Application Note AN92

Electrical Drive Considerations for Bridgelux Gen 7 and Vesta^{TM} Dim-To-Warm LED Arrays

Introduction

The Bridgelux Gen 7 and Vesta Series™ Dim-To-Warm LED array products, including Vero® Series, Vero® SE Series, and V Series™ arrays, deliver high performance, compact and cost-effective solid-state lighting solutions that serve the general lighting market. These products combine the higher efficiency, lifetime, and reliability benefits of LEDs with the light output levels of many conventional lighting sources.

Optimizing performance and reliability of a lighting system using Bridgelux Gen 7 and Vesta Dim-To-Warm arrays requires careful consideration of thermal management solutions (AN30), handling and assembly (AN31 and AN101) and selection of secondary optics (AN36).

To achieve optimal performance of the arrays, proper electronic drivers must be selected or designed. A key feature of the Gen 7 array is 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 application note will assist designers in selecting or developing electronic drivers for use with Bridgelux Gen 7 and Vesta Dim-To-Warm arrays. The first step is to become familiar with relevant electrical characteristics of the arrays. 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 application note provides general guidelines to the designer to assist in enabling a successful design.

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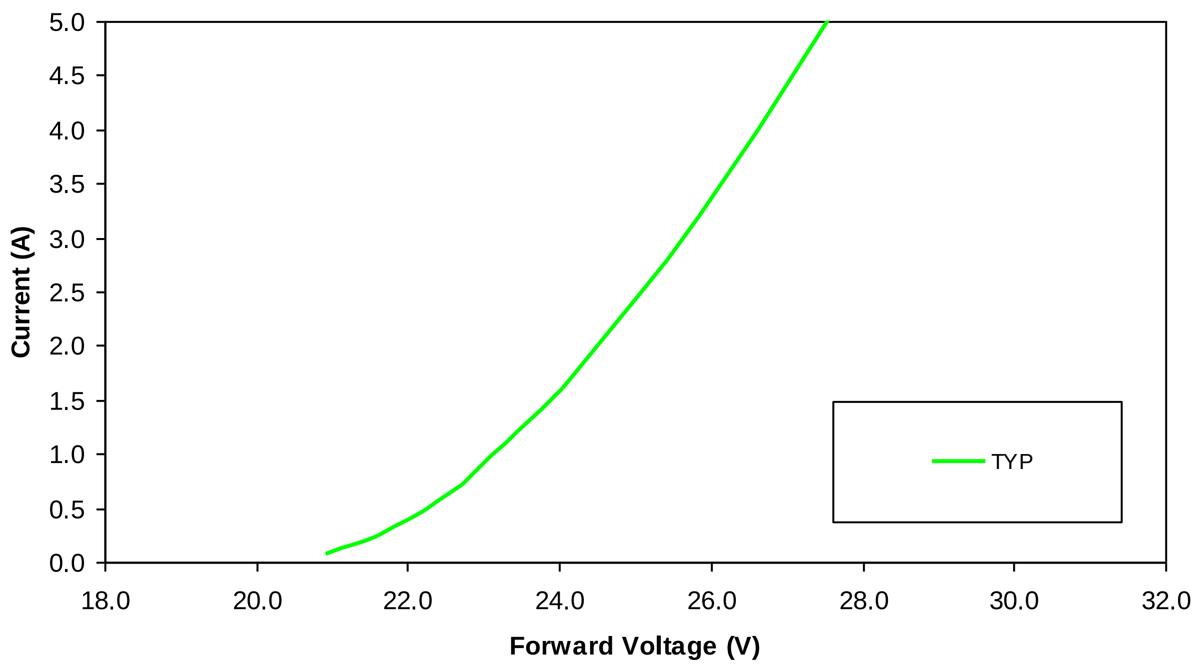
LED Array Electrical Characteristics

Bridgelux arrays are manufactured using high power light emitting diodes, a technology that is proven to be a robust solid state light source and one that exhibits specific electrical characteristics relevant to driver selection and design. The main electrical characteristic is the relationship between the voltage applied to the array and the resultant current through the array. This relationship is nonlinear and is usually shown as a graph which is commonly called the “current-voltage” or “I-V” curve (Figure 1).

Figure 1: Typical LED Array I-V (Current vs. Voltage) curve



An “I-V” curve is provided in each Bridgelux product data sheet as a figure with the title “Current vs. Voltage”. The curve may be different for each array product depending on the configuration of and the exact diodes within the device. It is important to always refer to the correct I-V curve for the particular LED array being used.

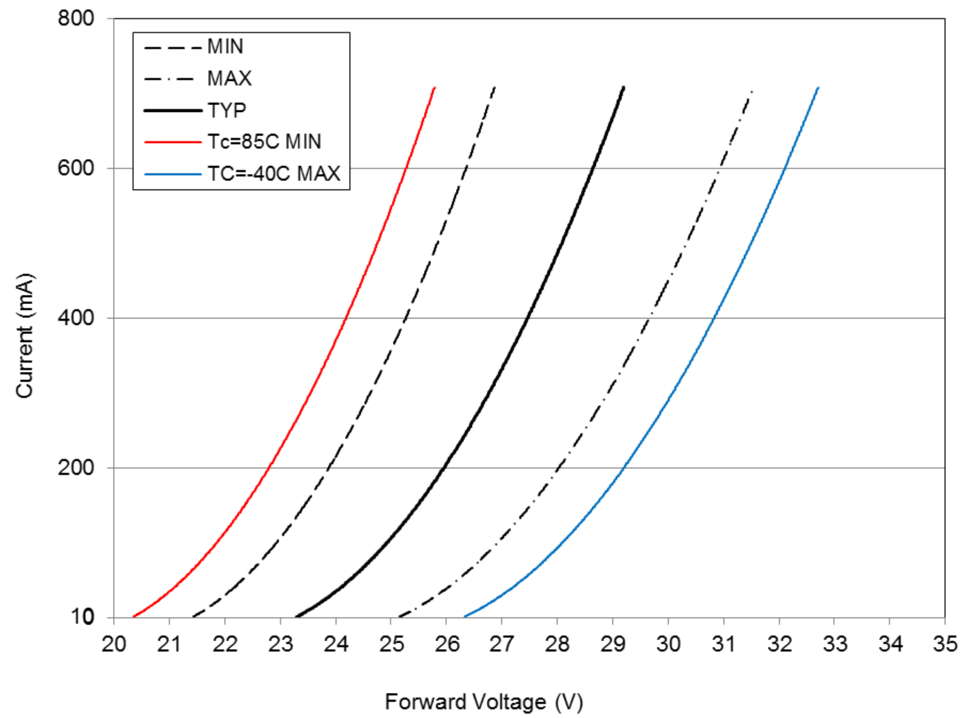
Two additional real-world considerations need to be made before using the simple “I-V” curve of Figure 1:

1. The current-voltage relationship of a diode is a function of temperature. The higher the diode junction temperature, the lower the forward conduction voltage (V_f) at a given current (i.e. the curve shifts to the left with increasing temperature).

2. Each LED will have some manufacturing tolerance which will affect the I-V curve. The shape of the curve will remain essentially the same, but there will be some variation which can be used to derive “minimum” and “maximum” curves that bound the possibilities of all devices built for that particular device number.

Figure 2 shows an example of these two conditions. Note that in addition to the “typical” I-V curve (shown in solid black), there is also a “MIN and a MAX” curve (shown in dashed black). The TYP, MIN and MAX curves all apply at T_c = 25°C. Effectively, these curves are showing the worst case variation that can occur as a result of manufacturing variances. Although in many cases parts will actually fall closer to the typical curve, the driver selected should be able to cover the spread in V_f shown in this curve for the particular drive current which the array is to be driven at. Also note that there is an additional curve, drawn as a solid red line to the left of the graph, labeled MIN Tc=85 deg C. Since the V_f will drop with increasing temperature, the lowest possible V_f will occur at the highest operating temperature point.

Figure 2: LED Array I-V curve with MIN and MAX limits



Unlike a rectifier or signal diode, an LED is not intended to operate reverse-biased; therefore the "negative" forward voltage characteristics of the I-V curve are not shown. LEDs are not designed to be driven with reverse voltage as they may be damaged. LED drivers should be selected or designed to avoid applying a reverse bias to the array.

