | 3200 |
| | | HLMP-EL30-STK00 | — | 1900 | 3200 |
| | | HLMP-EL30-SV000 | — | 1900 | 5500 |
| | Orange 605 | HLMP-EJ30-NR000 | — | 680 | 1900 |
| | | HLMP-EJ30-PS000 | HLMP-EJ32-PS000 | 880 | 2500 |
| | Red-Orange 615 | HLMP-EH30-MQ000 | — | 520 | 1500 |
| | | HLMP-EH30-PS000 | — | 880 | 2500 |
| | Red 626 | HLMP-EG30-KN000 | — | 310 | 880 |
| | | HLMP-EG30-MQ000 | — | 520 | 1500 |
| | | HLMP-EG30-NQ000 | — | 680 | 1500 |
| | | HLMP-EG30-NR000 | HLMP-EG32-NR000 | 680 | 1900 |
| | | HLMP-EG30-PR000 | — | 880 | 1900 |
| | | HLMP-EG30-PS000 | — | 880 | 2500 |
| | | HLMP-EG30-QT000 | — | 1150 | 3200 |

a. $\theta_{1/2}$ is the off-axis angle where the luminous intensity is half the on-axis intensity.

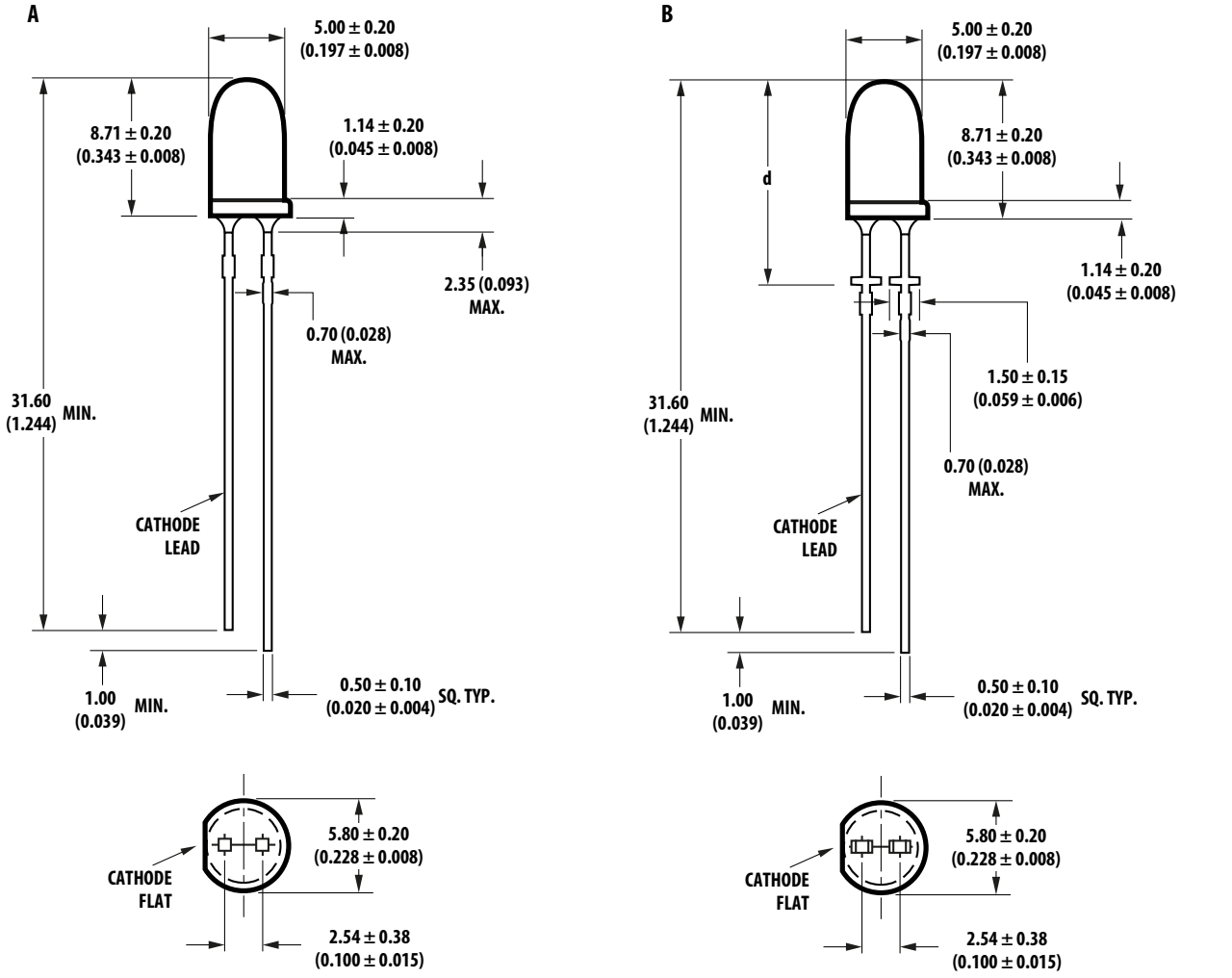
b. The dominant wavelength, $\lambda_d$, is derived from the CIE Chromaticity Diagram and represents the color of the lamp.

c. The luminous intensity is measured on the mechanical axis of the lamp package.

d. The optical axis is closely aligned with the package mechanical axis.

e. Tolerance for each intensity bin limit is ±15%.

