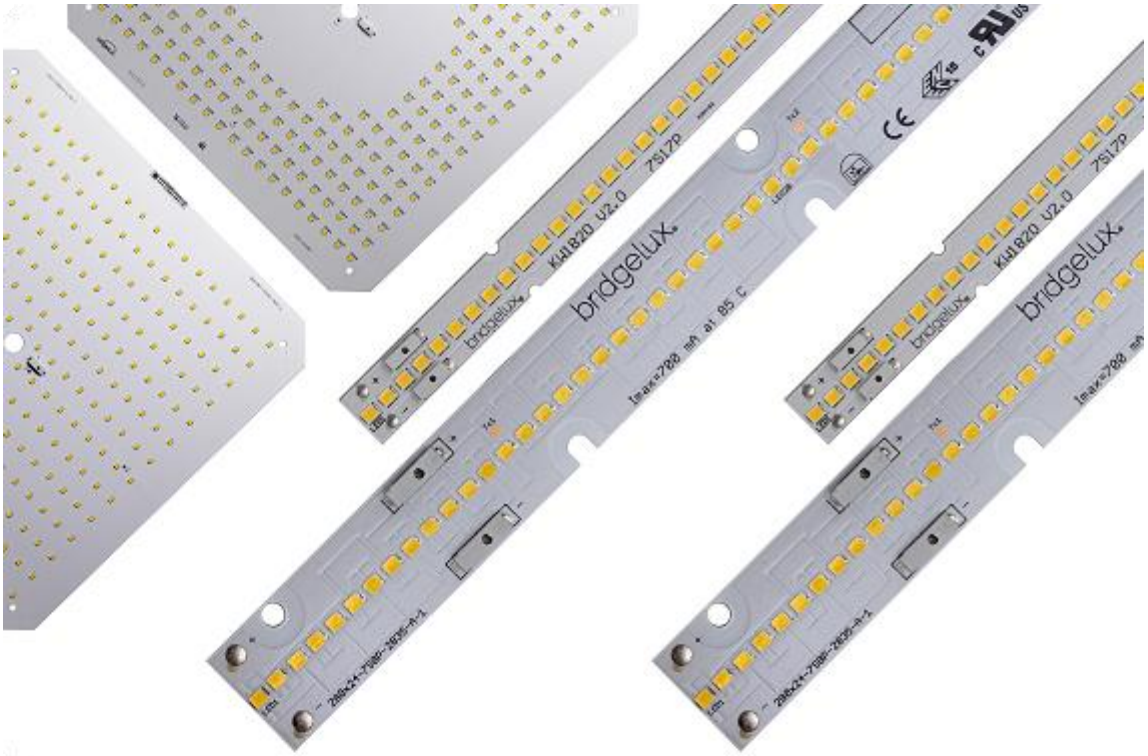
Introduction

The purpose of this document is to provide useful and important guidance to ensure the best outcomes using Bridgelux EB Series Linear, EB Series Square, Vesta Linear, and Vesta Edge modules. The target audience for this Application Note is designers, engineers, and specifiers who contribute to the success of a product's design and launch. This document is principally focused on:

- Choosing the correct product for the specified application
- Product Design Considerations – Electrical Wiring
- Product Design Considerations – Thermal Management
- ESD Prevention
- Handling
- Installation and Protection
- Chemical Compatibility



This Application Note covers a number of products of sizes and shapes, from one foot, static white EB linear modules, to two-foot Vesta linear tunable whites, to high lumen Square modules. While the products are different, their applications and design in processes are similar enough to include them into one document.

Bridgelux provides a number of other documents to help with auxiliary topics such as chemical compatibility tables, general guidance on electrical principles, and more. Bridgelux is always adding to and improving these products, and also has 3D models, instructional videos, and more linked at www.bridgelux.com.

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About the Bridgelux Module Series Families of Product

This application note covers a few different types of product families, including square shape modules, and linear modules (Figure 1). Of those linear modules, the color choices are either static white or dynamic white products. The commonalities of these families of products are that they have various arrays of Surface Mounted Devices (SMDs) on engineered substrates, which in its totality is a UL 8750 recognized component that we call a Module. In the case for all three of these product lines - these are easy to use, easy to install, plug-and-play types of products with more similarities than differences.

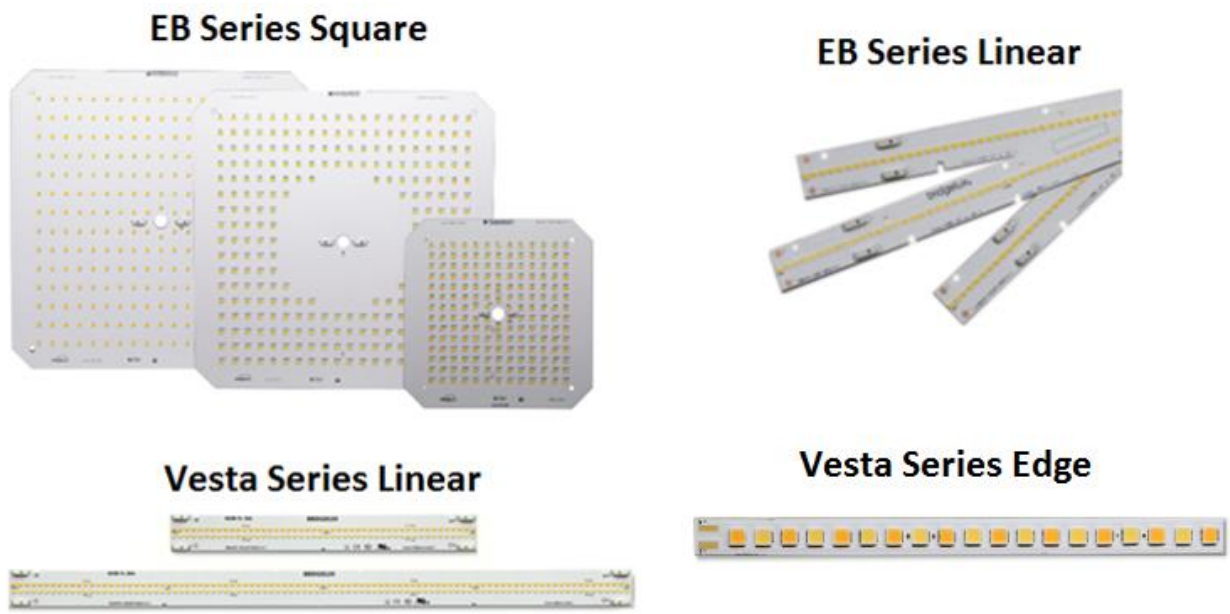


Figure 1: Four Series of Bridgelux Modules

There is an easy process to follow to determine which product is most suitable despite the similarities. This step-by-step process can help with not only the product selection, but also the overall luminaire product and retrofit kit design. We will go through that process in our Examples Section, but first we will begin with the higher level options that differentiate the various product families and products within them. The available options, other than lumen range, of the products described within are:

- Color Options – Static and Dynamic
- Shape options – Linear and Area

Inside each of those products are further options:

- Static white options
  - Voltage and Current ranges
  - CCT and CRI combinations

- Dynamic White options
  - Tuning range and CRI combinations
  - Single and Double Rows of SMDs

- Current and Power limitations

- Linear Options
  - EB Series of static white or Vesta Linear dynamic white
  - Length options between 280mm and 1190mm for standard products
  - EB Modules also available in width options, with a Slim option
  - Voltage, current and power options

- Square options
  - Overall size and lumen options
  - Voltage and current options
  - Center beam candle power option on large squares

Choosing the Correct Product for the Specified Application

When selecting a product, it is important to start with the end in mind at the beginning. This means understanding the final luminaire requirement before zeroing in on a final solution. This process requires understanding all aspects of a product's components, assemblies, costs, and the mosaic of decisions that are intertwined and co-dependent. The process tends to be iterative.

This section is focused on the highest level specifications of design performance, and the choices that product designers have to make prior to any prototype being produced. If you are familiar with how to estimate top level performance, including non-LED related losses from housing and driver and the like you can skip to the Product Design Considerations – Electrical Wiring Section and proceed from there.

One major issue in the LED market is understanding (or the confusion surrounding) the difference between the efficacy of the LED and the efficiency of the Luminaire that uses those LEDs.

Efficacy is the absolute physical ratio limit of energy conversion from electrical power to visible light in a given state. For the LED the input is power in wattage, the output is the power of the visible radiation, or human weighted radiation, also known as lumens. The efficacy, therefore, is given in lumens per Watt or LPW. The system is defined at the housing of the LED including phosphors and electrical connections. Efficacies of LEDs can be achieved up to the 200 lumen per watt range. LEDs, COBs, and Modules are typically evaluated at this stage. Items that change efficacies of various emitters are things like color point, case temperature, CRI, current and voltage among other things.

Efficiencies are the dimensionless ratios of the inputs and outputs, normally given as a percentage (%). For example, if light reflects off of a mirror then the ratio of the reflected light to the incident light would be the efficiency of the mirror, say 95%. Similarly, the power supply of a luminaire takes a certain amount of power on the input side as AC power and converts it to constant current DC power to drive the lighting circuitry; the ratio of output to the input is the efficiency of the power supply. Efficiencies can change based on things like quality, load percentage of rated maximum, input voltage, and temperature. Importantly, efficiencies can be improved to a certain extent.

The movement from the efficacy of the LED or COB or module to the overall efficacy of the system is done by applying the various efficiencies of each variable in the entire system. For example, you would calculate the overall efficiency of the systems by multiplying the various components, then applying that efficiency to the LED performance for the overall efficacy of the system at that given state. Once the efficiencies are applied to the overall system, efficacies in the 130 LPW and greater range can be achieved.

Efficiencies and Losses Add Up – Drivers, Optics, Thermals, and Housings

When designing a luminaire, it is important to know which stage of performance the product is truly specified: at the LED level or the system level? Is the specification truly the LED efficacy or is it specified after the system level efficiency are accounted for? For example, a specification of 135 LPW at the efficacy of the LED stage might be simple enough, but even with a source efficacy of 155 LPW, a system level efficiency of 80% may be insufficient to reach 135LPW.

