What You Need To Know Before Buying LED Cluster Lighting for Your Yacht

by

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Over the course of the past several months, dozens of customers have come to me very interested in the benefits of LED cluster lighting, but have explained that they are very wary of the claims surrounding LED lighting for marine applications, either because they have already had a bad experience with 12V LED products, or because they have heard a horror story, or two. Their confusion stems from the broad spectrum of products available, the wide range of pricing, and the general lack of information available to us as marine users.

Recently one of my customers suggested that I write a "white-paper" which condenses the information into a sort of "idiot's guide" to LED lighting for yachties. So, without getting too deep into the physics of things, the goal of this paper is to provide you with the necessary facts about the various forms of LED lighting, and to help you choose which LED products you should consider for use on your yacht. While this document is intended to give you the necessary information to choose between viable vendors as an informed consumer, we hope it will also allow you to understand why we at Marinebeam have chosen the components and technologies that we have, and why we think it adds significant value when offering a product for marine use.

It seems LEDs were made just for us yachties. LEDs are extremely long-lived, are impervious to vibration, and if designed correctly, they give off very little heat, and use about a tenth of the wattage of a halogen while producing similar output. So why don't most 12V LED products work well on our boats? In the past, the answer was the poor level of light output and the cold-and-clammy blue color of the early "white" LEDs. Well, all that has changed recently, and LEDs now have a light output and color that is the equal to the low-wattage halogens we typically find on our boats. The problem these days is that the products now on the market are not designed for the voltage variations that we see on our yachts (thanks to our battery chargers, alternators, and other energy replacement devices). LEDs by their nature are extremely sensitive to voltage variations and almost all of the products sold for 12V use are not suitable for use on your boat. You will see why shortly, but first a little basic LED 101.

All LED's are semiconductor diodes. They create their light at their P-N junction, which is the area inside the LED where the P-type (positive) semiconductor material and the N-type (negative) materials meet. When the LED is connected to an electrical circuit the free electrons from one side are induced to jump to the other side of the junction, and in the process, energy is released in the form of photons (light). The elements in the semiconductor materials used in an LED determine the wavelength, and therefore the color, of the light produced. In the warm white lights we desire in yachts, the LEDs are based on InGaN (Indium Gallium Nitride) semiconductors, and use other materials like phosphors to attain the pleasing 3000 – 3500 degree Kelvin color temperatures we associate with incandescent lighting.

I mention the P-N junction because it is the heart of the LED. If we apply the right amount of current to the junction, we get a beautiful, bright, energy-efficient light that will live tens of thousands of trouble-free hours. LEDs have just one enemy, and that is heat. Heat at the P-N junction is deadly to LEDs. It is excessive current at the junction that creates the heat, and the LED must either control the heat produced (through thermal efficiency), or dissipate it effectively, or the LEDs will die a quick death. As a general rule of thumb, every 10° C drop in junction temperature will double the life of the LED.

If we apply lots of current to the LEDs we will get a very bright light, but for a very short period of time. Conversely, if we don't feed the LEDs enough current, we get a very dim light. It is important to know that the current that is seen at the junction is roughly proportional to the LEDs source voltage, so voltage control, and thus current control, is very important.

Almost all of the inexpensive 12V LED cluster bulbs being sold today use a ballast resistor which bleeds off energy to limit the current. A ballast resistor can limit current according to a simple formula, which is: Voltage/Resistance = Current. So, if one knows the current required by the LED and also knows the source voltage, it is easy enough to select the correct ballast resistor for the resistance part of the equation. One can see from the formula that if the resistance is constant, and the Voltage goes up (or down), so does the Current proportionately. It follows then that the current can only be limited if the Voltage is limited. So, a ballast resistor would work fine if the voltage source is a transformer plugged into the wall that is providing a constant 12VDC. At precisely 12V the ballast resistor will just bleed off the excess energy in the form of heat, and the LED will be happy running at the right current. At anything but precisely 12V the current will vary, and so will the temperature at the P-N junction.

The most important point of all this is what happens to the current when the battery charger goes into its equalization stage and is no longer providing our sensitive little ballast resistor bulbs with *exactly* 12V, but is now providing 25% more power at 15V. Or worse yet, what happens during certain load-dumping situations where your 12V circuits can see transients of 20V or more? You guessed it; we are now way-overdriving our LEDs, and shortening their lives by a significant margin. It is actually worse than the 25% increase you expected. Because the LEDs themselves have a voltage drop of around 3V, the current has actually increased more than the 25% that the voltage increased. Additionally, that poor little ballast resistor is bleeding off that 25% more energy in the form of heat, which is captured in the stagnant air of your little fixture, in that hot stuffy boat. Not good.