**Figure 1: Package Dimensions**




| PART NO. | HLMP-XX10 | HLMP-XX17 | HLMP-XX26 | HLMP-XX32 |
|---|---|---|---|---|
| d | 12.37 ± 0.25 (0.487 ± 0.010) | 12.42 ± 0.25 (0.489 ± 0.010) | 12.52 ± 0.25 (0.493 ± 0.010) | 11.96 ± 0.25 (0.471 ± 0.010) |

**NOTE:**

1. All dimensions are in millimeters (inches).
2. Tapers shown at top of leads (bottom of lamp package) indicate an epoxy meniscus that may extend about 1 mm (0.040 in.) down the leads.
3. For dome heights above lead standoff seating plane, d, lamp package B, see table.

# Absolute Maximum Ratings at $T_A$ = 25°C

| Parameter | Value |
|---|---|
| DC Forward Current[a,b,c] | 50 mA |
| Peak Pulsed Forward Current[b,c] | 100 mA |
| Average Forward Current[c] | 30 mA |
| Reverse Voltage ($I_R$ = 100 µA) | 5V |
| LED Junction Temperature | 130°C |
| Operating Temperature | –40°C to +100°C |
| Storage Temperature | –40°C to +100°C |

a. Derate linearly as shown in Figure 5.

b. For long-term performance with minimal light output degradation, drive currents between 10 mA and 30 mA are recommended. For more information on recommended drive conditions, refer to Application Brief I-024.

c. Operating at currents below 1 mA is not recommended. Contact your local representative for further information.

# Electrical/Optical Characteristics at $T_A$ = 25 °C

| Parameter | Symbol | Min | Typ | Max | Unit | Test Conditions |
|---|---|---|---|---|---|---|
| Forward Voltage | $V_F$ | | | | V | $I_F$ = 20 mA |
| Amber ($\lambda_d$ = 590 nm) | | — | 2.02 | 2.4 | | |
| Orange ($\lambda_d$ = 605 nm) | | — | 1.98 | 2.4 | | |
| Red-Orange ($\lambda_d$ = 615 nm) | | — | 1.94 | 2.4 | | |
| Red ($\lambda_d$ = 626 nm) | | — | 1.90 | 2.4 | | |
| Reverse Voltage | $V_R$ | 5 | 20 | — | V | $I_R$ = 100 µA |
| Dominant Wavelength | $\lambda_d$ | | | | nm | $I_F$ = 20 mA |
| Red | | 620.0 | 626.0 | 630.0 | | |
| Amber | | 584.5 | 590.0 | 594.5 | | |
| Orange | | 599.5 | 605.0 | 610.5 | | |
| Red Orange | | 612.0 | 615.0 | 621.7 | | |
| Peak Wavelength | $\lambda_{PEAK}$ | | | | nm | Peak of Wavelength of Spectral Distribution at $I_F$ = 20 mA |
| Amber ($\lambda_d$ = 590 nm) | | — | 592 | — | | |
| Orange ($\lambda_d$ = 605 nm) | | — | 609 | — | | |
| Red-Orange ($\lambda_d$ = 615 nm) | | — | 621 | — | | |
| Red ($\lambda_d$ = 626 nm) | | — | 635 | — | | |
| Spectral Halfwidth | $\Delta\lambda_{½}$ | — | 17 | — | nm | Wavelength Width at Spectral Distribution ½ Power Point at $I_F$ = 20 mA |
| Speed of Response | $\tau_s$ | — | 20 | — | ns | Exponential Time Constant, $e^{-t/ts}$ |
| Capacitance | C | — | 40 | — | pF | $V_F$ = 0, f = 1 MHz |
| Thermal Resistance | $R\theta_{J\text{-}PIN}$ | — | 240 | — | °C/W | LED Junction-to-Cathode Lead |
| Luminous Efficacy[a] | $\eta_V$ | | | | lm/W | Emitted Luminous Flux/Electrical Power |
| Amber ($\lambda_d$ = 590 nm) | | — | 480 | — | | |
| Orange ($\lambda_d$ = 605 nm) | | — | 370 | — | | |
| Red-Orange ($\lambda_d$ = 615 nm) | | — | 260 | — | | |
| Red ($\lambda_d$ = 626 nm) | | — | 150 | — | | |
| Luminous Flux | $\varphi_V$ | — | 500 | — | mlm | $I_F$ = 20 mA |
| Luminous Efficiency[b] | $\eta_e$ | | | | lm/W | Emitted Luminous Flux/Electrical Power |
| Red | | — | 12 | — | | |
| Amber | | — | 13 | — | | |
| Orange | | — | 13 | — | | |
| Red Orange | | — | 13 | — | | |