For the maximum reverse potential that can be applied to a Bridgelux array without causing damage, please refer to the table titled "Maximum Ratings" in the data sheet for that device. A sample of this table appears in Table 1 below:

Table 1: Maximum Ratings (sample table)

	Part Number	Maximum DC Forward Current (mA)	Maximum Peak Pulsed Current (mA) [1]	Maximum Reverse Voltage (Vr)
Vero 10	BXRC-30E1000-B-xx	540	770	-60
Vero 13	BXRC-30E2000-C-xx	1260	1800	-60
Vero 18	BXRC-30E4000-C-xx	2340	3340	-60
Vero 29	BXRC-30E10K0-D-xx	4200	6000	-65
DW 9A	BXRV-DR-1830H-1000-A-13	420	600	-30
DW 9B	BXRV-DR-1830H-1000-B-13	420	600	-60
DW 15A	BXRV-DR-1830H-3000-A-13	1050	1500	-60

[1] Bridgelux recommends a maximum duty cycle of 10% when operating LED Arrays at the maximum peak pulsed current specified. Maximum peak pulsed currents indicate values where the LED array can be driven without catastrophic failures.

Also shown in Table 1 is maximum DC forward current for the array. The maximum DC forward current is self-explanatory – to avoid potential reliability issues do not operate the array at drive levels above this maximum. For pulsed operation the higher "Peak Pulsed" limit may be used, not to exceed the duty cycle specified in the data sheet (normally 10% duty cycle). As for the minimum value, the array will illuminate down to a few milliamps of driver current. The colorimetric performance of the array can be affected by very low drive levels. At very low drive levels, the color can shift, however, the array will continue to illuminate stably until the V_f falls below the turn on voltage of the array, at which time the array will turn off. Significant light output can be generated at milliamp levels, and for very deep dimming, operation to those levels may be desired and is permitted. Though for a parallel configuration dimming at low levels will be an issue due to the amount of light output for each array might vary due to current hogging.

Bridgelux recommends the use of a constant current driver because the light output of the array is directly proportional to the current through the array. If a constant voltage source, as opposed to a constant current source, is used to apply power to the array, a small change or difference in the forward voltage of the array can result in a large change in the forward current flowing through the junction, and ultimately in a large change in flux performance (Figure 3).

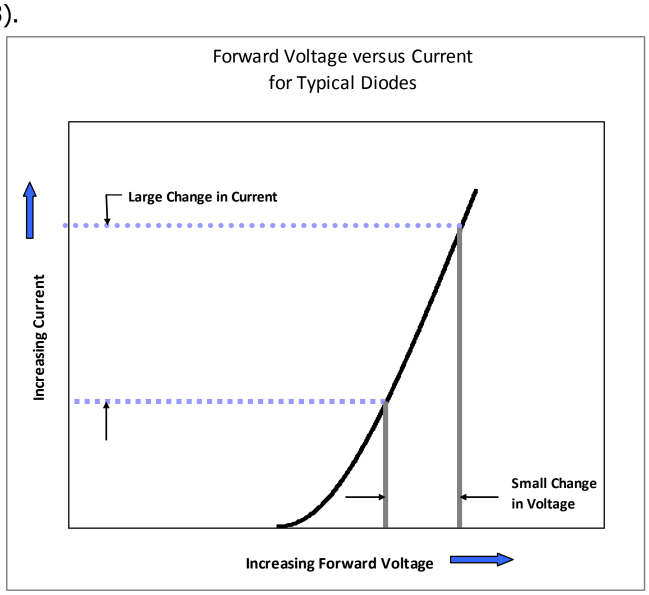


Figure 3: Impact of a small voltage change on forward current for a typical diode

The light, or luminous flux, emitted by the array is dependent upon the forward current applied across the junction. At a fixed voltage the current flowing through the devices can vary dramatically depending on the forward voltage of the individual array. Consider the range of currents that occur at a fixed voltage. If we look at Figure 4 we see that the maximum, typical, and minimum currents for this array with an applied voltage of 26.5V would be 650mA, 260mA, and 40mA, respectively (at 25C), depending on the I-V characteristic of the particular array. Another array, even from the same production lot could have a different I-V characteristic (curve position). The light output from a single luminaire using a constant voltage driver could be dramatically different than that of a nearby luminaire also with an equivalent constant voltage driver. This is generally not very desirable. It is for this reason that Bridgelux recommends against driving arrays with constant voltage sources or connecting multiple arrays in parallel. If the application requires the use of multiple arrays in parallel, please refer to the "Multiple Array Circuit Design Recommendations" section of this document for recommendations on how to do this.

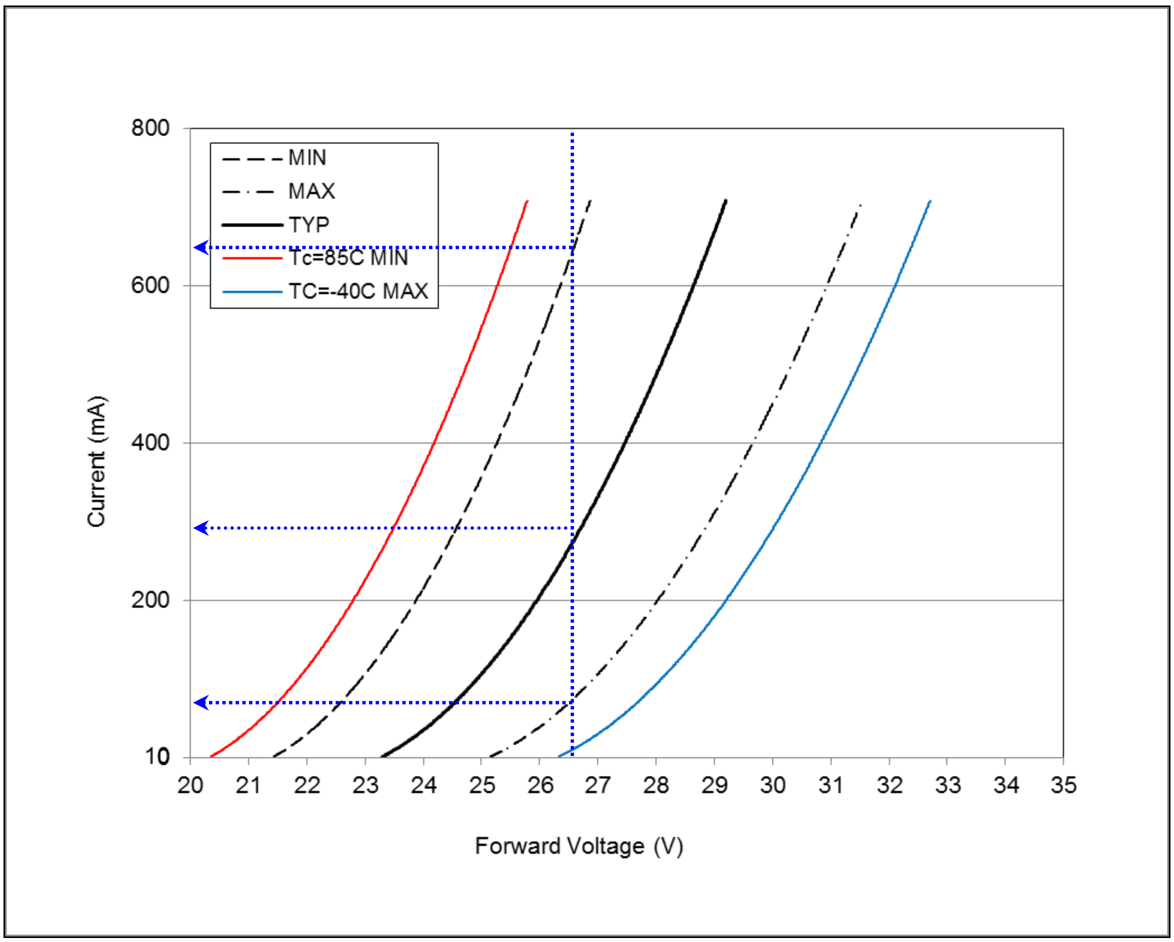


Figure 4: Current vs. Voltage Curve of an Array

Another important electrical characteristic of the Bridgelux arrays is the relationship between forward current and luminous flux. Figure 5 shows a representative typical flux versus current plot for a Vero 10C SE. All Bridgelux array products exhibit these similar characteristics:

1. Increasing the forward current increases the luminous flux output of the array. However, the relationship between flux performance and forward current is not linear, a common characteristic for all arrays. For example, doubling the forward current does not lead to doubling of the flux output. This non-linear relationship of flux vs. forward current (or LED efficacy vs. forward current) is typically referred to as "droop."