Ballast resistors are, overall, a bad and inefficient way to control voltage and current on LED cluster lighting used on a boat. The result is the disappointment in LED lighting that you have heard about from all your cruising friends.

I recently tested a $17 "anchor light" cluster bulb that I bought from a well-known internet vendor. It was touted as a "marine-quality". I powered up this bulb using a 13.5V source to point out some of its deficiencies in a short video I was making, and this "marine-quality" bulb lasted only 3 or 4 minutes before it lost a third of its LEDs. Not surprisingly, a post-mortem showed the bulb not only had the wrong sized resistor, but it was a tiny resistor not rated for the power it was seeing. The bulb was also missing the circuitry it needed to accommodate either polarity. In other words, it was useless as a marine bulb, and a big waste of money.

So, the problem for us yachties is that we have battery chargers, alternators, solar panels, etc, and our source voltage varies all over the place. Well, a car charges its batteries too, right? If most "auto-store" bulbs use a ballast resistor why doesn't it work for boat? There are actually a couple of answers to this question. The first and most obvious reason is that a car doesn't have a large battery bank that gets depleted by 50% or more on a regular basis, nor does it see the huge swings in voltage that result when recharging deeply discharged batteries using sophisticated multi-stage chargers and regulators. The second reason is that in a car, LED clusters are principally used for indicators (turn signals, brake-lights, etc.) rather than for area illumination where absolute brightness is important. The trick that auto store bulbs use is to size the ballast resistor conservatively for 14V rather than for 12V, which gives them some headroom on current. Of course, the downside to that strategy is the bulb is now proportionately less bright at 12V. But who cares with a brake light? It looks cool enough.

Cheap auto store LED clusters suffer an additional problem. Due to variations in the LED manufacturing process, the specifications of individual LEDs in a manufacturing batch vary all over the map. These variations include brightness, color, forward voltage and maximum current. The industry offers a solution for this problem by utilizing a process called "binning". Binning is simply testing each and every LED for its characteristics, and then segregating the various LEDs into bins based on like characteristics. This is obviously an expensive process, and the manufacture gets a premium for a batch of these binned LEDs. Binning is especially critical when creating a cluster light consisting of many LEDs, both for controlling the current, and for ensuring consistent brightness and color. For tail lights, however, it doesn't matter, and the cheap auto-store clusters are usually made up of non-binned orphan LEDs. With China boasting of more than 3,000 LED foundries now, that translates into millions upon millions of orphan LEDs without a home. They practically give them away, and yes, you get what you pay for.

Hopefully the above makes it very clear why ballast resistor bulbs and cheapo bulbs have no place on a boat. If you have read and understood the previous paragraphs then you are now considerably better informed than the average Joe looking for LED lightings. To put an even finer point on it, you are also now better informed than most of the merchants out there selling LED bulbs to the unsuspecting boater.

So what do we really know so far? We know that the vast majority of bulbs sold as marine bulbs are really ballast resistor bulbs with orphan LEDs. We know that we have a variable voltage source on our yacht, and that is a fact not likely to change. We also know that a resistor is a passive device and can’t adapt the current to our changing voltage, so all ballast resistor bulbs are not worthy of our consideration.

So, what are our other options? What if we had a type of resistor which wasn’t a passive device, but was variable to accommodate the changing voltage? As it turns out, there is such a device, and it is utilized by many LED cluster manufacturers selling in the marine marketplace. The device is a Linear Regulator, and it is the next step up in control technology from the humble ballast resistor. A Linear Regulator is a low-cost control method which can be thought of as a variable resistor that varies the resistance according to the load in order to provide a constant output voltage to the LEDs. Because it is still a resistive device, it controls excess energy (above that required by the LEDs) by turning it into heat. While additional heat being added to an LED cluster can never be thought of as a good thing, a proper design can overcome some of these issues and allow this type of control to handle voltage safely over a small voltage range. A designer can manage this issue by stringing LEDs together in series in such a way as to match up their required voltage with that of the input source voltage. This way, very little energy is actually wasted as heat. This method requires a safety factor to give the LEDs some headroom against voltage variation. This margin of safety prevents the LEDs from being driven at maximum design brightness, so most LEDs driven in this way are being driven at something less than their design output. Linear Regulation is useful in very small clusters where there is not enough real estate for other more sophisticated driver controls. Linear regulators by their nature do not emit much RF interference.

So what else is available in state-of-the-art LED driver controls? It seems what we really need is a sort of closed-loop device that looks at the incoming voltage and maintains the current feeding the LEDs even as the voltage fluctuates. We need something that is very efficient at doing its job and doesn’t generate a lot of heat. As it happens, such a device exists. It is called a DC/DC Buck Power Converter. It is one of the more expensive ways to drive LEDs, but it has multiple advantages over other methods for 12VDC LED lighting applications.