a. The radiant intensity, $I_e$, in watts per steradian, may be found from the equation $I_e = I_v/\eta_v$, where $I_v$ is the luminous intensity in candelas and $\eta_v$ is the luminous efficacy in lumens/watt.

b. $\eta_e = \varphi_V / I_F \times V_F$, where $\varphi_V$ is the emitted luminous flux, $I_F$ is electrical forward current, and $V_F$ is the forward voltage.

# Part Numbering System

| H | L | M | P | - | $x_1$ | $x_2$ | $x_3$ | $x_4$ | - | $x_5$ | $x_6$ | $x_7$ | $x_8$ | $x_9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| Code | Description | Option | |
|---|---|---|---|
| $x_1$ | Package type | E | 5mm Standard Round AlInGaP |
| $x_2$ | Color | G | Red |
| | | H | Red Orange |
| | | J | Orange |
| | | L | Amber |
| $x_3$ $x_4$ | Viewing Angle and Lead Standoffs | 08 | 8° without lead standoffs |
| | | 10 | 10° with lead standoffs |
| | | 15 | 15° without lead standoffs |
| | | 17 | 15° with lead standoffs |
| | | 24 | 23° without lead standoffs |
| | | 26 | 23° with lead standoffs |
| | | 30 | 30° without lead standoffs |
| | | 32 | 30° with lead standoffs |
| $x_5$ | Minimum intensity bin | | Refer to Device Selection Guide |
| $x_6$ | Maximum intensity bin | | Refer to Device Selection Guide |
| $x_7$ | Color bin selection | 0 | Full range |
| | | 4 | Amber Color bin 4 only |
| | | K | Color bin 2 and 4 |
| $x_8$ $x_9$ | Packaging option | 00 | Bulk Packaging |
| | | DD | Ammopack |
| | | YY | Flexi-bin: Bulk Packaging |
| | | ZZ | Flexi-bin: Ammopack |

**NOTE:** Refer to AB 5337 for complete information on part numbering system.

# Intensity Bin Limits (mcd at 20 mA)

| Bin Name[a] | Min. | Max. |
|---|---|---|
| K | 310 | 400 |
| L | 400 | 520 |
| M | 520 | 680 |
| N | 680 | 880 |
| P | 880 | 1150 |
| Q | 1150 | 1500 |
| R | 1500 | 1900 |
| S | 1900 | 2500 |
| T | 2500 | 3200 |
| U | 3200 | 4200 |
| V | 4200 | 5500 |
| W | 5500 | 7200 |
| X | 7200 | 9300 |
| Y | 9300 | 12000 |
| Z | 12000 | 16000 |
| 1 | 16000 | 21000 |
| 2 | 21000 | 27000 |

a. Tolerance for each bin limit is ±15%.

# Amber Color Bin Limits (nm at 20 mA)

| Bin Name[a,b] | Min. | Max. |
|---|---|---|
| 1 | 584.5 | 587 |
| 2 | 587 | 589.5 |
| 4 | 589.5 | 592 |
| 6 | 592 | 594.5 |

a. Tolerance for each bin limit is ±0.5 nm.

b. Bin categories are established for classification of products. Products may not be available in all bin categories.