2. LEDs are less efficient at higher driver currents than at lower currents. Driving the LED array with a fixed current will maintain a given efficiency level.

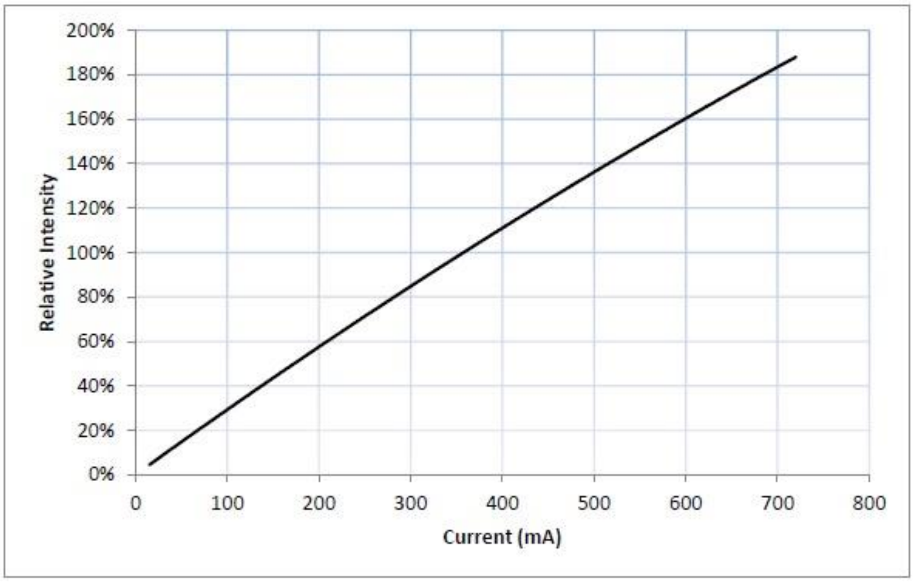


Figure 5: Typical Vero 10C SE Intensity vs. Current

Dimming

Dimming is the action of reducing the light output of the array 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:

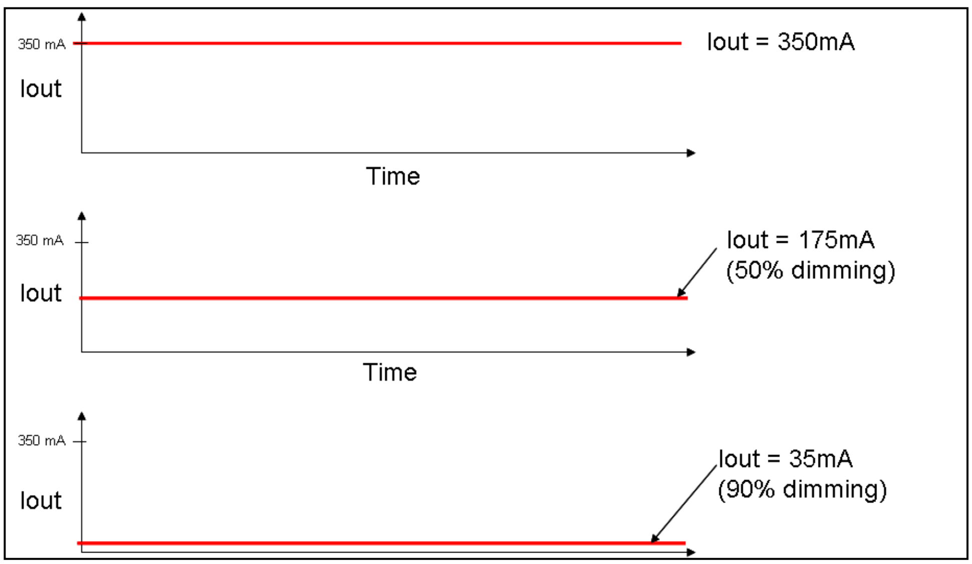
1. The dimming control signal is an input to the driver, and

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), triac (phase cut), 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.

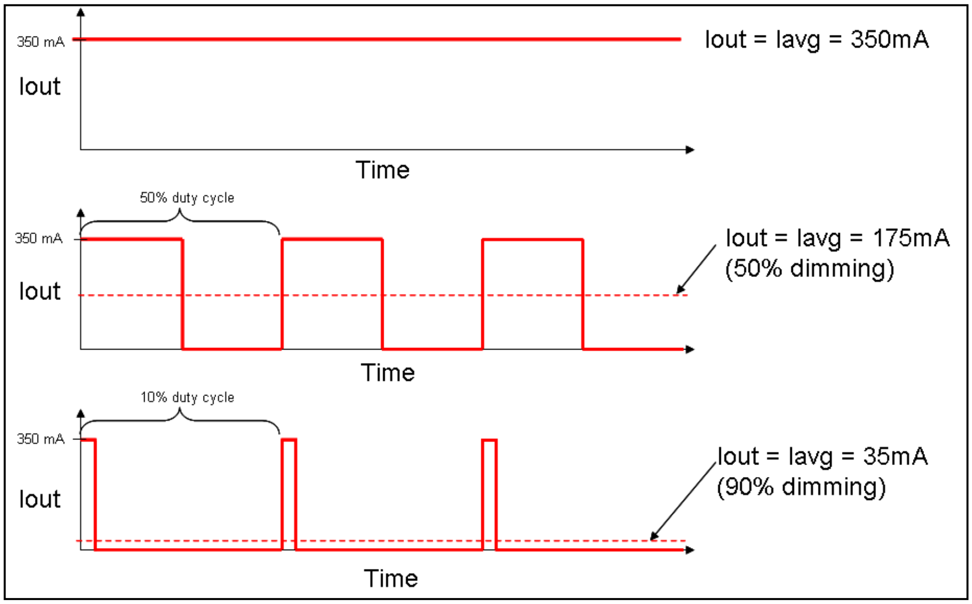
Commonly used technology to control the drive current to the LED for dimming are based on two approaches – analog or Pulse Width Modulated (PWM). In analog dimming, the output current of the driver is reduced to the percentage of full level as requested by the dimming control signal. This is illustrated in Figure 6a. 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 Gen7 arrays and Vesta Dim-to-Warm arrays. 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 6b). **PWM technology cannot be used as a driver output signal to dim Vesta Dim-To-Warm arrays** but may be used to dim Gen7 arrays.

Figure 6a: Analog Dimming output to LED



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 6b: PWM Dimming output to LED



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

With the analog method, since the driving current "I_f" 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. For parallel arrays, if analog dimming is required, it's recommended to have the arrays under a common lens.

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).

General Electrical Drive Recommendations

Based on the electrical characteristics of Bridgelux arrays, Bridgelux recommends the following basic guidelines for electronic driver design:

1. Drive the arrays using constant current sources, not constant voltage sources.
2. Ensure that the driver "Vout" range is sufficient to cover the full range of V_f that may occur for the array chosen at the drive level specified.
3. Do not apply a reverse voltage to the array.