The calculation from LED efficacy to system level efficacy may include the following performance ranges:

- Thermal losses, from excessive heat that lower initial efficacy (0-10%)
- Optical efficiency, from reflectors and lenses (67-92%)
- Housing efficiency, from other components and interactions unique to the design (67-98%)
- Driver efficiency in terms of AC/DC conversion (80.0% - 94.5%)
- Other variables' efficiencies and/or losses

It is always a good practice to start from a worst case scenario and work out a way to an improved product. The design process is inherently repetitive, cyclical, or even described visually as a spiral: as the iterations increase, the design is dialed in to center on the final conclusion. And the design process has to be that way: with many free variables available to designers, the choice of variable such as efficiency of the driver can help to inform the minimum efficiency and performance of other aspects of the luminaire design. A high performing driver may afford for more modest performance elsewhere. As such, as more than one variable is dialed in to its final choice, all of the other variables can be finalized through subsequent iterations.

When using the lowest cost components, metals, paints, power supplies, and the like, you can make a low cost, but likely a low performing product. When using more expensive types of materials a more premium product can be produced, and hence premium performance can be achieved. Performance in lighting has in the past been viewed qualitatively, but the quantitative aspects of lighting are how we can leave aesthetic bias out of the evaluation and design on performance metrics, the primary quantification being lumens per Watt (LPW). We will show how understanding the various efficacies and efficiencies can help to choose the right product for the right situation by walking through three examples. In our examples, we make some basic assumptions about the various efficiencies, read the datasheets, and use some external compliance sources to create different levels of quantifiable performance. Specifically, we will use Energy Star rating and the two different DLC ratings as our guideposts (Standard and Premium) (Table 1). In each example we will show a simple five question method to help in selecting the correct product.

Bridgelux is not affiliated with Energy Star or DLC or their standards and use them only as reference.

Table 1: Different levels of efficiency by category type

System Efficiency	50 LPW - Energy Star	105 LPW – DLC Standard	135 LPW – DLC Premium (Top 5%)
Lower Bound	>50	>105	>135
Upper Bound	-	<135	-

Example #1 – Small Parking Garage Light

Typical parking garage lights require shoebox style mounting since the ceiling (and floors) tends to be concrete, with low hanging and visible optics to light large areas with low ceilings. Incumbents have used omnidirectional bulbs such as CMH for their long life and energy savings. Small sized versions of these lights are less than 12" on a side, and have a batwing radiation pattern. DLC performance levels are currently at 105 LPW and 120 LPW as Standard and Premium for low-output outdoor devices, with a minimum of 2,000 lumens. Static white, motion sensor (PIR) dimming control, neutral color point and 65 CRI are minimum viable options in our scenario.

Which Bridgelux module products are most suitable?

In this example, our options are quite simple. If it were more complicated, the method product designers can use to find the most suitable product can follow as:

1. What type of white light is required? Static or dynamic? CCT/CRI Combination?
2. What shape is the intended product and what dimensions are limiting?
3. What is the total lumen requirement?
4. How is the electrical system defined? Driver, dimmer, and voltage class?
5. What are your system efficiencies? Or if unknown, what do they need to be?

By following along on this punch list, we can say that we need a static white, small square shaped layout to start. That already reduces the options to the BXEB-SQ0182-xxE4000-C-B3 product (Figure 2)!

While we know which product to choose, our example isn't finished. We can use this selected variable to inform us about the rest of the system by using the datasheet for the Square Module, along with assumptions (or datasheets from other manufactures), on performance metrics such as the driver, optics, and paint efficiencies.

Based on our datasheet, we can see that we need a constant current power supply, with 700mA current at 36.7VDC (Table 2). We can make some basic assumptions about the quality of the ingredients we will use based on the desired final level outcome we specify.

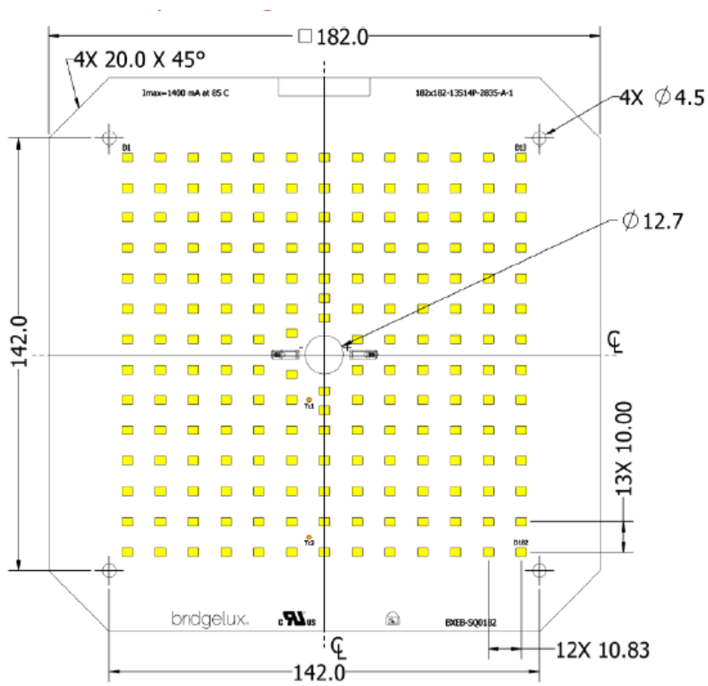


Figure 2: Small EB Series Square module, ideal for the small parking garage light

Table 2: Typical product performance from DS180 Rev A

Part Number	Nominal CCT[1] (K)	Min CRI	Typical Flux[2,3] T_c = 25° C (lm)	Nominal Drive Current (mA)	Typical V_f (V)	Typical Power (W)	Typical Efficacy (lm/W)
BXEB-SQ0182-40E4000-C-B3	4000	80	4450	700	36.7	25.7	173
BXEB-SQ0182-50E4000-C-B3	5000						

If we are targeting a DLC Standard listing, with 105 LPW product at the nominal drive current, achieving over 2,000 total lumens, we can make some assumptions about the physical properties of the remaining variables, and we perform the following calculations to determine more completely the final product specifications.

- Assume 10% thermal losses: 4450 lumens x 90% = 4,005 lumens
- Assume 75% transmission on the optical system (reflector and glass lens): 4,005 lumens x 75% = 3,004 lumens
- The maximum power for 105 LPW and 3,004 lumens = 28.6W
- The power supply efficiency we need is then: 25.7/28.6 = 89.8%

In order to meet the requirements of size, light quality and performance, we selected the smallest square option in the 4000K, 80 CRI. By starting with nominal performance, we are able to calculate the efficiency level of an as of yet unspecified power supply/ driver. While 89.8% is high, it is achievable for a cost, thus confirming that the DLC Standard product deserves its rightful designation in the top of all performing products, even as a Standard product.

Example #2 – Under Cabinet Home Kitchen Light

Cabinets are notoriously made to fit the kitchen they are installed in, and rarely are the kitchen dimensions chosen to satisfy the cabinet maker. As such, Under Cabinet Lighting designers are opting for smaller modular options that can fit under cabinets from 14” wide to 42” wide with a variety of brightness and CCT choices, including color tuning for enhanced living experiences. Energy Star guidance on Under Cabinet Solid State Lighting suggests modest requirements: efficiencies of 50 LPW, 125 lumens per foot, 80 CRI, and at least one of the ANSI CCT bins between 2700-5000K as acceptable color points, among other easy to satisfy residential requirements.

Which Bridgelux module products are most suitable?

Recalling the advice from the previous example, if we follow this simple punch list of questions, we can arrive at our most suitable Bridgelux product:

1. What type of white light is required? Static or dynamic? CCT/CRI Combination?
2. What shape is the intended product and what dimensions are limiting?
3. What is the total lumen requirement?
4. How is the electrical system defined? Driver, dimmer, and voltage class?
5. What are your system efficiencies? Or if unknown, what do they need to be?

In this example we want a dynamic white choice, so we are going to use the Vesta Linear products. We need a short length, as the modules are going to be able to fit under 14” cabinets. The total lumen output is relatively low, so of the two options we have left, we should explore the lowest powered version first. This version is the “Single Row” Vesta Linear (Table 3), as opposed to the “Double Row”. The single row version uses only half the LEDs and slightly more than half of the power of the Double Row version.

Table 3: Typical performance data for single row Vesta Linear 1ft

<table>
<tr><th>Product (LED Configuration)</th><th>Dimensions</th><th>CCT Tuning Range</th><th>CRI</th><th>Typical Flux (lm)</th><th>Nominal Drive Current (mA)</th><th>Typical Forward Voltage (V)</th><th>Typical Power (W)</th><th>Typical Efficacy (lm/W)</th><th>SDCM</th></tr>
<tr><td rowspan="8">Linear (1 Row)</td><td rowspan="8">280mm x 24mm</td><td>2700K-5000K</td><td rowspan="2">80</td><td>1320</td><td rowspan="8">375</td><td rowspan="6">19.9</td><td rowspan="6">7.5</td><td>177</td><td rowspan="8">3</td></tr>
<tr><td>2700K-6500K</td><td>1285</td><td>172</td></tr>
<tr><td>1800K-3000K</td><td rowspan="4">90</td><td>1045</td><td>140</td></tr>
<tr><td>1800K-4000K</td><td>1115</td><td>149</td></tr>
<tr><td>2700K-5000K</td><td>1115</td><td>149</td></tr>
<tr><td>2700K-6500K</td><td>1100</td><td>147</td></tr>
<tr><td>2700K-5000K</td><td rowspan="2">Thrive (97)</td><td>1000</td><td rowspan="2">20.4</td><td rowspan="2">7.7</td><td>131</td></tr>
<tr><td>2700K-6500K</td><td>1000</td><td>131</td></tr>
</table>

If we are targeting an Energy Star Product, 50 LPW products at the nominal drive current, achieving over 125 total lumens per foot, the method for determining the physical properties of the remaining variables, we perform the following calculations.