**Figure 2: Relative Intensity vs. Peak Wavelength**

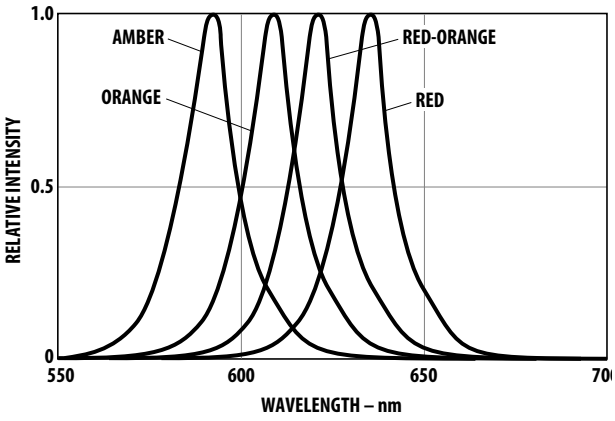



**Figure 3: Forward Current vs. Forward Voltage**

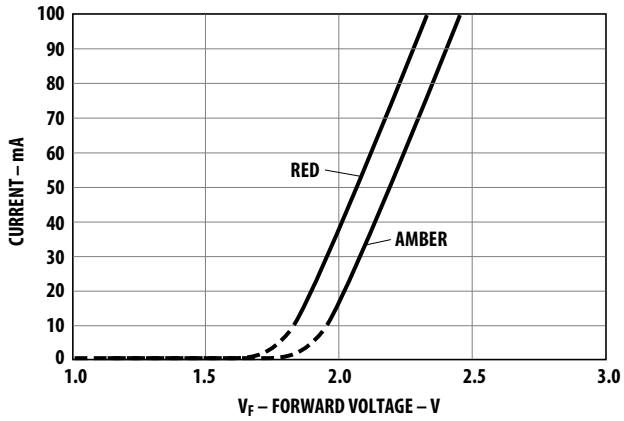



**Figure 4: Relative Luminous Intensity vs. Forward Current**

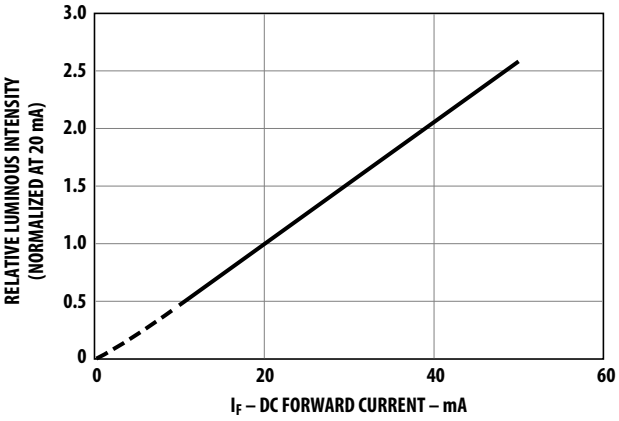



**Figure 5: Maximum Forward Current vs. Ambient Temperature**

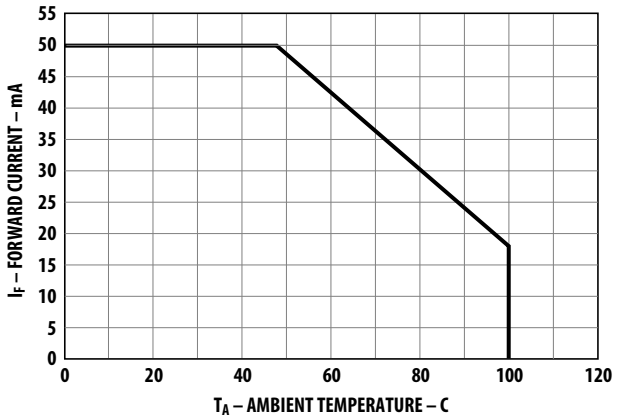


**Figure 6: Representative Spatial Radiation Pattern for 8° Viewing Angle Lamps**

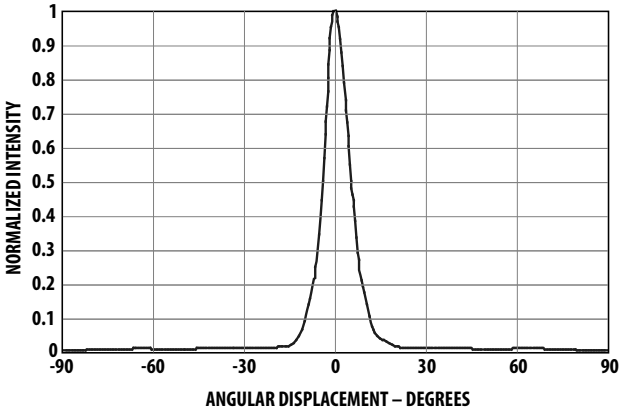



**Figure 7: Representative Spatial Radiation Pattern for 15° Viewing Angle Lamps**

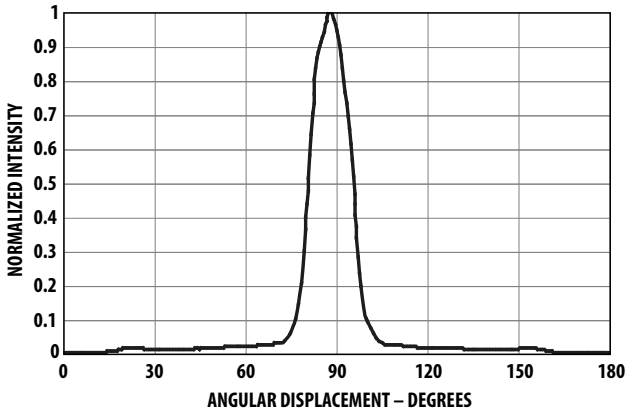



**Figure 8: Representative Spatial Radiation Pattern for 23° Viewing Angle Lamps**

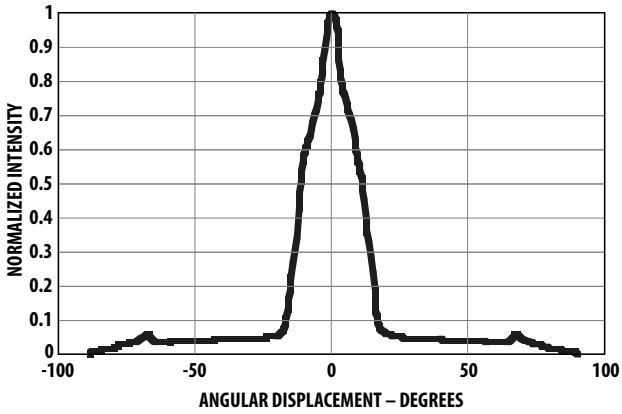



**Figure 9: Representative Spatial Radiation Pattern for 30° Viewing Angle Lamps**

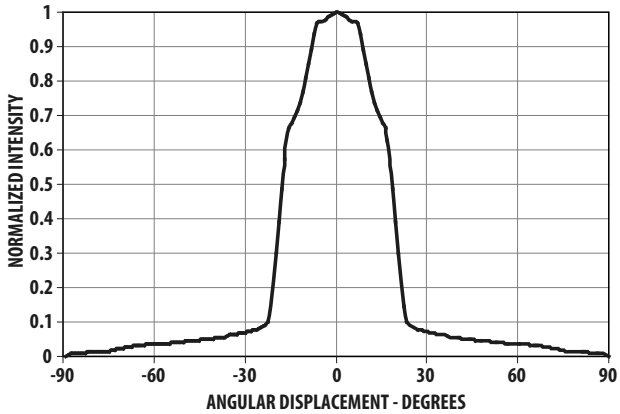
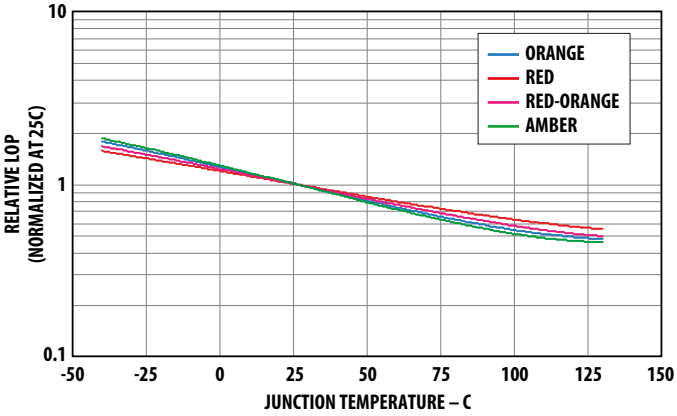



**Figure 10: Relative Light Output vs. Junction Temperature**



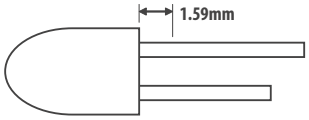
# Precautions

## Lead Forming

- The leads of an LED lamp may be preformed or cut to length prior to insertion and soldering on PC board.
- For better control, use the proper tool to precisely form and cut the leads to the applicable length rather than doing it manually.