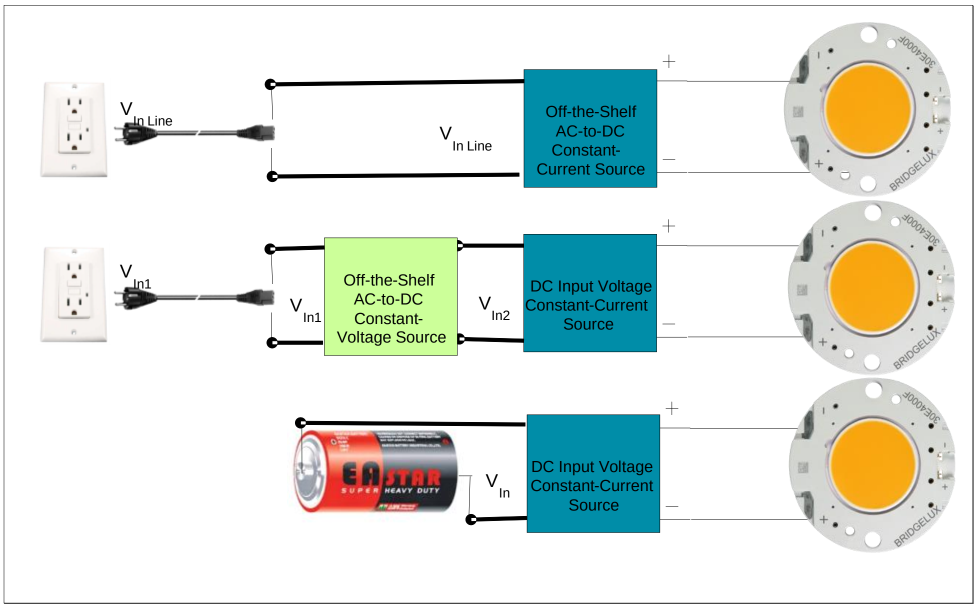


Figure 7: Illustration of drivers that accommodate different input voltage requirements

Multiple Array Circuit Design Recommendations

For some luminaire designs, multiple arrays 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 arrays in series to complete the electrical circuit (Figure 8). This arrangement ensures that all arrays will be operated at the same current.

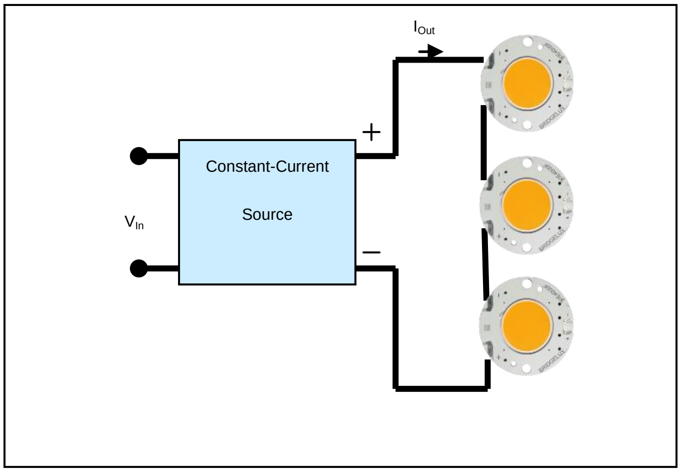


Figure 8: Multiple Arrays driven in series with a single constant current source

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 arrays (Figure 9).

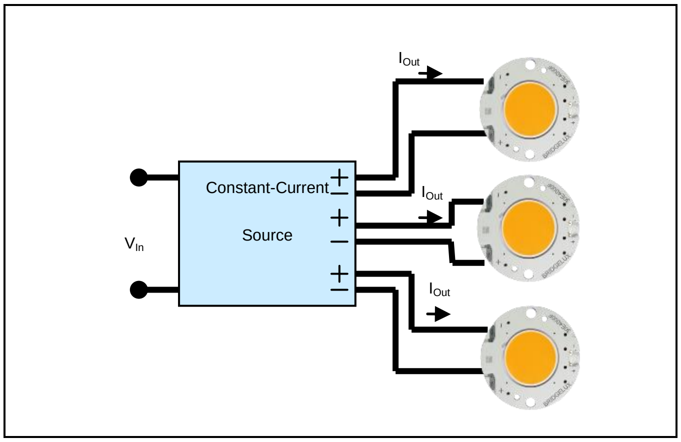


Figure 9: Multiple Arrays driven by a driver with multiple constant current channels

3. A combination of the two configurations above can also be applied. Arrays can be connected in multiple series strings from a multi-channel LED driver, allowing for an increased quantity of arrays to be powered from a single driver.

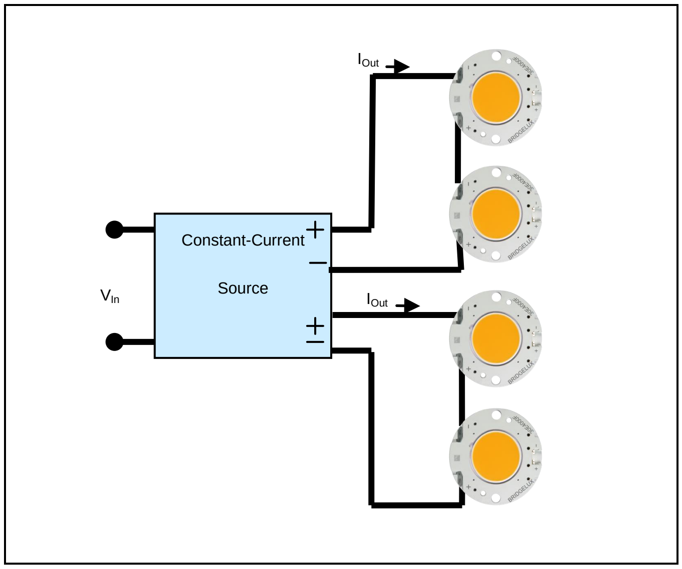


Figure 10: Series strings of multiple Arrays driven by a multi-channel driver

4. Bridgelux does not recommend connecting multiple arrays in a parallel circuit if using full V_f distribution product. Variation in the forward voltage of the individual arrays can result in current hogging, where a lower V_f array may see a higher forward current compared to a higher V_f array connected in parallel. This may produce non-uniform flux and color, and may affect the reliability of the lighting system.

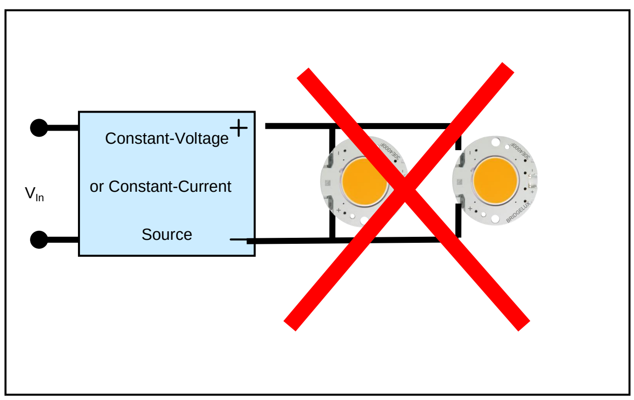


Figure 11: Parallel connection of multiple Arrays to a driver – *NOT RECOMMENDED FOR FULL V_f DISTRIBUTION PRODUCT*

5. If the application requires multiple arrays to be connected in a parallel configuration, such as the one shown in Figure 12 below, Bridgelux recommends using arrays from the same V_f Bin. The V_f bin of a Gen 7 array is identified by the last two digits of the array part number coding that is scribed on the back of the array. Figure 13 shows an example of the V_f bin code on the back of a Gen 7 array. Please refer to Appendix A for detailed V_f Bin definitions.

Figure 12: Example of parallel connection of multiple Arrays to a driver –*ONLY USE ARRAYS FROM SAME V_f BIN*

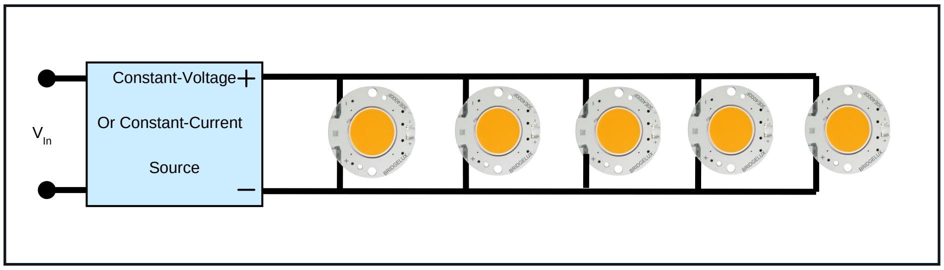
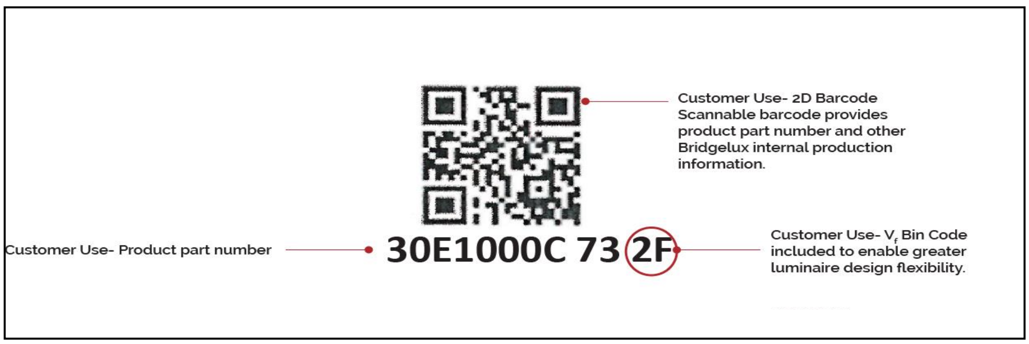


Figure 13: Markings on the back of the Gen 7 array which identify the V_f bin of the array.