- Assume 10% thermal losses: 1320 lumens x 90% = 1,188 lumens
- Assume 75% transmission on the optical system (reflector and glass lens): 1,188 lumens x 75% = 891 lumens
- The maximum power for 50 LPW and 891 lumens = 17.82W

- The power supply efficiency we need is then: 7.5W/17.82W = 42.1%

In this example, we can easily find small power supplies that operate at efficiency greater than needed. Since the requirements are met so easily, we can entertain the idea of saving money or increasing the scope of the product. We might change the product to the Bridgelux Thrive® ultra-premium circadian products, or increase diffusion of our lens for softer shadows, or simply modify the reflectors to use aluminum instead of chrome plating. Alternatively, we could lower the current and therefore power, saving costs on lower powered and smaller drivers while saving money in operating costs. We could make any number of the mentioned trade-offs, allow for cost savings, all while still making an Energy Star approved product.

Example #3 – High Bay Light 8ft Length, Very High Output for Very High Ceilings

Assembling large and complex machines, such as airplanes or helicopters, requires both a lot of space and a lot of light. The large parts and ultra-high level of precision required for the assembly requires special lights. In this scenario, large lights with very high lumen output are required. Besides the financial benefit of qualifying for DLC approved rebates, the factories in this example tend to operate in multiple shifts, sometimes 24 hours a day, and thus need the utmost energy efficiency to save on operating costs. Couple those factors with the relatively extreme ceiling height and the maintenance costs are also a significant consideration: so a long life is a must. A Premium product, it seems, is a must. DLC Premium requires over 135 LPW, and in our example at least 20,000 lumens +/-5%.

Which Bridgelux module products are most suitable?

Recalling the advice from the previous examples, if we follow this simple punch list of questions, we can arrive at our most suitable Bridgelux product:

1. What type of white light is required? Static or dynamic? CCT/CRI Combination?
2. What shape is the intended product and what dimensions are limiting?
3. What is the total lumen requirement?
4. How is the electrical system defined? Driver, dimmer, and voltage class?
5. What are your system efficiencies? Or if unknown, what do they need to be?

In our example, we need a series of long length modules where static white is acceptable. This points us to the four-foot EB Series Linear modules. Since we know we need high efficiency, we will start with 5,000K 80CRI options, driven nominally, and move on with our analysis from there (Table 4).

On first look, we can see that we need at least four such modules. The lights do not necessarily need optics or covers so they can tend to be open and not trap hot air. In these types of products, driving the modules at nominal drive current does not have the same thermal losses as possible in other scenarios. Plus when used, the reflectors are highly efficient. We will follow the same method as our other two examples and find out what we need to have in terms of power supply requirements.

Table 4: Typical product performance at 25C from DS132 Rev A

BXEB-L1120Z-27E4000-C-C3	2700	80	4760	700	38.3	26.8	178
BXEB-L1120Z-27G4000-C-C3		90	4160				155
BXEB-L1120Z-30E4000-C-C3	3000	80	4980				186
BXEB-L1120Z-30G4000-C-C3		90	4390				164
BXEB-L1120Z-35E4000-C-C3	3500	80	4980				186
BXEB-L1120Z-35G4000-C-C3		90	4390				164
BXEB-L1120Z-40E4000-C-C3	4000	80	5350				200
BXEB-L1120Z-40G4000-C-C3		90	4390				164
BXEB-L1120Z-50E4000-C-C3	5000	80	5350				200
BXEB-L1120Z-50G4000-C-C3		90	4390				164
BXEB-L1120Z-57E4000-C-C3	5700	80	5350				200
BXEB-L1120Z-57G4000-C-C3		90	4390				164

- Assume 5% thermal losses: 21,400 lumens x 95% = 20,330 lumens
- Assume 98% reflectance on the optical system (highly reflective and no lens or cover): 20,330 lumens x 98% = 19,923 lumens
- The maximum power for 135 LPW and 19,923 lumens = 147.6W
- The power supply efficiency we need is then: 107.2/147.6 = 72.6%

We are in good shape to have a successful design again in this case. If we need to push for more lumens to meet the 20k level, that is possible. If we needed to save money on less efficient reflectors, we can increase the initial lumens, and still have a fairly easy time finding a more efficient power supply at a low cost.

About the Examples

These examples were selected because they are easy to understand. They use nominal drive currents, well known standards, conservative estimates of performance, and simple multiples of products that can be easily understood. They were also selected specifically to reduce the number of correct solutions available. For example, the size limitations and color options in the first two examples left only one option that needed only one piece in either example (#1, #2). In the final example, there is one clear choice that needs only 4 total pieces to meet the requirement, and not some odd or prime number such as 3, 5 or 7.

In real life though, where design considerations dictate profit, performance, and power consumption, many options may present themselves as potential fits. You can even imagine wanting to push the products shown in Example #3 to use only 2 pieces. Conversely, a product design requirement may seem impossible, like achieving an unprecedented lumen per watt level. Should those scenarios arise, and the solution is not obvious to you, please contact your local distributor, or Bridgelux Salesperson for assistance.

Product Design Considerations – Electrical Wiring

To achieve optimal performance of the modules, proper electronic drivers must be selected or designed. A key feature of the Bridgelux Linear Modules are the wide range of current drive capabilities of each product family, making it possible for LED lighting designers to create luminaires that are scalable in power output to meet different application needs, while keeping the overall mechanical and optical design unchanged. This feature also enables luminaire manufacturers to keep the design and manufacturing cost low.

This section of the application note will assist designers in selecting or developing electronic drivers for use with Bridgelux Linear Modules. The first step is to become familiar with relevant electrical characteristics of the modules. This includes the relationship between forward voltage and current, and the relationship between light output (luminous flux) and current.

The second step is to define LED driver requirements, usually specific to the given application. Design considerations include defining the driver's input voltage (e.g., AC line voltage input, a combination of AC-DC and DC-DC drivers, or DC input from batteries), defining an optimal driver output current, establishing dimming requirements, and determining both temperature and lifetime requirements to satisfy the needs of the application. This section of the application note provides general guidelines to the designer to assist in enabling a successful design.

Once the correct product is identified, as we showed through three examples in the previous section, we need to be more precise about the power supply choice or driver considerations, as well as the electrical wiring considerations such as by choosing parallel or series or hybrid circuitry. This is not needed when designs call for one-to-one driver to module, but when more than one module is required the choice must be made. The follow section outlines the various ways that multiple modules can be wired together.

Multiple Module Circuit Design Recommendations

For some luminaire designs, multiple modules driven at the same forward current may be incorporated. For these designs, Bridgelux provides the following recommendations:

1. When using a single LED driver with a single constant current output channel, connect the modules in series to complete the electrical circuit (Figure 3). This arrangement ensures that all modules will be operated at the same current.

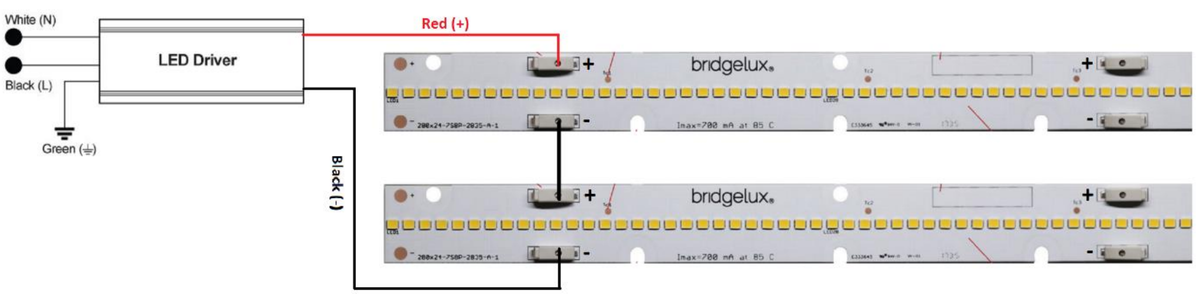


Figure 3: Showing Two EB Series modules in Series Configuration

2. LED drivers are also available which have multiple output channels. If a driver with multiple constant current output channels is selected, the number of channels needs to be sufficient to drive all of the modules. While similar to dual channel drivers, this version is not intended to operate as a tunable white system. See the following section for more details on tunable white drivers.

3. A combination of the two configurations above can also be applied. Modules can be connected in multiple series strings from a multi-channel LED driver, allowing for an increased quantity of modules to be powered from a single driver.
4. If the application requires multiple modules to be connected in a parallel configuration, such as the one shown in Figure 4 below, Bridgelux recommends using modules with the same forward voltage +/-0.5V.

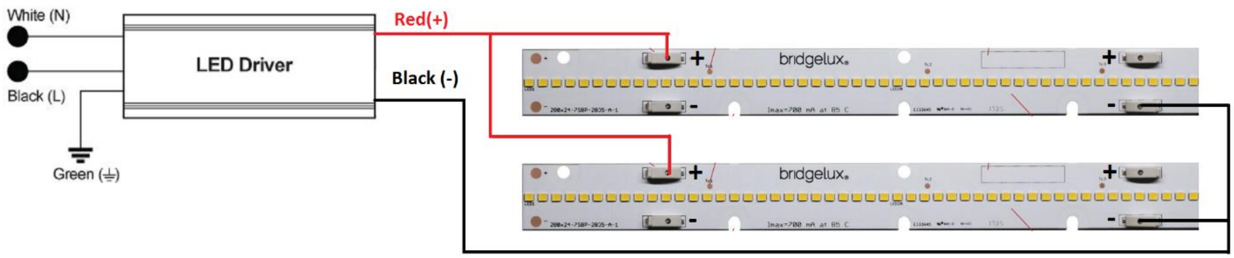


Figure 4: Two EB Series modules in Parallel Configuration

If the application requires multiple Vesta EB modules to be connected in parallel configuration, such as the one shown in Figure 5, Bridgelux recommends using the Vesta® Flex LED driver.