- If manual lead cutting is necessary, cut the leads after the soldering process. The solder connection forms a mechanical ground that prevents mechanical stress due to lead cutting from traveling into LED package. Use this method for hand soldering operation, because the excess lead length also acts as small heat sink.

## Soldering and Handling

- Take care during the PCB assembly and soldering process to prevent damage to the LED component.
- The LED component may be effectively hand soldered to PCB; however, do this only under unavoidable circumstances, such as rework. The closest manual soldering distance of the soldering heat source (soldering iron's tip) to the body is 1.59 mm. Soldering the LED using soldering iron tip closer than 1.59 mm might damage the LED.




- Properly apply ESD precautions on the soldering station and personnel to prevent ESD damage to the LED component that is ESD sensitive. Refer to Broadcom® application note AN-1142 for details. The soldering iron used should have a grounded tip to ensure electrostatic charge is properly grounded.
- Recommended soldering condition:

| | Wave Soldering[a,b] | Manual Solder Dipping |
|---|---|---|
| Pre-heat temperature | 105°C max. | — |
| Preheat time | 60s max. | — |
| Peak temperature | 250°C mMx. | 260°C max. |
| Dwell time | 3s max. | 5s max. |

a. Above conditions refer to measurement with thermocouple mounted at the bottom of PCB.

b. It is recommended to use only bottom preheaters in order to reduce thermal stress experienced by LED.