Note: Vesta Dim-To-Warm arrays do not including Vf bin marking on the back of the arrays

As opposed to full V_f distribution array products without V_f binning information, Gen7 array products of the same part number and bin code have V_f performance that falls within a 0.5V range. Using arrays from the same V_f bin reduces the amount of current hogging by the arrays in a parallel circuit. However, to minimize the magnitude of current hogging by the arrays in a parallel circuit, Bridgelux requires that the following conditions be met:

1. All arrays in the parallel circuit should be the same part number and should come from the same 0.5V wide V_f bin.
2. All arrays are strongly recommended to be on the same heatsink to ensure that the current through the individual arrays do not diverge as a result of differences in the array case temperatures. If there are sources of heat generation, such as power supply or a driver, these should be located away from the arrays to ensure that the case temperatures of the individual arrays in the circuit remain within 10 degrees of each other during operation.
3. The maximum array case temperature of any array in the circuit should not exceed 85°C.
4. The current through the arrays should not exceed 1.5X the nominal drive current specified in the array datasheet.

For best results, maintain the array case temperature as low as possible, minimize the number of arrays that are placed in a parallel circuit and minimize the average current through each array. In order to quantify the magnitude of current through each array in a parallel circuit, Bridgelux performed experiments and developed models for various array part numbers. The results of two distinct modeling scenarios are included in Appendix B and C.

Appendix B describes the minimum and maximum drive currents through a simple parallel configuration of two arrays as shown in Figure 14. The outcome of two different scenarios of driving the arrays at an average nominal drive current (I_f) and 1.5 times the average drive current are included in Tables 5a and 5b.

Appendix C describes the approximate number of arrays that can be placed in parallel and meet Class 2 dry indoor driver requirements. Two specific currents of an average nominal drive current of (I_f) and an average drive current of 1.5 times $I_{f,}$ are included in Tables 6a and 6b. Figure 15 shows a parallel combination of n LED arrays.

Figure 14: Simple Parallel Configuration of 2 Arrays

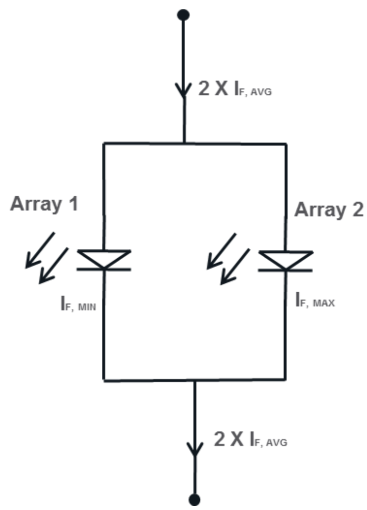
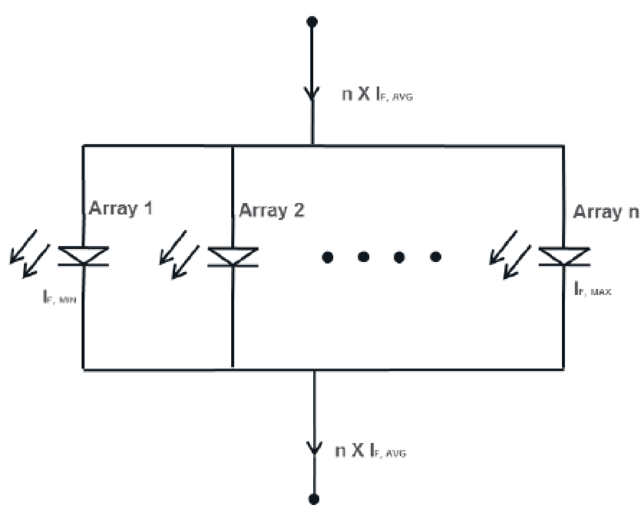


Figure 15: n Parallel Configuration



LED Driver Input Power Requirements

LED drivers convert available input power into the required output current and voltage, analogous to ballasts used with fluorescent and other conventional light sources. Bridgelux recommends the use of constant current sources to drive the arrays. In addition to meeting input requirements specified by the user (such as 110V AC input, 220V AC input, 12V DC input etc.), the driver selected must meet the output requirements as specified for the application. These include, but are not limited to, V_{out}, I_{out}, and Power.

All of the design information required for successful specification of driver requirements to match Bridgelux arrays are contained in the array data sheets. If you have any questions or need assistance in selecting a driver for evaluation, please contact your local Bridgelux sales representative.

The following is an example of how the driver for a luminaire is to be designed using the Bridgelux "Vero SE 10" BXRC-xxx100x-B array to be driven at a 270mA level to get the desired optical output, and the luminaire designer wishes to select a LED driver/power supply to power and drive the array.

First step is to locate the electrical characteristics from the "Vero SE 10 data sheet", reproduced in Figure 16 below:

Figure 16: Example of Gen 7 Datasheet

Sample Gen 7 datasheet Table 5: Electrical Characteristics and Driver Selection Voltages

Current (mA)[1]	**Forward Voltage Pulsed, T_C=25°C[1,2]**			**Typical Coefficient of Forward Voltage $\Delta V_f/\Delta Ti$[4]** (mV/°C)	**Typical Thermal Resistance Junction to Case RΘj-c** (C/W)	**Driver Selection Voltages[7] (V)**	
	Minimum (V)	**Typical (V)**	**Maximum (V)**			**V_f Min. Hot T_C = 105°C** (V)	**V_f Max. Cold T_C = -40°C** (V)
270	**32.4**	**35.0**	**37.6**	**-16.1**	**0.49**	**31.1**	**38.7**
540	34.9	37.8	40.6	-16.1	0.57	33.6	41.6

Example from Vero SE 10 Array Series datasheet

Notes for Table 5:

1. Parts are tested in pulsed conditions at the rated test current (indicated in bold font), Tj = 25°C. Pulse width is 10 ms.
2. Voltage minimum and maximum are provided for reference only and not a guarantee of performance.
3. Bridgelux maintains a tester tolerance of ± 100mV on forward voltage requirements.
4. Typical coefficient of forward voltage tolerance is ± 100mV for nominal current.
5. Thermal resistance values are based from test data of a 3000K 80CRI product.
6. Thermal resistance value was calculated using total electrical input power optical power was not subtracted from input power. The thermal interface material used during testing is not included in the thermal resistance value.
7. V_f Min hot and V_f max cold values are provided as reference only and are not guaranteed by test. These values are provided to aid in driver design and selection over the operating range of the product.
8. This product has been designed and manufactured per IEC 62031:2014. This product has passed dielectric withstand voltage testing at 1160V. The working voltage designated for the insulation is 80VDC. The maximum allowable voltage across the array must be determined in the end product application.

The power rating of the driver to be designed or selected will need to deliver 270mA at the maximum V_f expected. 270mA x 37.6V would mean that the output power of the LED driver selected will have to be no less than 10.15W, and a 12W driver would probably be an appropriate choice (with typical 15% safety margin built in). It should also be confirmed that the driver will maintain acceptable current regulation down to a 31.1V output (even at Tc 105C operating condition), so that compatibility over array production variations will be maintained.

If it is desired to operate at a drive level other than 270mA, the current vs. voltage graph contained in the array data sheet can be consulted to determine the required Vout range for the driver.

LED Driver Design and Selection Considerations

It is the responsibility of the system designer to ensure that the selected LED driver meets all local regulatory requirements. Bridgelux also recommends considering the following specifications when selecting or designing an LED driver.

Power Factor

The power factor of an AC electric power system is defined as the ratio of the real power to the apparent power, specified as a number between 0 and 1. A power factor of 1.0 is the goal of any electric utility. For LED drivers, power factors greater than 0.9 are recommended.