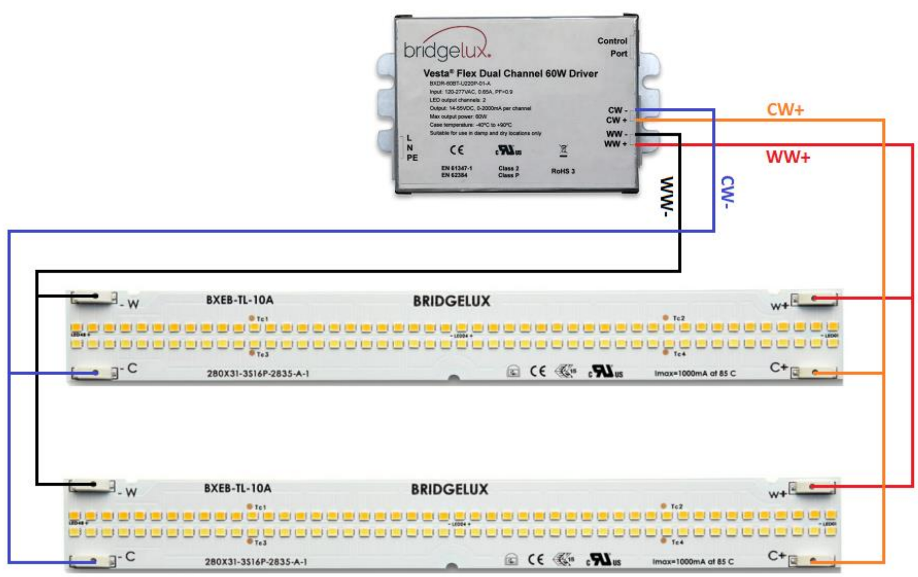


Figure 5: Vesta Tunable White modules in parallel configuration on Bridgelux's Vesta® Flex driver.

Variation in the forward voltage of the individual module can result in current hogging, where a lower total Vf module may see a higher forward current compared to a higher Vf module connected in parallel. This may produce non-uniform flux and color, and may affect the reliability of the lighting system.

Checking the voltage of modules intended to be installed in parallel can aid in avoiding current hogging. If that step is not followed, a visual inspection is the minimum quality assurance step: if the modules are noticeably different the voltages are likely different by more than 0.5V.

Further to checking the voltage difference, to minimize the magnitude of current hogging by the modules in a parallel circuit, Bridgelux suggests that the following conditions be met:

1. All modules are strongly recommended to be on the same heatsink to ensure that the current through the individual modules do not diverge as a result of differences in the module case temperatures. If there are sources of heat generation, such as power supply or a driver, these should be located away from the modules to ensure that the case temperatures of the individual modules in the circuit remain within 10 degrees of each other during operation.
2. The maximum module case temperature of any reference point in the circuit should not exceed 85°C.
3. The current through the modules should not exceed 2.43X the nominal drive current specified in the appropriate datasheet.
4. In order to maintain the appropriate levels of voltage and current, a hybrid series of modules can be created as in Figure 6.

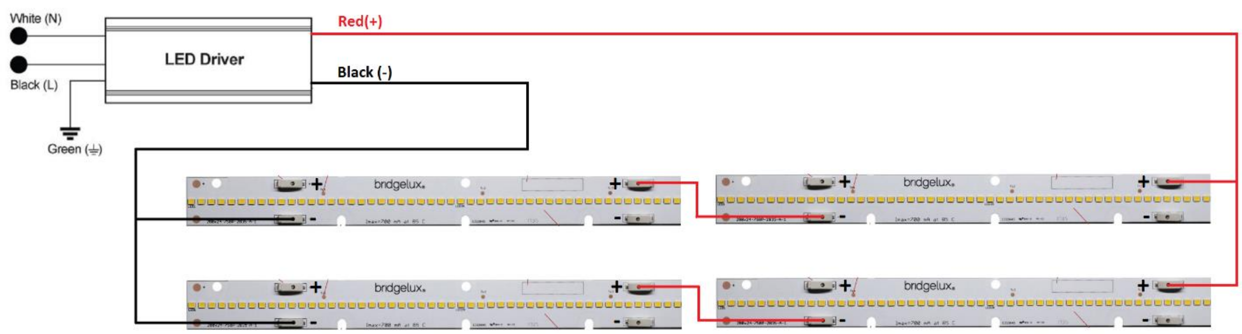


Figure 6: Showing two sets of two EB Series modules in Series Configuration, in parallel.

For best results, maintain ***the module case temperature as low as possible***, minimize the number of modules that are placed in a parallel circuit and minimize the average current through each module.

The power supply and the dimming control units need to be selected with the proper wiring configurations in mind. In series examples, the voltage of the modules at a rated current are additive. In parallel configurations, the current is additive. And in hybrid scenarios, they both are.

By using proper circuit analysis, Figure 6 can aid in finding a suitable driver from a suitable company. Table 5 shows the number of channels required for various products, the typical and maximum ratings per those channels. After calculating for the needed voltage and current, the companies listed in the reference section can be used to find a suitable driver.

Table 5: Table of nominal and maximum driving current (subject to change, see website)

Product Family	Nominal Length (mm)	Number of Channels	Typical Voltages (V)	Typical Current per Channel (mA)	Maximum Current Per Channel (mA)	Maximum Total Current (mA)
EB Series	280	1	19.1	350	700	700
	560	1	19.1	700	1400	1400
	1120	1	38.3	700	1400	1400
Slim Series	340	1	10.9	700	1700	1700
	590	1	19.1	700	1700	1700
	1190	1	38.2	700	1700	1700
VESTA Linear (1-row)	280	2	19.9	375	750	750
	560	2	19.9	750	1500	1500
	1120	2	39.8	750	1500	1500
VESTA Linear (2-row)	280	2	19.3	500	1000	1000
	560	2	19.3	1000	2000	2000
	1120	2	38.6	1000	2000	2000
Square	186	1	36.7	700	1400	1400
	286 - C	1	53.6	700	1400	1400
	287 - D	1	39.5	700	1400	1400
	286 - E	1	39.5	950	1900	1900
Vesta Edge	570	2	34.6	600	1200	1200

Driving and Dimming

The selection of a suitable electronic driver is critical to achieve optimal performance from all Bridgelux modular products.

General Driver Recommendations

LED drivers convert available input power into the required output current and voltage, and are analogous to ballasts used with fluorescent and other conventional light sources. When selecting a driver for use with a Bridgelux Module, follow these basic guidelines:

- Drive the products using constant current sources, not constant voltage sources.
- Do not apply a reverse voltage to the modules.
- UL max voltage rating requirements might limit total number of modules that may be placed in series. Consult with UL and Bridgelux sales representatives for details.
- When selecting a driver, please ensure that the current does not exceed the Absolute Maximum Rating noted in the product data sheet.

Driver Selection

A driver should be selected to enable operation over the entire voltage range of the selected modules in its intended real world applications. The typical voltage for each module is included in the performance tables in the various datasheets. These tables include sufficient guard band to account for voltage binning and temperature differences so no calculations are needed to determine the module voltage range for driver selection. Refer to sections titled “Electrical Characteristics” and “Driver Selection Voltages” in the datasheets.

It is the responsibility of the designer to ensure that the selected LED driver meets all local regulatory requirements. We also recommend consideration of the following specifications when selecting or designing an LED driver.

- Power factors greater than 0.9 are recommended.
- Design or select drivers that are highly efficient over the range of loads expected in the lighting system.
- The expected life of the LED driver should match that of the lighting system.
- Ensure compliance to all regulatory and approbation requirements.
- Some applications may benefit, or require, LED drivers that include active feedback.
- Ripple is the small and unwanted residual periodic variation of the direct current output of an AC to DC LED driver. Ripple values that are less than ± 10% are recommended.
- Specify an LED driver with low noise to avoid interference and/or violation of regulated standards.
- Carefully consider the type of dimming technology that is used to ensure application needs are met

Dimmer Selection

Dimming is the action of reducing the light output of the module below its normal operating level. It may be done with the intention of energy savings, or just to create an ambiance or a more appropriate lighting level for the task at hand. The dimming effect is usually specified as a percentage of full driver output. This is also one of the first areas of confusion, because the percentage of dimming is expressed by the driver manufacturer as a percentage of ELECTRICAL output. The end customer is usually concerned about dimming to a percentage of LIGHT output.

The light produced by a LED is proportional to the current flowing through the LED. However, that relationship is not linear. The light produced is also a function of LED junction temperature, and as the drive current is reduced, the junction temperature will drop (assuming that the thermal solution remains unchanged), adding additional non-linearity to the dimming characteristic and range. The two considerations from a specification standpoint that should be kept in mind for dimming are the range or depth of dimming, and the linearity or dimming curve.

From a driver perspective, there are two aspects regarding dimming that should be distinguished and clarified:

1. The dimming control signal is an input to the driver, and
2. The actual technology employed to achieve the dimming effect which is the output from the driver.

Commonly used dimming control driver input signaling methods include 0-10V (analog), Phase-cut (TRIAC or ELV), PWM, DALI control, and many other signaling methods. Regardless of the method used, the result is the same – the desired level of output is communicated to the driver.

Commonly used technology to control the drive current to the LED for dimming are based on two approaches – analog or Pulse Width Modulated (PWM). In analog dimming, the output current of the driver is reduced to the percentage of full level as requested by the dimming control signal. This is illustrated in Figure 7. Since the current through the LED is reduced, the luminous flux produced by the LED is also reduced and dimming is achieved. Analog technology can be used to dim Bridgelux Linear Modules.

In PWM the current to the LED is always either 100% or 0% (on or off) and the ratio of "on" time to "off" time is changed to achieve dimming. Assuming that the frequency of the change is high enough to not be visually perceptible (e.g. at least 120Hz per -ENERGY STAR® Program Requirement for Integral LED Lamps, but preferably several thousand Hz, to avoid stroboscopic effects), the human eye will average the light intensity produced, and the net result is that for a given percentage duty cycle the light will look the same as if the LED was driven by an analog drive of that same percentage (Figure 8). PWM technology cannot be used as a driver output signal to dim Vesta Dim-To-Warm modules but may be used to dim Bridgelux Linear, Square and Vesta-Linear Modules.