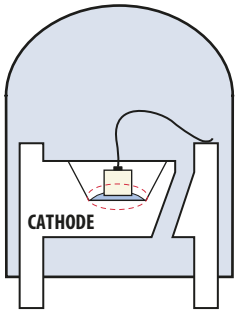
- Set and maintain wave soldering parameters according to the recommended temperature and dwell time. Perform daily checks on the soldering profile to ensure that it conforms to the recommended soldering conditions.

**NOTE:**

1. PCBs with different sizes and designs (component density) will have different heat mass (heat capacity). This might cause a change in temperature experienced by the board if the same wave soldering setting is used. Therefore, recalibrate the soldering profile again before loading a new type of PCB.
2. Broadcom's AlInGaP high-brightness LEDs use a high-efficiency LED die with a single wire bond as shown below. Take extra precautions during wave soldering to ensure that the maximum wave temperature does not exceed 250°C and the solder contact time does not exceed 3s. Overstressing the LED during the soldering process might cause premature failure to the LED due to delamination.

## Broadcom LED Configuration

**Figure 11: LED Configuration**




**NOTE:** Electrical connection between the bottom surface of the LED die and the lead frame is achieved through conductive paste.

- Loosely fit any alignment fixture that is being applied during wave soldering and do not apply weight or force on the LED. Use nonmetal material because it absorbs less heat during the wave soldering process.
- At elevated temperatures, the LED is more susceptible to mechanical stress. Therefore, allow the PCB to cool down to room temperature prior to handling, which includes removal of alignment fixture or pallet.

- If the PCB board contains both through hole (TH) LED and other surface-mount components, solder the surface-mount components on the top side of the PCB. If the surface mount must be on the bottom side, solder these components using reflow soldering prior to the insertion of the TH LED.
- The following table shows the recommended PC board plated through holes (PTH) size for LED component leads.

| LED Component Lead Size | Diagonal | Plated Through Hole Diameter |
|---|---|---|
| 0.45 mm × 0.45 mm (0.018 in. × 0.018 in.) | 0.636 mm (0.025 in.) | 0.98 mm to 1.08 mm (0.039 in. to 0.043 in.) |
| 0.50 mm × 0.50 mm (0.020 in. × 0.020 in.) | 0.707 mm (0.028 in.) | 1.05 mm to 1.15 mm (0.041 in. to 0.045 in.) |

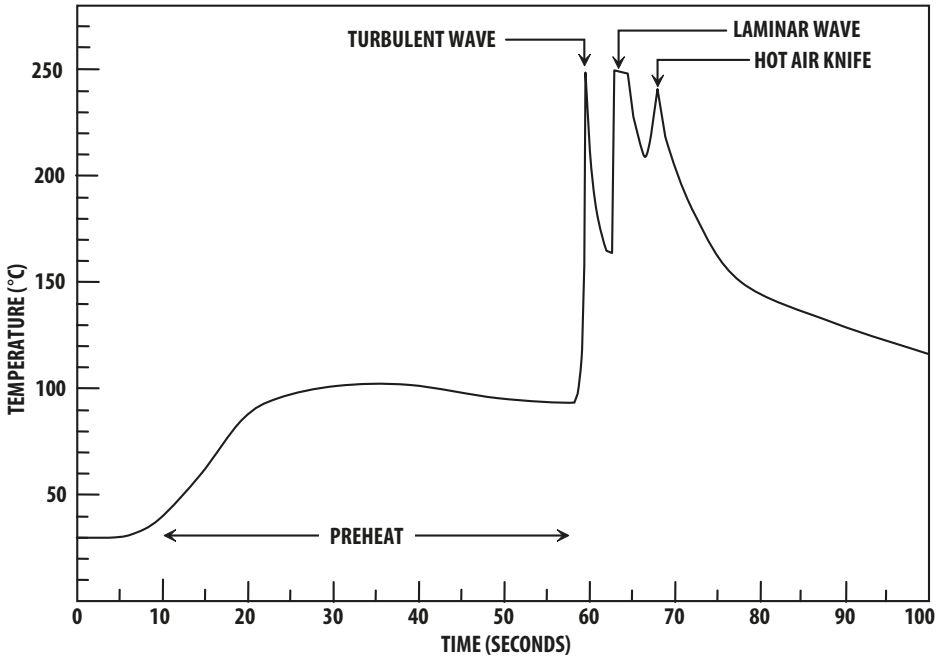
- Over-sizing the PTH can lead to a twisted LED after clinching. On the other hand, under-sizing the PTH can cause difficulty when inserting the TH LED.

**NOTE:** Refer to application note AN-5334 for more information about soldering and handling high-brightness TH LED lamps.