Efficiency

Many lighting applications are governed by local energy use requirements, such as ENERGY STAR, Title 24, Part L and other global standards. As these requirements are based on not only the array but on the entire lighting system, it is important to select a driver with an appropriate efficiency to meet these regulatory requirements. Driver efficiencies can range from 50% to 95% for switch-mode power supplies depending on the design and manufacturer. Losses are typically due to switching, internal resistances, and transformer selection. Efficiencies may also vary considerably as a function of the load. Bridgelux recommends designing or selecting LED drivers that are highly efficient over the range of loads expected in the lighting system.

Reliability

The expected life of the LED driver should match that of the array over the required operating temperature range of the lighting system. Vibration, heat, moisture, and other environmental conditions can have negative effects on components that comprise the LED driver. For example; FETs typically have maximum junction temperatures of 125°C, electrolytic capacitors can dry out when exposed to heat, and mechanical vibrations can cause sensitive electronic assemblies to fail. It is important to consider these potential limitations during the component selection and design of the LED driver.

Safety

Please ensure compliance to all regulatory and approbation requirements. Certain approvals such as UL, CE and others may be required for the lighting system, which may pose requirements on output voltage, electrical isolation, maximum operating temperature, and other parameters critical to the design of the LED driver. It is the responsibility of the designer to ensure a safe and compliant design of not only the LED driver but of the entire lighting system.

Feedback Features

Some applications may benefit from, or require, LED drivers that include active feedback. For example a temperature sensor may be included to safeguard against thermal run away, adjusting the current in the event that a maximum case temperature for the array is reached or exceeded. Light or motion sensors may also be desired to provide feedback to the driver circuit, enabling additional system functionality and power saving capabilities in the lighting installation for some applications.

Ripple

Ripple is the small and unwanted residual periodic variation of the direct current output of an AC to DC LED driver. Ripple does not have any detrimental effect to the LED, but may cause objectionable visual effects. Bridgelux recommends using LED drivers with low ripple, defined as a ripple value of within ± 10%. While higher levels of ripple, especially if at frequencies above 120Hz may not yield any objectionable visual effects, care should be exercised to ensure that there is no problem with stroboscopic effects or possible medical hazards (i.e. triggering epileptic seizures)

Noise

Electromagnetic and radio frequency noise is not desirable and often regulated by standards. Care should be taken to specify an LED driver with low noise to avoid interference and/or violation of regulated standards.

Hot Swapping

Hot swapping is the ability to connect and disconnect an energized driver from the array without damaging the array. While most applications do not intentionally use hot swapping, hot swapping situations may occur during field installation if the driver is not integral in the luminaire. If hot swapping is possible, testing should be performed on the driver to make sure that it will not cause surge currents during the hot swap that can damage the array.

Commercially Available AC-to-DC Constant Current Source LED Drivers

There are many commercially available drivers that work well with Bridgelux arrays to enable rapid system design. Bridgelux works with many of these commercial LED driver manufacturers to confirm compatibility between our arrays and their drivers. Information on commercially available drivers that have been reviewed by Bridgelux can be obtained by contacting your local Bridgelux sales representative. Bridgelux does not warrant the suitability of any of these drivers for a particular application and it is the luminaire designer's responsibility to thoroughly evaluate the suitability of a driver to ensure that all application specific requirements are met. Always check with the supplier of the LED driver for the latest information, specifications and availability.

To illustrate the process of selecting a commercially available LED driver for a particular lighting luminaire, the same array, BXRC-xxx100x-B, will be used. The column data referenced below comes from the tables in the product data sheet.

By reading the "Current" column and the "Forward Voltage V_f" columns, it can be determined that for BXRC-xxx100x-B, the constant current output needed from the driver should be 270mA. At 270mA constant current source, the "Forward Voltage V_f" columns shows that the BXRC-xxx100x-B arrays have a distribution of V_f between 32.4V to 37.6V when the T_j = 25°C, and from the "Typical Temperature Coefficient of Forward Voltage" column, it's indicated that V_f will change at a rate of -16.1mV per °C rise in junction temperature. And this should be factored into the driver design or selection process such that the driver designed or selected will have to be able to deliver 270mA with output voltage between the V_f min and V_f Max adjusted for the junction temperature at the operating condition.

For example, assuming that a lighting luminaire is constructed with specification that the case temperature of the BXRC-xxx100x-B will be maintained at 60°C or lower, the junction temperature of the BXRC-xxx100x-B can be calculated using the information from the "Typical Thermal Resistance Junction to Case" column:

Tj at case temperature 60°C = 60°C + 0.49°C/W x 10.15W = 64.97°C

At Tj = 64.97°C, V_f min = 32.4V – 16.1mV/°C x (64.97°C - 25°C) = 25.96V

So the LED driver to be selected should be one with 270mA constant current output over an output voltage range of 25.96V to 37.60V or wider (in 25C ambient operating environment) and with minimum power rating of 12W (as we established in the previous section).

Driver manufacturers would list their driver products' key specifications similar to Table 2 below:

Table 2: Sample Driver Specifications

Model no.	Input	Output Voltage	Output Current	Power Rating
xxx	90-305VAC 47-63Hz	18-54 VDC	270mA Constant	20W

The results from the estimations done above can be used to assist in the selection of an appropriate LED driver.

Bridgelux arrays are tested and binned at their rated nominal current, a current optimized to deliver the desired performance in terms of lumen output and efficacy. In designing with the Bridgelux arrays, however, the designer is free to set the drive current to meet application specific requirements.

For example, a customer may decide to power the array at a drive current lower than nominal conditions to achieve a higher LED efficacy or to fall within thermal constraints in the system design. Alternatively, a customer may decide to drive the array at a higher drive current to deliver increased light output in order to meet application requirements. As long as the drive current is within the maximum rating for the array, there will be no electrical or optical problem driving at these alternative levels. Care must be given to ensure that the thermal solution is appropriate – especially at higher power levels. Please refer to Bridgelux Application Note AN30 "Thermal Management of LED arrays" for more information on thermal solutions.

The LED driver industry has developed many drivers with output currents in multiples of 250 and 350 mA based on nominal drive levels of commercially available LED components from many different LED manufacturers. As such, many constant current drivers exist with typical drive currents of 250, 350, 500, 700, 1000, 1050, and 1400 mA. In addition, there are many drivers with "programmable outputs" which can set the drive level as required either by switches, jumpers, external resistors or software programming tools. Dimmable drivers can be used, where the dimming function allows the desired drive level to be 'dialed in' by the luminaire manufacturer to meet the needs of the particular application.

Special Considerations for Selecting or Designing Drivers for Gen 7 LED Arrays

The Gen 7 arrays are different from previous Bridgelux array generations in one aspect: the driving current range is substantially wider while the overall array optical output efficacy is kept relatively constant.

Refer to the Gen 7 Vero SE 10 BXRC-30E1000-B-7x-SE part as an example of suggested nominal drive current levels, output and overall efficacy:

Table 3: Typical Product Performance at Alternate Drive Currents (from Vero SE 10 datasheet)

Part Number	CRI	Current (mA)	Typical V_f (V)	Typical Flux T_j = 25ºC (lm)	Typical Flux T_c = 85ºC (lm)	Typical Efficacy T_j = 25ºC (lm/W)
BXRC-30E1000-B-7x-SE	80	135	33.3	734	660	164
		180	33.8	963	863	158
		270	**35.0**	**1378**	1240	**146**
		405	36.4	2021	1798	137
		540	37.8	2590	2292	127

Within the current drive range of between 180mA and 540mA (3 times ratio), the efficacy remains within 15.5% of each other. The product manages to achieve the level of stable optical performance based on Bridgelux's advanced LED die and phosphor technology and high optical efficiency and high performance thermal management technologies.

The Gen 7 arrays are highly flexible and scalable LED light sources that allow luminaire designers to come up with broad product portfolios with a wide performance range based on identical optical and mechanical designs.

With such flexibility in the array, luminaire designers may wish to pick one driver model to cover the full series of luminaires at different light output levels based on the current setting on the driver. This way, only one driver need be stocked for a complete series of different models of luminaires.

To do this, the driver should have a voltage output range wide enough to cover the driving requirements of the Gen 7 array at the different current levels expected.