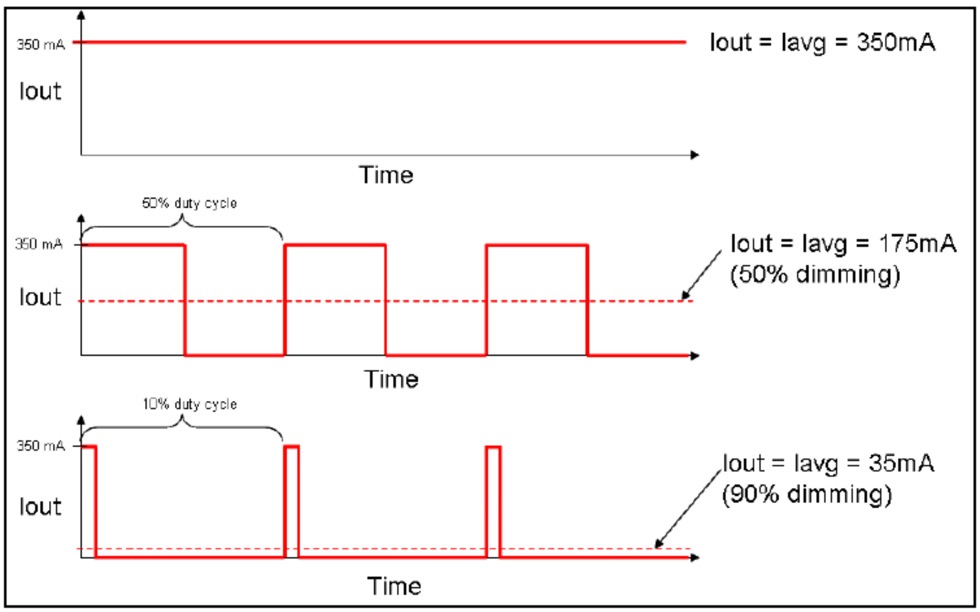
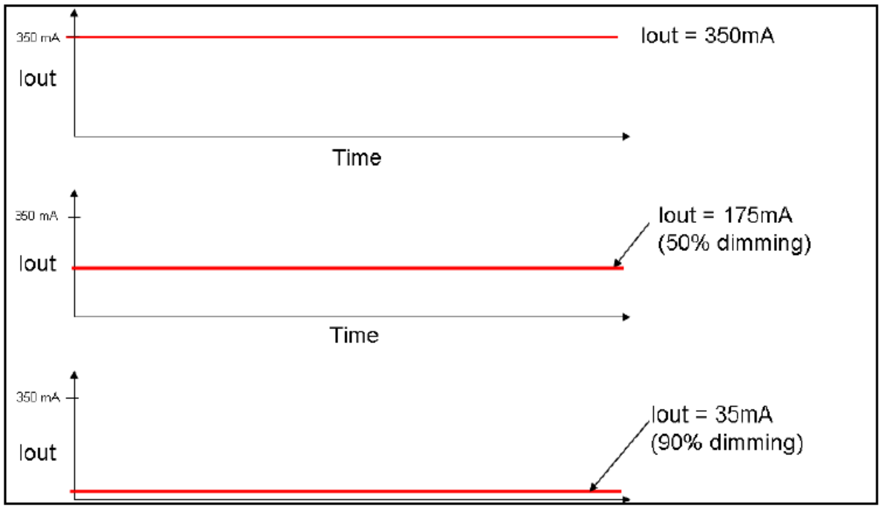


Figure 7: PWM dimming to LED output



Note: A linearly dimmed current level does not bear a linear relationship to the actual light output (LOP) level of a LED and therefore the dimmed current percentage does not necessarily correspond to the same percentage of LOP reduction versus the maximum LOP level at 100% current level.

Figure 8: Analog dimming to LED output

Each of these two dimming implementation methods has advantages and disadvantages.

With the analog method, since the driving current "If" is continuously conducting through the LED, there is no possibility of flickering. Since there are no high frequency switching effects, the possibility of electromagnetic interference (EMI) is reduced, possibly simplifying testing for regulatory compliance. On the downside, at very low drive levels, the possibility of electrical noise on the drive signal is very real, and that noise can sometimes be visually disturbing, resulting in a flickering or "popping", especially because the human eye is so sensitive to small changes in light at very low ambient light levels.

With the PWM dimming method, the PWM frequency has to be chosen carefully to avoid stroboscopic effects in some applications. With current pulsing with fast slew rates in both rising and falling edge, the driver and the wiring installation will have to be designed carefully to avoid EMI and other switching noise related problems. An advantage of PWM dimming is that it can be more electrically efficient than analog dimming, and is less sensitive to the "popping" noise problem at very low duty cycles (light levels).

See the references section at the end of this document for a list of links to dimming control manufacturers.

Product Design Considerations – Thermal Management

These products generally do not need heatsinking like other products with higher power densities do. A high powered COB might, as an example, use 20W of power concentrated on a substrate that is less than a square inch. Even the highest powered Square Module when using 80W of power, already spreads that power over 125 square inches. The density is not comparable from 20W/sq-in to 0.65W/sq-in. As such most linear and square module products do not require thermal interface materials as do COBs. That being said, in the design process, all the maximum temperature ratings, as listed in the respective datasheets, needs to be maintained and all designs should be checked using appropriate thermocouples and temperature readers.

Measuring Effectiveness of a Thermal Solution

As mentioned previously, it is critical to experimentally validate the effectiveness of the product design in terms of thermal management, even if they normally do not require elaborate heat sinking and TIM use. This is typically done by building a prototype, simulating the worst-case use conditions, and measuring the Module's case temperature, Tc. When simulating worst-case use conditions ensure the following:

- Convection conditions are realistic.
- Material properties and dimensions, including wall thicknesses, surface areas, and component sizes are representative of the design.
- Surface properties, including color and roughness properties, are representative of the design.
- Additional heat sources that may impact the thermal performance of the device are included (such as a power supply that is placed inside a luminaire enclosure or attached to an external housing).

Once the representative prototype is built, and realistic use conditions are simulated, Tc may be measured to validate the design.

Special care is required when measuring the Tc to ensure an accurate measurement. As mentioned above, a Tc measurement location is provided on the top side of the modules for easy access in locations which Bridgelux has defined near the array of SMD LEDs, and are intended for measuring the temperature with a fine gage thermocouple. These measurement locations are identified in the mechanical section in the respective datasheets of each product.

The thermocouple attach area is large enough to accommodate a 30 gauge thermocouple, but a smaller gage such as 36 gauge is recommended for ease of attachment and better accuracy, see Figure 8 which shows an attachment location on an EB Module. The following approach is recommended to minimize measurement errors for attaching the thermocouple to the case temperature measurement point of the modules. A microscope will aid in the installation of the thermocouple detailed in the next steps.

- Use a 36 gauge or higher (smaller wire diameter) thermocouple for measuring Tc. Thermocouples of different size and type can be found at www.omega.com. A 36 gauge K type thermocouple with connector is PN: 5SRTC-TT-K-36-36.
- Attach the thermocouple bead (junction) to the measurement point surface of the module as shown in Figure 9.
- Attach the thermocouple to the Bridgelux modules using a thermally conductive, but electrically non-conductive adhesive such as OmegaBond-101.
    - First temporarily secure the thermocouple wire using Kapton tape to act as a strain relief and holder for the thermocouple during attachment.
    - Next, bend the thermocouple wire in order to create a "spring loading" effect such that the bead will land on the prescribed area and ensure mechanical contact to the surface so that it remains in contact with the surface without an external mechanical force.
    - There should be no air gaps between the thermocouple tip and the surface of the modules. A visual inspection using a microscope or stereo scope is beneficial when attaching the thermocouple to inspect the bead contact with the surface.

- Apply enough adhesive around the thermocouple bead to secure the thermocouple in place and allow the adhesive to cure. The adhesive should not be excessive and should never contact an LED.
- Place a small strip of Kapton tape over the thermocouple junction to insulate the thermocouple from the surrounding air temperature and tape the wire down to the top side of the housing, see Figure 10.
- The wire of the thermocouple should be routed away from the optical sources so that the thermocouple is not in the direct path of the light emitted. Wrapping the wire with Teflon tape will be a good practice.
- If the product uses multiple modules in the assembly, identify the module that will be at the hottest temperature for monitoring with the thermocouple, and the hottest point on that module to monitor.

After turning on the modules, Tc will increase with time as the assembly heats up. Eventually, the lighting assembly should reach a steady state temperature. The time required to reach a steady state temperature depends on the time constant of the assembly. For small fixtures that are natural convection cooled this time is likely to be in the range of an hour. Larger fixtures could take several hours to reach steady state. It is important to monitor the temperature over time to ensure the system has reached steady state and that the Bridgelux Modules' Tc is at or below the maximum temperatures listed in the Product Data Sheet to ensure functionality and reliability.