# Application Precautions

- The drive current of the LED must not exceed the maximum allowable limit across temperature as stated in the data sheet. Constant current driving is recommended to ensure consistent performance.
- LEDs exhibit slightly different characteristics at different drive currents that might result in larger performance variations (such as intensity, wavelength, and forward voltage). Set the application current as close as possible to the test current to minimize these variations.
- The LED is not intended for reverse bias. Use other appropriate components for such purposes. When driving the LED in matrix form, ensure that the reverse bias voltage does not exceed the allowable limit of the LED.

**Figure 12: Example of Wave Soldering Temperature Profile for TH LED**




**Recommended solder:**
**Sn63 (Leaded solder alloy)**
**SAC305 (Lead free solder alloy)**

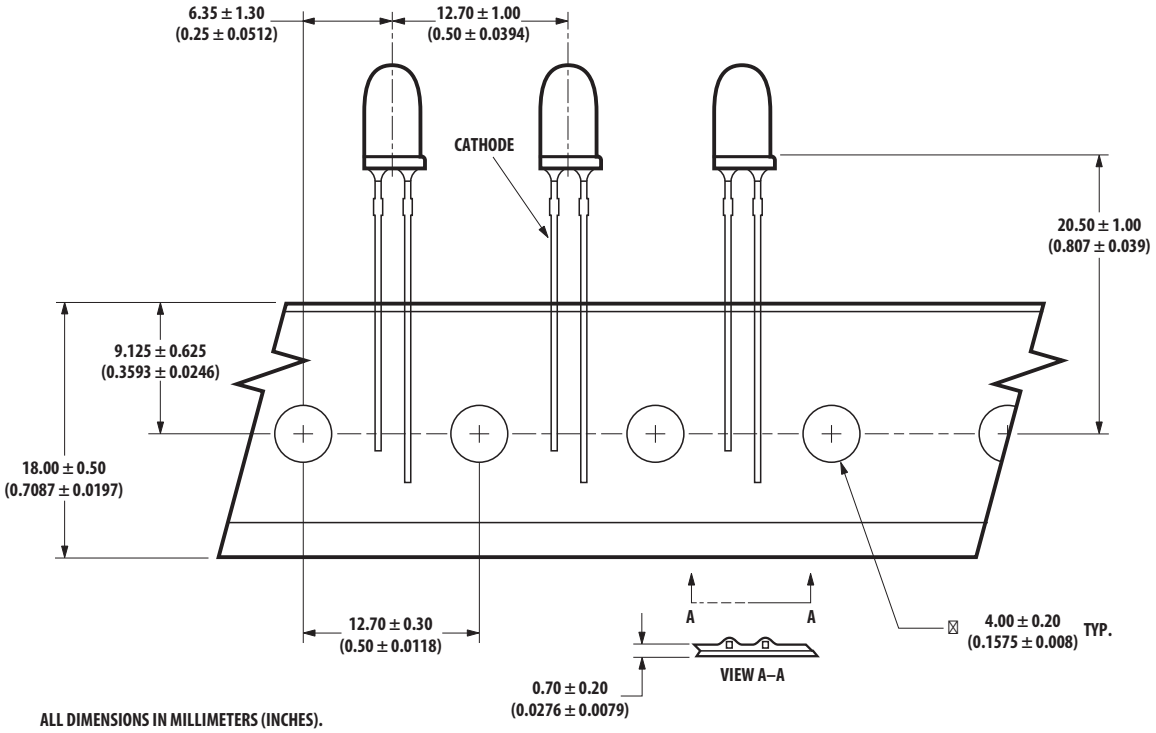
**Flux: Rosin flux**

**Solder bath temperature:**
**245°C± 5°C (maximum peak temperature = 250°C)**

**Dwell time: 1.5 sec - 3.0 sec (maximum = 3sec)**

**Note: Allow for board to be sufficiently cooled to room temperature before exerting mechanical force.**

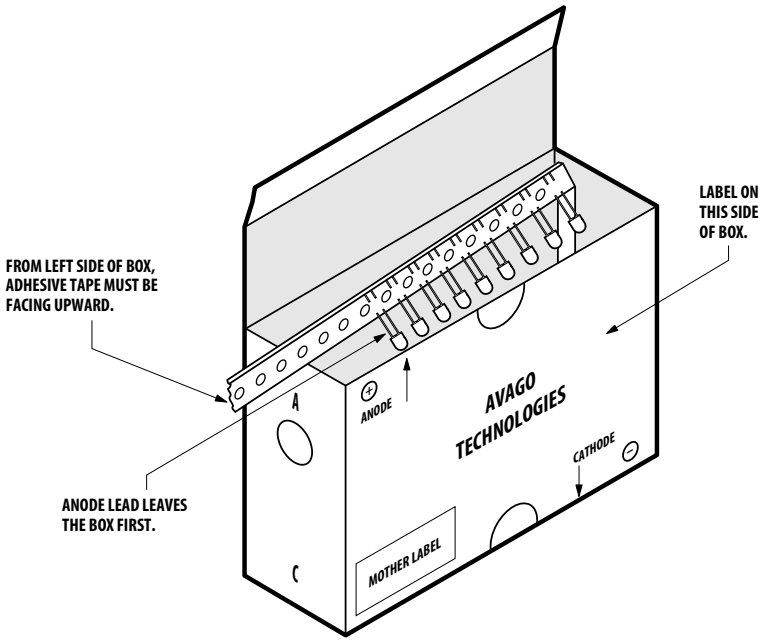
**Figure 13: Ammo Pack Drawing**




ALL DIMENSIONS IN MILLIMETERS (INCHES).

NOTE: THE AMMO-PACKS DRAWING IS APPLICABLE FOR PACKAGING OPTION -DD & -ZZ AND REGARDLESS OF STANDOFF OR NON-STANDOFF.