If the Gen 7 array based lighting series consists of three models that require to be driven at 270mA, 405mA and 540mA respectively, below is how the driver output voltage range and power handling capability is determined (using the information contained in the electrical characteristics of the Gen 7 Vero 10 datasheet, shown in Figure 16 of this application note):

1. Power handling capability: Maximum power = 21.63W = 540mA x 40.6V (this is the max V_f of BXRC-30E1000-B-7X-SE when driven at 540mA).
2. Driver output high end voltage = 40.6V + additional voltage needed to account for cold start up in certain geographic location (e.g. -40C for some outdoor application in the northern territories see page 18 for detailed calculation method and for -40C the V_f is expected to be 1.05V higher so V_f max can be as high as 41.65V in this condition).
3. Driver output low end voltage = 34.9V – V_f de-rating expected when the LED runs up to operating temperature at steady state, e.g. T_C = 85C (34.9V is the 25C V_f min of BXRC-30E1000-B-7X-SE when driven at 540mA) Note: If "analog" dimming is being used, the output low end voltage will need to go lower. In this case, check the driver manufacturer's data sheet carefully to determine if the minimum output voltage range accounts for dimming or not . Figure 17 illustrates the MIN and MAX values on the IV curve which were generated from the product simulator. The product simulator can be downloaded from www.Bridgelux.com.

For this example, seek out a 25W or larger driver with an output voltage range of 30V to 42V or wider.

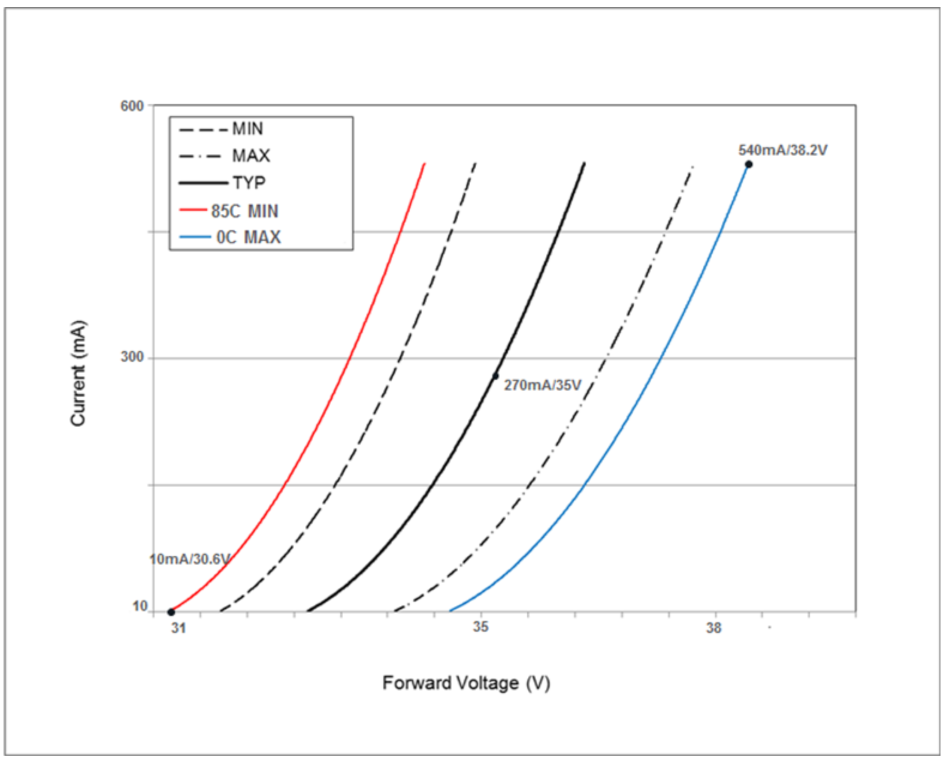


Figure 17: BXRC-30E1000-B-7X-SE Array IV curve with MIN and MAX limits

Power handling capability and maximum output voltage is determined by characteristics of the array at the maximum current drive level and at lowest start-up temperature condition.

Minimum output voltage of the driver is determined by the characteristics of the array at the minimum current drive level and at maximum expected junction temperature in steady state operation.

Custom LED Drivers

Depending on the application requirements, designing a custom LED driver may have advantages for a given lighting system. Custom LED drivers are typically IC based solutions, requiring a DC input voltage. These drivers may be advantageous in the fact that they can deliver miniaturized designs. Several IC suppliers have standard driver ICs with associated reference designs available to enable the development of suitable drivers for Bridgelux arrays. These designs can be "customized" to meet application specific needs and are capable of working with a wide spectrum of input and output requirements.

Information on IC driver solutions that have been reviewed by Bridgelux can be obtained by contacting your local Bridgelux sales representative. Bridgelux does not warrant the suitability of any of these IC driver reference designs for a particular application and it is the luminaire designer's responsibility to thoroughly evaluate the suitability of a driver to ensure that all application specific requirements are met. Always check with the supplier of the LED driver IC for the latest information, specifications and availability.

Design Resources

References

Steve Winder. Power Supplies for LED Driving. Oxford: Elsevier, 2008. ISBN: 978-0-7506-8341-8

Appendix A: Gen 7 Array V_f Bin

Table 4 provides the Gen 7 Array V_f bin in 0.5V increments.

Table 4: V_f Bin Code

V_f (V)	V_f Bin Code
≥ 10.0	1A
≥ 10.5	1B
≥ 11.0	1C
≥11.5	1D
≥ 12.0	1E
≥12.5	1F
≥ 13.0	1G
≥ 13.5	1H
≥ 14.0	1J
≥ 14.5	1K
≥ 15.0	1L
≥ 15.5	1M
≥ 16.0	1N
≥ 16.5	1P
≥ 17.0	1Q
≥ 17.5	1R
≥ 18.0	1S
≥ 18.5	1T
≥ 19.0	1U
≥ 19.5	1V

V_f (V)	V_f Bin Code
≥ 20.0	2A
≥ 20.5	2B
≥ 21.0	2C
≥ 21.5	2D
≥ 22.0	2E
≥ 22.5	2F
≥ 23.0	2G
≥ 23.5	2H
≥ 24.0	2J
≥ 24.5	2K
≥ 25.0	2L
≥ 25.5	2M
≥ 26.0	2N
≥ 26.5	2P
≥ 27.0	2Q
≥ 27.5	2R
≥ 28.0	2S
≥ 28.5	2T
≥ 29.0	2U
≥ 29.5	2V

V_f (V)	V_f Bin Code
≥ 30.0	3A
≥ 30.5	3B
≥31.0	3C
≥ 31.5	3D
≥ 32.0	3E
≥ 32.5	3F
≥ 33.0	3G
≥ 33.5	3H
≥ 34.0	3J
≥ 34.5	3K
≥ 35.0	3L
≥ 35.5	3M
≥ 36.0	3N
≥ 35.5	3P
≥ 37.0	3Q
≥ 37.5	3R
≥ 38.0	3S
≥ 38.5	3T
≥ 39.0	3U
≥ 39.5	3V

V_f (V)	V_f Bin Code
≥ 40.0	4A
≥ 40.5	4B
≥ 41.0	4C
≥41.5	4D
≥ 42.0	4E
≥42.5	4F
≥ 43.0	4G
≥ 43.5	4H
≥ 44.0	4J
≥ 44.5	4K
≥ 45.0	4L
≥ 45.5	4M
≥ 46.0	4N
≥46.5	4P
≥ 47.0	4Q
≥ 47.5	4R
≥ 48.0	4S
≥ 48.5	4T
≥ 49.0	4U
≥ 49.5	4V

V_f (V)	V_f Bin Code
≥ 50.0	5A
≥ 50.5	5B
≥ 51.0	5C
≥ 51.5	5D
≥ 52.0	5E
≥ 52.5	5F
≥ 53.0	5G
≥ 53.5	5H
≥ 54.0	5J
≥ 54.5	5K
≥ 55.0	5L
≥ 55.5	5M
≥ 56.0	5N
≥ 56.5	5P
≥ 57.0	5Q
≥ 57.5	5R
≥ 58.0	5S
≥ 58.5	5T
≥ 59.0	5U
≥ 59.5	5V

V_f (V)	V_f Bin Code
≥ 60.0	6A
≥ 60.5	6B
≥61.0	6C
≥ 61.5	6D
≥ 62.0	6E
≥ 62.5	6F
≥ 63.0	6G
≥ 63.5	6H
≥ 64.0	6J
≥ 64.5	6K
≥ 65.0	6L
≥ 65.5	6M
≥ 66.0	6N
≥ 66.5	6P
≥ 67.0	6Q
≥ 67.5	6R
≥ 68.0	6S
≥ 68.5	6T
≥ 69.0	6U
≥ 69.5	6V

V_f (V)	V_f Bin Code
≥ 70.0	7A
≥ 70.5	7B
≥ 71.0	7C
≥71.5	7D
≥ 72.0	7E
≥72.5	7F
≥ 73.0	7G
≥ 73.5	7H
≥ 74.0	7J
≥ 74.5	7K
≥ 75.0	7L
≥ 75.5	7M
≥ 76.0	7N
≥76.5	7P
≥ 77.0	7Q
≥ 77.5	7R
≥ 78.0	7S
≥ 78.5	7T
≥ 79.0	7U
≥ 79.5	7V

Appendix B: 2 Parallel Gen7 Arrays

Tables 5a and 5b provides an estimate on the current hogging when two Gen 7 arrays are placed in a parallel configuration and when the arrays are driven at nominal current and 1.5 times the nominal current.