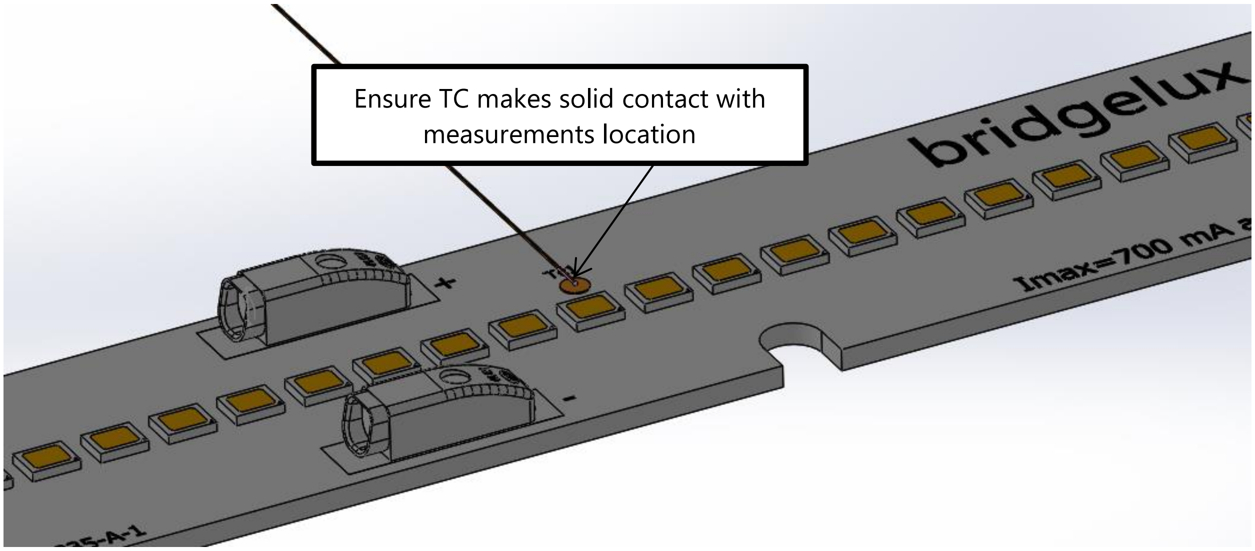


Figure 9: Example of a thermocouple attachment location

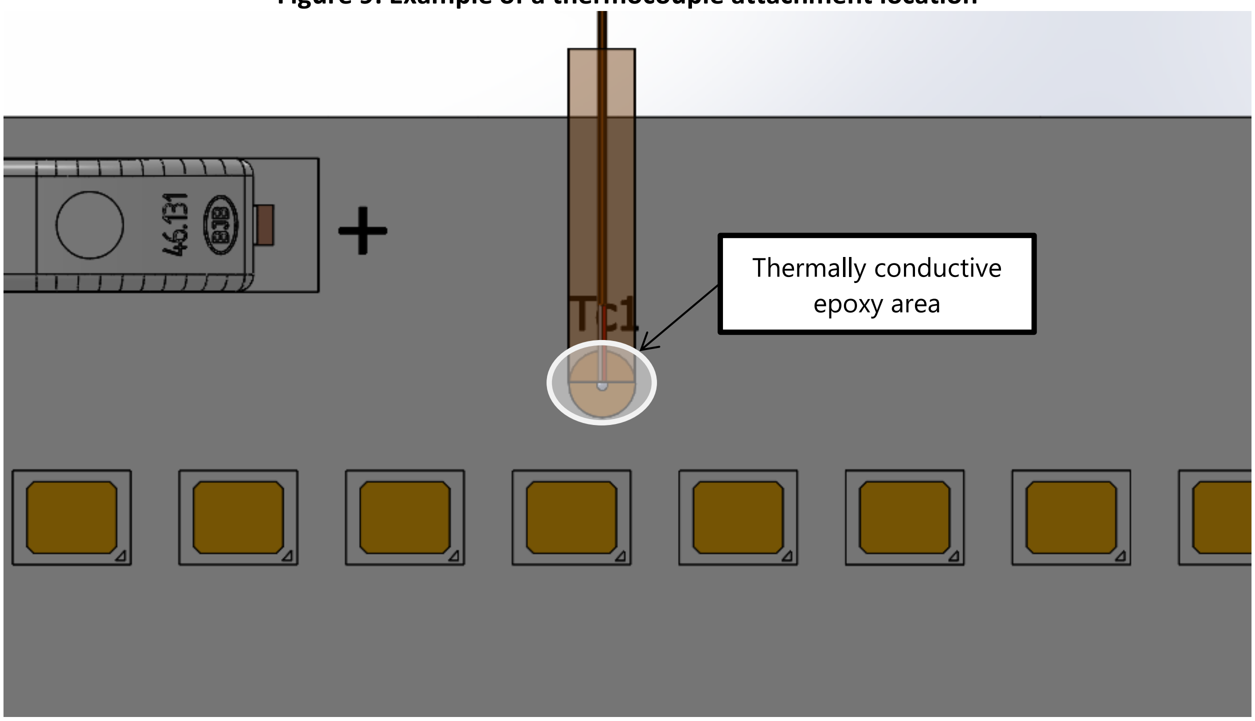


Figure 10: Example of Kapton tape being used as a strain relief and highlighting the epoxy area

ESD Prevention

Bridgelux EB, Vesta and Square Modules have passed ESD testing to levels which do not require special handling for most assembly processes. However, to prevent inadvertent damage, Bridgelux recommends using appropriate ESD grounding procedures while handling the modules.

According to the ESD Association out of Rome, New York, there are six basic principles in the development and implementation of effective ESD control programs:

1. Design in protection by designing products and assemblies to be as robust as reasonable from the effects of ESD.
2. Define the level of control needed in your environment.
3. Identify and define the electrostatic protected areas (EPAs), the areas in which you will be handling ESD sensitive parts (ESDS).
4. Reduce Electrostatic charge generation by reducing and eliminating static generating processes, keeping processes and materials at the same electrostatic potential, and by providing appropriate ground paths to reduce charge generation and accumulation.
5. Dissipate and neutralize by grounding, ionization, and the use of conductive and dissipative static control materials.
6. Protect products from ESD with proper grounding or shunting and the use of static control packaging and material handling products.

Having passed ESD testing already, the Bridgelux modules are already well suited for assembly. Following the guidelines above ensure the most likely chances for success without ESD damage. For more information, visit www.esda.org.

Handling and Transportation

Handle the parts with care. It is recommended to wear finger cots or gloves to prevent dirt or other contaminants from adhering to the Bridgelux Linear Modules (see Figure 11). Bridgelux Linear Modules are optical devices. Please ensure that nothing comes into contact with the yellow resin area, as this may adversely affect performance.

Figure 11: Required tools – Bridgelux modules, wire, wire strippers, hardware, gloves, and drill. Not shown: glasses and goggles.

Although use of a clean room is not required, the environment in which the Bridgelux Linear Modules are assembled should be clean, avoiding dust and particles which may adhere to the resin area of the Bridgelux Linear Module.

Safety glasses should be worn at all times per local, state, or federal work ordinances. It is in the best interest of the operator and the company that glasses be worn any time work is performed, sometimes goggles can be more appropriate.

Optical Areas

Avoid any contact with the optical area (yellow phosphor area and surrounding SMD devices). Do not touch the optical area of the Bridgelux Linear Modules or apply stress to the optical area. Contact may cause damage to the LED module.

Optics and reflectors must not be mounted in contact with the yellow phosphor resin area or the white packaging around the yellow phosphor area. Optical devices may be mounted on the PCBA's surface of the Bridgelux Linear Modules. Use the mechanical features of the PCB, edges and/or mounting holes to locate and secure optical devices as needed.

Packaging Overview

Bridgelux linear, Vesta and square Modules are packaged for volume shipment in trays of various sizes. However, all trays are sealed in anti-static bags, within a shipping container (Figure 12). Depending on the volume ordered, the shipping containers themselves may also be placed into larger containers or boxes.

Figure 12: Image of products in trays on top of anti-static bags

Low volume sample shipments may be packaged using other methods. To manually remove the modules simply lift the module from the tray by gripping the side of the PCB away from the LEDs and connectors. The trays come with notched areas around the module that accommodate fingers for grabbing the modules from the sides. Figure 13 illustrates a suitable method of removing the Bridgelux EB Series Modules, Figure 14 shows the removal of a Bridgelux Square Module, and Figure 15 shows the removal of a Vesta Linear Module.

Figure 13: Removal of 4’ EB Series Linear Module from Tray

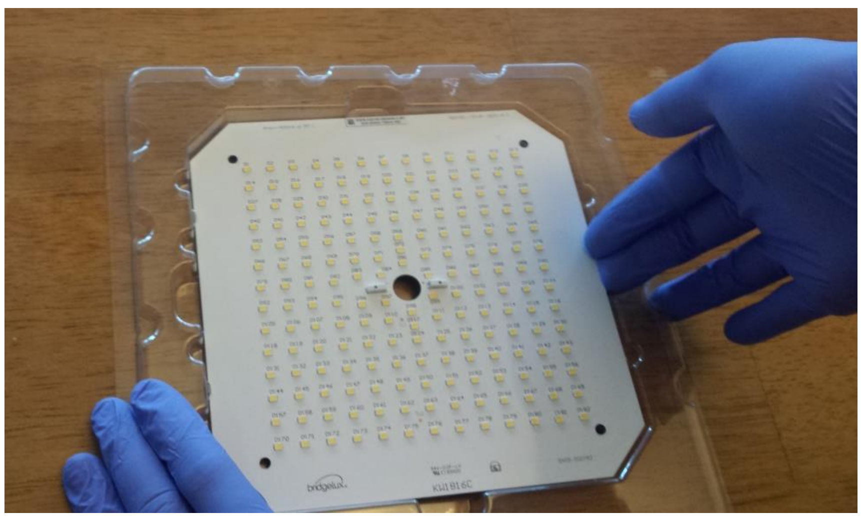


Figure 14: Removal of EB Series Square module from tray

Note that for longer products of the two and four foot nominal lengths that the products can bend and twist. This is not desirable as creating sweeps, bows, and twists imparts mechanical stress onto the SMD components, both the LEDs and the connectors. If those stresses are too great then solder joints can be compromised and the product can fail to light or create an arcing scenario. When removing the longer and less rigid products, do so near their installation site and always use two hands to support either side of the long PCBs.

Both the EB Series modules and Vesta Linear modules come packed back to back, as shown in Figure 15. Keep this in mind when grabbing the units as there are SMD devices on the other side of the visible product.

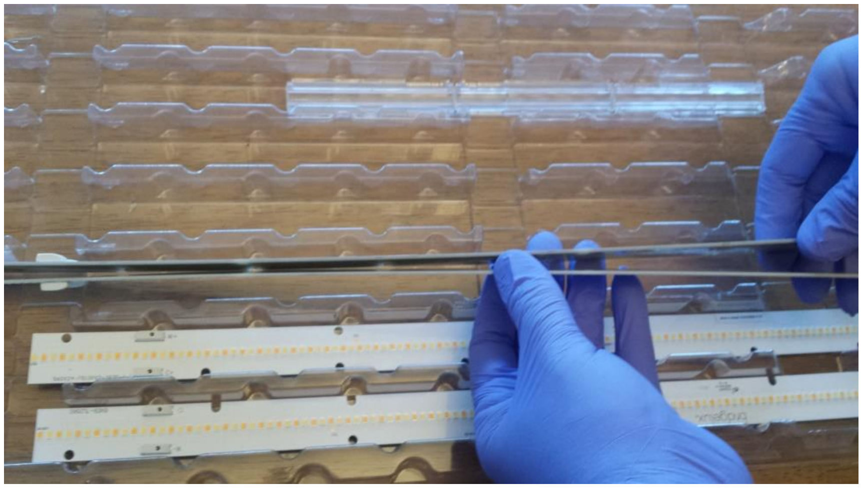


Figure 15: Removal of a Vesta Linear Modules from tray

Installation and Protection

The installation process of the Bridgelux modules is very straight forward, but the correct hardware, wiring, and processes must be followed to ensure a robust product. The EB Series and Vesta Linear modules are outfitted with Zhaga compliant mounting holes and slots. And the Square series, while custom with the location of the mounting holes, follows the same easy to method of installation.