**Figure 14: Packaging Box for Ammo Packs**

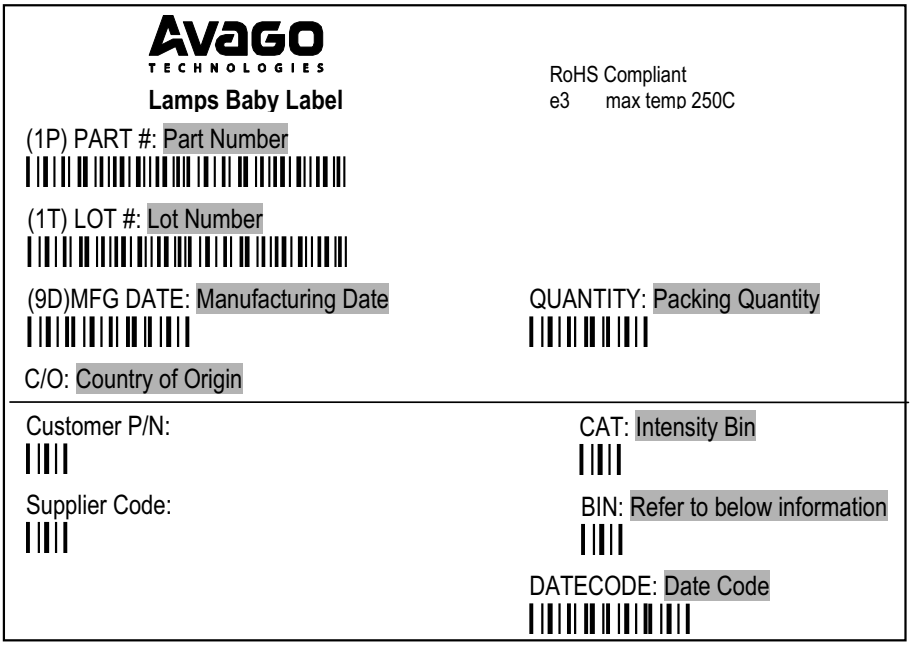



NOTE:
THE DIMENSION FOR AMMO PACK IS APPLICABLE FOR THE DEVICE WITH STANDOFF AND WITHOUT STANDOFF.

# Packaging Label

**Figure 15: Mother Label (Available on packaging box of ammo pack and shipping box)**

**Figure 16: Baby Label (Only available on bulk packaging)**



# Acronyms and Definitions

BIN:

- (i) Color bin only or $V_F$ bin only

  Applicable for part number with color bins but without $V_F$ bin OR part number with $V_F$ bins and no color bin

  OR
- (ii) Color bin incorporated with $V_F$ Bin

  Applicable for part number that have both color bin and $V_F$ bin

Example:

- (i) Color bin only or $V_F$ bin only
  - BIN: 2 (represent color bin 2 only)
  - BIN: VB (represent $V_F$ bin “VB” only)
- (ii) Color bin incorporate with $V_F$ Bin
  - BIN: 2VB, where:
    - 2 is color bin 2 only
    - VB is $V_F$ bin "VB"

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Адрес: 105318, г.Москва, ул.Щербаковская д.3, офис 1107

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**Офис по работе с юридическими лицами:**

105318, г.Москва, ул.Щербаковская д.3, офис 1107, 1118, ДЦ «Щербаковский»

Телефон: +7 495 668-12-70 (многоканальный)

Факс: +7 495 668-12-70 (доб.304)

E-mail: info@moschip.ru

Skype отдела продаж:
moschip.ru
moschip.ru_4
moschip.ru_6
moschip.ru_9