Table 5a: 1x I_f per Array at T_C=85C Model Results

Product Family	$I_{f,AVG}$ (mA) per Array	V_f (V)	P(W)	I_f Min Array (mA)	I_f Max Array (mA)	Current Hogging
V 10B Vero 10B Vero SE 10B	270	34.0	9.2	249	291	16.9%
V 10C Vero 10C Vero SE 10C	360	34.0	12.2	332	388	17.1%
Vero 10D Vero SE 10D	350	25.5	8.9	315	385	22.5%
V 13B Vero 13B Vero SE 13B	450	33.9	15.2	411	489	19.0%
V 13C Vero 13C Vero SE 13C	630	33.9	21.3	577	683	18.5%
Vero 13D Vero SE 13D	500	31.0	15.5	457	543	19.0%
V 18B Vero 18B Vero SE 18B	900	33.9	30.6	827	973	17.7%
V 18C Vero 18C Vero SE 18C	1170	33.9	39.7	1074	1266	17.9%
Vero 18D Vero SE 18D	1050	28.4	29.9	953	1147	20.4%
V 22B	1170	50.5	59.1	1107	1233	11.3%
V 22C	1440	50.5	72.2	1360	1520	11.7%
V 22D	1400	34.8	48.7	1291	1509	16.8%
Vero 29B Vero SE 29B	1800	50.5	91.0	1700	1900	11.8%
Vero 29C Vero SE 29C	1710	67.4	115.2	1639	1781	8.6%
Vero 29D Vero SE 29D	2100	36.6	77.0	1975	2225	12.6%

Table 5b: 1.5x I_f per Array at T_C=85C Model Results

Product Family	$I_{f,AVG}$ (mA) per Array	V_f (V)	P(W)	I_f Min Array (mA)	I_f Min Array (mA)	Current Hogging
V 10 B Vero 10B Vero SE 10B	405	36.5	14.4	381	429	12.3%
V 10 C Vero 10C Vero SE 10C	540	35.4	19.1	527	592	12.4%
Vero 10D Vero SE 10D	525	26.7	14.0	486	564	16.1%
V 13 B Vero 13B Vero SE 13B	675	35.2	23.8	630	720	14.2%
V 13C Vero 13C Vero SE 13C	945	35.2	33.3	885	1005	13.6%
Vero 13D Vero SE 13D	700	32.1	22.5	654	746	14.2%
V 18B Vero 18B Vero SE 18B	1350	35.4	47.8	1266	1434	13.2%
V 18C Vero 18C Vero SE 18C	1755	35.4	62.1	1645	1865	13.3%
Vero 18D Vero SE 18D	1575	29.7	46.8	1465	1685	15.0%
V 22B	1755	52.7	92.49	1685	1825	8.3%
V 22C	2160	50.5	109.1	1360	1520	11.7%
V 22D	2100	36.2	78.0	1965	2235	13.7%
Vero 29B Vero SE 29B	2700	52.6	142.0	2585	2815	8.9%
Vero 29C Vero SE 29C	2565	70.1	179.9	2483	2647	6.6%
Vero 29D Vero SE 29D	3150	38.6	121.6	3012	3288	9.2%

Appendix C: Parallel Gen7 Array Configurations for UL Class 2 Indoor Dry

Tables 6a and 6b provides an estimate on the number of parallel arrays possible for the Gen 7 Arrays to meet UL Class 2 indoor dry conditions when the arrays are driven at nominal current and 1.5 times the nominal current along with an approximate Min and Max current through the array in a parallel configuration. Customers are advised to check current UL indoor dry Class 2 driver specification for their application.

Class 2 has the following characteristic:

- < 60V 100W max

Table 6a: 1x I_f per Array at T_C=85C Model Results

Product Family	$I_{f,AVG}$ (mA) per Array	V_f (V)	P(W)	Max # Parallel Arrays	I_f Min Array (mA)	I_f Max Array (mA)	Current Hogging
V 10B Vero 10B Vero SE 10B	270	34.0	9.2	10	266	308	16.0%
V 10C Vero 10C Vero SE 10C	360	34.0	12.2	8	353	410	16.3%
Vero 10D Vero SE 10D	350	25.5	8.9	11	336	407	21.3%
V 13B Vero 13 B Vero SE 13B	450	33.9	15.2	6	437	516	18.1%
V 13C Vero 13C Vero SE 13C	630	33.9	21.3	4	603	711	17.8%
V 18B Vero 13D Vero SE 13D	500	31.0	15.5	6	485	573	18.0%
V 18C Vero 18B Vero SE 18B	900	33.9	30.6	3	851	998	17.3%
Vero 18C Vero SE 18C	1170	33.9	39.7	2	1074	1266	17.9%
Vero 18D Vero SE 18D	1050	28.4	29.9	3	985	1181	19.9%
V 22B	1170	50.5	58.5	1	-	-	-
V 22C	1440	50.5	72.7	1	-	-	-
V 22D	1400	34.6	48.7	2	1291	1509	16.8%
Vero 29B Vero SE 29B	1800	50.5	91	1	-	-	-
Vero 29C Vero SE 29C	1710	67.4	115.2	N/A*	-	-	-
Vero 29D Vero SE 29D	2100	36.6	77	1	-	-	-

***N/A (Not Applicable): Does not meet Class 2 requirement**

Table 6b: 1.5 x I_f per Array at T_C=85C Model Results

Product Family	$I_{f,AVG}$ (mA) per Array	V_f (V)	P(W)	Max # in Parallel Arrays	I_f Min Array (mA)	I_f Min Array (mA)	Current Hogging
V 10B Vero 10B Vero SE 10B	405	36.5	14.4	6	397	445	12.0%
V 10C Vero 10C Vero SE 10C	540	35.4	19.1	5	527	592	12.4%
Vero 10D Vero SE 10D	525	26.7	14.0	6	512	592	15.6%
V 13B Vero 13B Vero SE 13B	675	35.2	23.8	4	652	743	13.9%
V 13C Vero 13C Vero SE 13C	945	35.2	33.3	3	905	1026	13.4%
Vero 13D Vero SE 13D	700	32.1	22.5	4	677	770	13.9%
V 18B Vero 18B Vero SE 18B	1350	35.4	47.8	2	1266	1434	13.2%
V 18C Vero 18C Vero SE 18C	1755	35.4	62.1	1	-	-	-
Vero 18D Vero SE 18D	1575	29.7	46.8	2	1011	1208	19.5%
V 22B	1755	52.7	92.5	1	-	-	-
V 22C	2160	52.3	113.0	N/A *	-	-	-
V 22D	2100	34.8	72.0	1	-	-	-
Vero 29B Vero SE 29B	2700	52.6	142.0	N/A *	-	-	-
Vero 29C Vero SE 29C	2565	70.1	179.9	N/A *	-	-	-
Vero 29D Vero SE 29D	3150	38.6	121.6	N/A *	-	-	-

***N/A (Not Applicable): Does not meet Class 2 requirement**

Disclaimer

This application note has been prepared to provide guidance on the application of Bridgelux LED arrays in customer products. Bridgelux provides this information in good faith, but does not assume any responsibility or liability for design deficiencies that might exist in the design based on the information contained in this document.

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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.

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