The details of the wire type, size, and strip length is found in Table 6. Images of unacceptable cuts for wires are shown in Figure 16.

Table 6 Wire Strip Lengths for EB Series Modules

Connection Data	
Connection Tehcnology	Push wire contacts
Solid wires	0.20-0.75mm^2, AWG 24-18
Stranded, tinned wires	0.20-0.75mm^2, AWG 24-20
Stranded wires	0.20-0.75mm^2, AWG 24-18
Strip Length	8 + 1 mm
Conductor entry angle into the PCB	0°
Wire relase function	Contact opening tool

Note: Bridgelux's Vesta Edge modules have no connectors, but soldering pads. Please search "How to Solder a Wire to a Pad" online, and you'll see instructions on how to solder.

Although not required, stranded wires may be tinned prior to insertion in the terminal or port. Manual tinning of the wire using a solder iron may result in solder lumps along the tinned wire that may cause mechanical interference at the wire terminal. For this reason, Bridgelux recommends using a tin pot to tin wires as shown in Figure 17. If wires are tinned, the diameter of the wire should not exceed 1.02 mm.

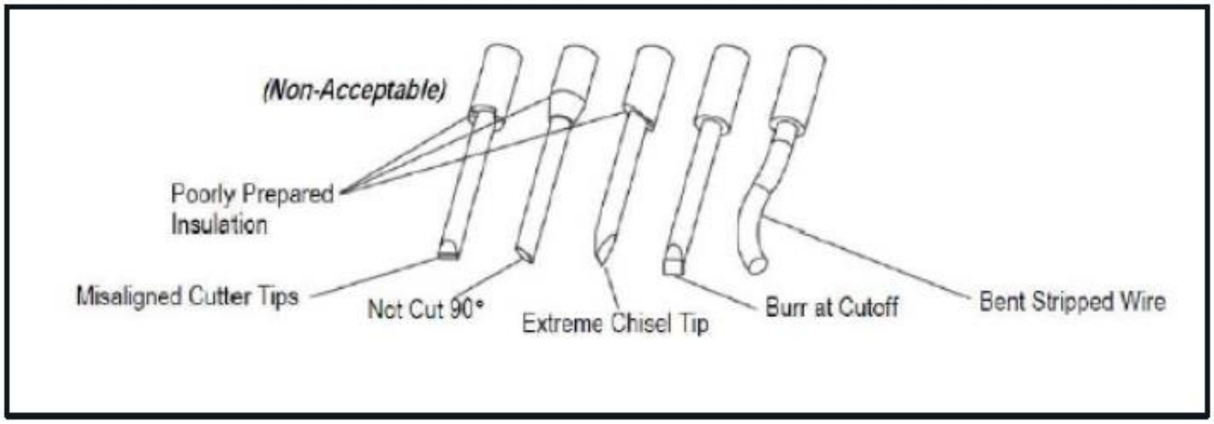


Figure 16: Examples of unacceptable wire cuts

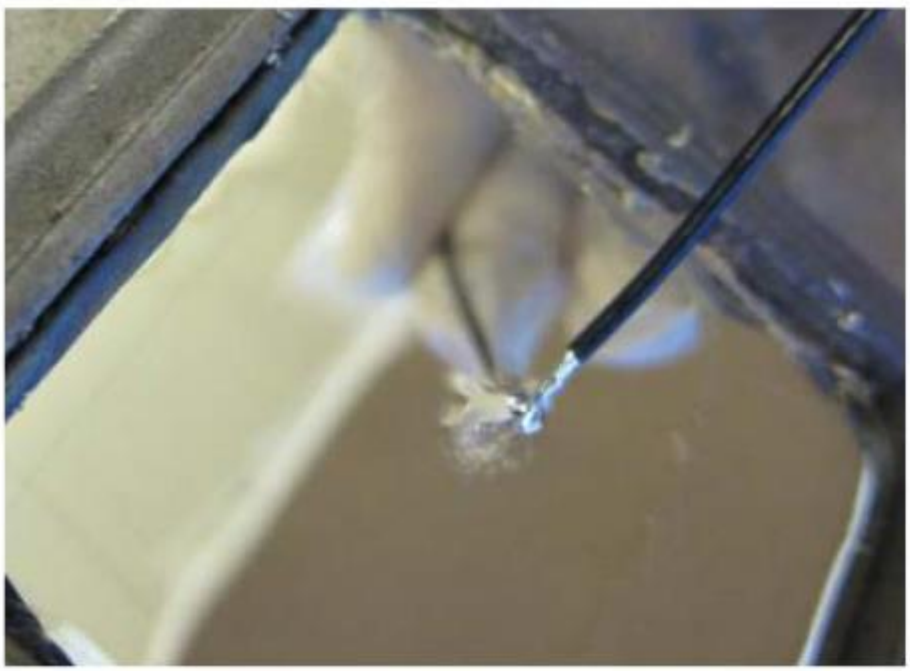


Figure 17: Tinning pot – the preferred way to cleanly tin stranded wires

Wire Insertion Mechanics

Once wires have been prepared by stripping appropriate amounts of insulation (and tinning if needed) (Figure 17), the wire is ready to be inserted into the surface mounted wire ports.

For solid or stranded and tinned wires (Figure 18), the wires can be inserted into the wire ports until the wire comes to a stop. A certain force or resistance is felt along the wire as the tip of the wire enters the port and wire trap in the integrated holder. The inserted wire will be retained by a push contact inside of a wire trap. To check for proper insertion of the wire, gently pull on the wire away from the port while holding the module in place. A properly inserted wire will remain locked inside the wire trap when it is gently pulled away from the terminal or port. An improperly inserted wire will not remain in the wire trap and will come out of the terminal or port.

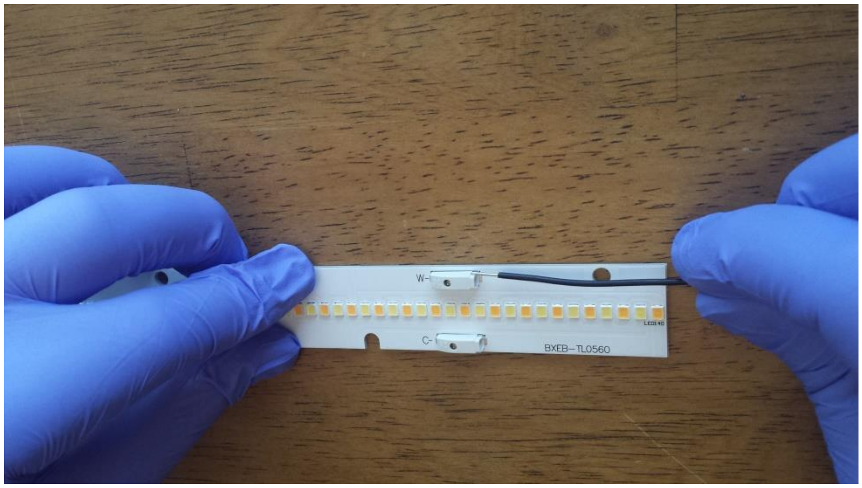


Figure 18: Wire insertion by hand

For stranded wires that are not tinned, the wire trap has to be opened while the wire is inserted into the wire terminal or port. Instructions for opening the wire trap can be found in the Wire Release section of this document.

Wire Release

The wire can be released from the wire terminal or trap by using a screwdriver. We recommend a screwdriver with a tip of 1.0 mm x 0.18 mm. The screwdriver has to be placed into the wire release ports and a small amount of pressure must be applied. The direction of the screwdriver tip should be parallel to the edge that defines the outermost corner that is pointing toward the wire in the wire trap. The wire release process is illustrated in Figure 19.

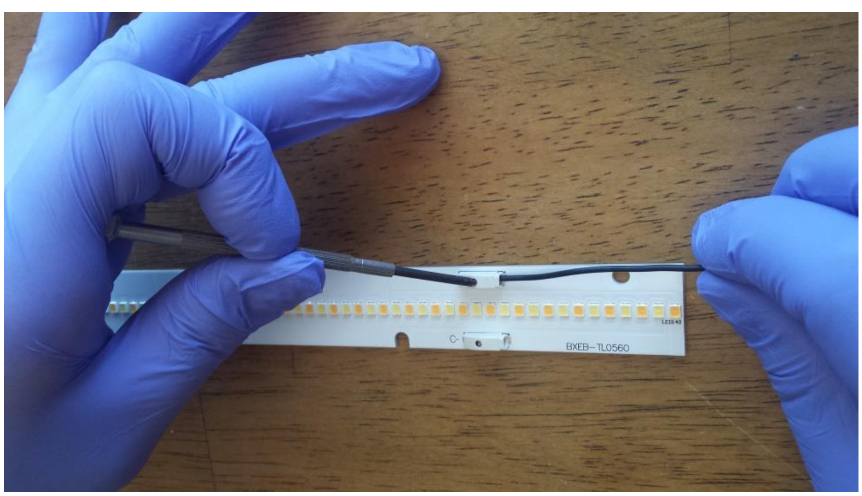


Figure 19: Removal of wire from wire trap

To release a wire from the wire trap, the wire must be pulled out at same time that the pressure is applied on the leaf spring. Note that the screwdriver tip is always angled toward the wire that is being released. Although not clearly visible in the pictures, the screwdriver tip should come in contact with the leaf spring that is visible in the wire release mechanism port. **Wire may be removed up to three times from the wire trap.**

Note that the modules must be de-energized prior to attempting to remove the wire(s). Also note that applying an excessive force and/or a force in the wrong direction on the leaf spring could damage the wire trap mechanism. Do not pull the wire up and perpendicular to the PCBA as this can damage the product. For additional information visit www.bridgelux.com/resources.

Hardware Options – Screws, Rivets, Clips and More

For all Bridgelux Module products, screws can be used to secure the modules to the mounting surface. The slots, mouse-bites and holes are sized for M3 screws. When using a screw, it is best to position the modules by aligning the threaded holes in the mounting surface with the mounting locations for the module.

Each product, be it a linear module of varying sizes, or the square modules, there are multiple holes and slots that can be used in mounting the devices. In the case of the EB Series modules, some products have over a dozen available holes and slots to mount the device. Since the product itself is very light weight, only a few screws are needed in long modules to prevent bowing from the surface and secure the device. However larger forces from vibrations or impacts can significantly increase the force needed to hold the product in place. As such all considerations need to be vetted in the prototype that simulate real world applications.

Once the correct screw requirements are identified, it is recommended to place the product in place and engage the screws in their threaded holes or with their respective washers and nuts. Then, it is recommended to tighten each screw in an alternating pattern until each screw is tightened to the correct torque setting. If one screw is tightened fully first, the module could warp or move out of center. If sufficient screws are not in place, the boards can rotate as they are tightened down upon.

Screw Head Type and Size – Creepage and Clearance

Bridgelux recommends using screws with a flat shoulder for mounting Bridgelux modules (see Figure 20). A wide variety of commercially available screws types can be used to meet design requirements. Examples include pan head, button head, round head, and truss head screws. Flat head and oval head screws or other screws with an angled surface should not be used.

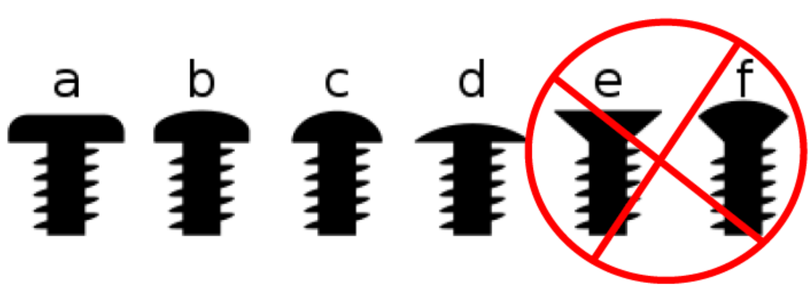


Figure 20: pan head, button head, round head, and truss head screws are acceptable options

Please note that while the module is rated for a certain creepage and clearance, all considerations are made in the final assembly by the authorities with jurisdiction. Insulating washers can be used to maintain the ratings (Figure 21). Any alternative method to adhere, such as tapes and plastic clips need to be similarly vetted for reliability and per local safety agency requirements. Often, they are only suitable as secondary attachment methods.

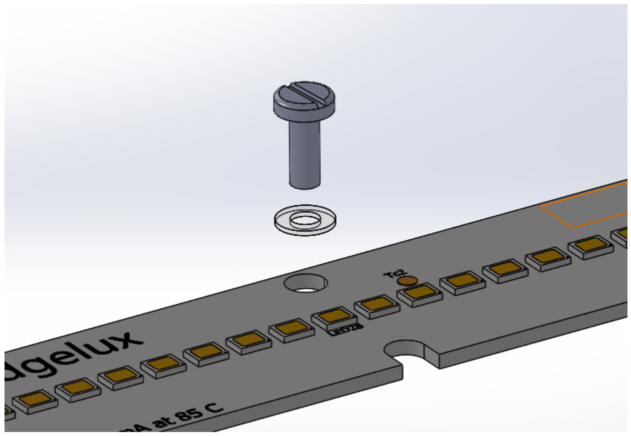


Figure 21: Plastic, or insulating washers, can be used to help maintain clearance distances

Screw Torque

It is critical to ensure the proper torque is applied to the fasteners when mounting the Bridgelux modules to a housing or a heat sink. If too little torque is applied, the thermal path between the Bridgelux Linear Module and the heat sink will be compromised while excessive torque may result in damage to the modules itself. Many variables affect the actual torque required to seat the screw such as thread friction, materials of the housing or heat sink and screw, screw head friction, etc. For example, a M3 machine screw with typical thread friction can be seated with < 0.5 N-m (50 N-cm) of torque, but it may take much higher torque to seat a thread forming screw. It is the responsibility of the customer to test and ensure the correct torque values are specified and used during the assembly process.

Washers

Flat washers may be used to protect the Bridgelux Linear Modules from damage resulting from excess torque and to provide a wider distribution of the force applied by the screw. Flat washers, however, do not prevent fasteners from loosening in vibration environments. To prevent loosening of screws during vibration or thermal cycling, Bridgelux recommends using lock washers, self-locking fasteners, or thread locking sealants.

As with all designs, the final combination of the components determines the ultimate suitability determined by the authorities that have jurisdiction. Please consult with Bridgelux for safety and compliance documents, or consult with your local authorities with jurisdiction.

Chemical Compatibility

Optimizing performance and reliability of a lighting system using Bridgelux modules requires safe handling and use of appropriate manufacturing procedures and materials during the assembly of the module into the lighting system. Careful consideration must be given to the materials and chemicals used when processing the modules and to materials that are incorporated into a luminaire. This section provides a list of commonly used chemicals that should be avoided or carefully managed during processing of all Bridgelux modules and during their subsequent use.

Silicone encapsulation is commonly used by most LED manufacturers, including Bridgelux. The silicone encapsulation is permeable to gas molecules. The gas molecules, including volatile organic compounds (VOC's), halogen and sulfur compounds, can interact with silicone and other components that comprise the Bridgelux modules and cause degradation in performance. The possibility and extent of degradation is dependent on the type of chemical, the concentration of the chemical, the temperature during exposure, and the length of time the LED module is exposed to the chemical. Additional considerations should be given to IP rated or "sealed" luminaires that create "air tight environments" around the module. Luminaires sealed in this fashion can trap potentially damaging gas molecules from manufacturing processes or subsequent out-gassing of materials used in the luminaire which can result in long term exposure of the modules to the contaminant.

The source of the gas molecules can be out-gassing from polymeric materials such as glues, gaskets, paints and/or under-cured materials. Materials used inside a luminaire with a potential to outgas should be characterized as part of the luminaire design to understand the environment that will be surrounding any Bridgelux module during the luminaire lifetime. The silicone encapsulation is also vulnerable to nonpolar fluids and solvents commonly used during the manufacturing process of the luminaire such as cleaning, oil assisted drilling, and any processes that would allow the module to come into contact with the fluids or solvents. Care should be taken such that the modules are protected from such chemicals to avoid ingress of small non-polar molecules into the encapsulation silicone.

Common chemicals that are known to be harmful to Bridgelux modules are listed in Table 7. Note that the chemicals listed in Table 7 may be found in various states – liquid, gas, and/or solid. All physical states of these chemicals can be harmful to the modules, but those that are in a gaseous state, such as volatile organic compounds (VOCs), can readily permeate the lens material of the module and damage the SMD internally and/or externally. Because it is impossible to determine all of the chemicals that may be detrimental to the performance of the Bridgelux modules, the list of chemicals may not be exhaustive. It is the responsibility of the luminaire manufacturer to ensure that any and all materials used in the luminaire design or manufacturing process does not cause damage to the subsystems.

Table 7: List of known chemical contaminants and likely sources

Classification	Chemical Name	Found In Some
Acids	Hydrochloric Acid Sulfuric Acid Nitric Acid Phosphoric acid	Cleaners, cutting fluids
Organic acids	Acetic acid	RTV silicones, cutting fluids, degreasers, adhesives
Bases	Sodium Hydroxide Potassium hydroxide Amines	Detergents, cleaners
Organic Solvents	Ethers such as glycol ether Ketones such as MEK, MIBK Aldehydes such as formaldehyde	Cleaners, mineral spirits, petroleum, paint, gasoline
Aromatic solvents	Xylene Toluene Benzene	Cleaners
Low Molecular Weight Organics Volatile Organic Compounds (VOC's)	Acetates Acrylates Aldehydes Dienes	Superglue, Loctite adhesives, threadlockers and activators, common glues, conformal coatings
Petroleum Oils	Liquid hydrocarbons	Machine oil, lubricants
Non-petroleum Oils	Siloxanes, fatty acids	Silicone oil, lard, linseed oil, castor oil
Oxidizers/Reducers	Sulfur compounds	Gaskets, paints, sealants, petroleum byproducts
Halogen compounds	Cl, F,or Br containing organic and inorganic compounds	Solder fluxes/pastes, flame retardants

References

Bridgelux does not make any recommendation or endorse any third party supplier

Eco-system partner links

https://www.bridgelux.com/company/ecosystem-partners

Other Driver Companies

Meanwell - www.meanwell.com
Inventronics - www.inventronics.com
Thomas Research Products - www.trpssl.com
Moons' Industries – www.moonsindustries.com
Xitanium - https://www.signify.com/en-us/brands/advance/led-drivers/xitanium
EldoLED – www.eldoled.com

Other Dimming Control Companies

Lutron - www.lutron.com
Leviton - www.leviton.com

Wire Gauge Maximum Current Capacity

www.powerstream.com/Wire_Size.htm

Mounting Screws, Washers, Lock Washers, and Self Locking Fasteners

www.longloklocking.com
www.nord-lock.com
www.nylok.com

Soldering and Pick and Place Tools

www.micro-mechanics.com
www.smallprecisiontools.com

Soldering Processes and Procedures

IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies
IPC/EIA J-STD-002 Solder ability Tests for Component Leads, Terminals and Wires
J-STD-004 Requirements for Soldering Fluxes

Disclaimer

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It is the responsibility of the customer to ensure that their design meets all necessary requirements and safety certifications for its intended use.

About Bridgelux

At Bridgelux, we help companies, industries and people experience the power and possibility of light. Since 2002, we've designed LED solutions that are high performing, energy efficient, cost effective and easy to integrate. Our focus is on light's impact on human behavior, delivering products that create better environments, experiences and returns—both experiential and financial. And our patented technology drives new platforms for commercial and industrial luminaires.

For more information about the company, please visit
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