The Buck Power Converter is a complex little device, but its function is somewhat simple. To describe it in layman’s terms, it basically takes an energy source and switches it on and off via a transistor, so that during the "on" state the energy is stored in an inductor, and during the “off” state the energy is discharged from the inductor to the load (the LED). The device has an oscillator or "clock" that switches it on and off. This on-off wave-form has a duty-cycle which is the ratio of its on-state to its total switching period. So, if it is on 25% of the time and off 75% of the time it has a 25% duty cycle. By using this method, the ratio of voltage-in to voltage-out is proportional to this duty cycle. So, if your oscillator is set to have a 25% duty-cycle and you put 12V in, you get 3V out. Controlling the voltage out by controlling the on time in a cycle is known as Pulse Width Modulation (PWM). You can think of it as a device that takes bits of energy, a piece at a time, from the input voltage, and regulates the rate at which the energy is transferred to the output load. Care must be taken in the design of these switching circuits to avoid any RF or EMI. The introduction of LEDs into the automotive and cell phone sectors has produced robust designs and filtering methods for reducing EMI and RF issues below the strict European Union (CE) thresholds.

We already know that LEDs require the current to be controlled to a constant value, and the Buck Power Converter controller does this by monitoring the current to the LEDs through a current-sense resistor and adjusts the duty cycle either up or down to correct the current. Increasing the duty cycle increases the voltage and current, and decreasing the duty cycle decreases the voltage and current. This design is highly efficient, and generates very little heat, which has the additional benefit of lowering component temperatures, which translates into longer life.

So, we now have a way to control the current efficiently, and this gives us the ability to push the envelope on the brightness of the LEDs without worrying that the source voltage fluctuations will take us past the maximum rated current of the LED. This leads us to one final issue to solve in order to make our bulbs the brightest marine-use replacement bulbs available, while still ensuring maximum life, and that is packaging; in other words, the form factor of the bulb itself. For most interior marine lighting applications, halogen marine lamps use a 10W G4 bulb, which is quite compact, so the fixtures tend to be small as well. Therefore, our replacement LED cluster bulb needs to be very small to be able to serve as a retrofit for the original halogen bulb. It also has to produce similar output and color to the original halogen, and still be able to dissipate heat. This ends up being quite a challenge.

There are two approaches to make lots of light in a small package, and each has its advantages and disadvantages and they are both acceptable. One is to use many small lower-powered through-hole LEDs clustered together in a small package, and the other is to use just a few high-powered surface mount device (SMD) LEDs arranged on a thermally efficient substrate for maximum heat dissipation. The best solution ends up being a compromise of three important issues: 1) Output; 2) Thermal Management; and 3) Form-Factor.

Because traditional through-hole LEDs are encapsulated in little plastic domes, and can only dissipate their heat through their little parallel legs, the power and output is necessarily lower. So, given that they have lower output, we just need to use more of them to get more light. Said a different way, the more LEDs we put in the cluster the brighter it gets. Unfortunately, the practical size limits for these lamps in G4 applications is about 21-LEDs in a 30mm diameter package. If we used more LEDs, we couldn't fit it into our marine fixtures. These 21-LED lamps can approach the output of a 10W halogen, but in order to get any brighter we would violate the available real-estate of most G4 fixtures.

The newer high-powered surface mount (SMD) LEDs used in high-output cluster products are specially designed to dissipate heat. Improvements in the quality and consistency of the constituent materials that make up the semiconductor layers allow higher forward currents to be applied to the junction, and more current translates into more brightness. With each individual LED being much brighter, we can get the equivalent of 10 to 15W with just 6-LEDs. Lower thermal resistance is another result of the improved design and manufacturing. In the case of the newer SMD clusters, this allows there to be approximately ½ of the temperature increase at the junction compared to that of traditional LEDs at the same current. Compared to a traditional through-hole LED, the surface mount package is by design much more efficient at heat transfer because it transfers the heat directly to the thermally efficient substrate which makes up the circuit board. The surface mount LEDs are not enclosed by a domed lens, again for heat transfer reasons, and as a result, the light distribution is much wider (120°) than with traditional LEDs.

It is clear that we can use higher-output LEDs and build a G4 cluster with an even brighter output, but we cannot maintain the G4 form-factor *and* dissipate the heat to allow it to survive in the confines of a G4 fixture. We could use just two 1W CREE LEDs to get the same output as a 6-LED SMD cluster, but we would then require a large heat sink to dissipate the heat. To give an example, a compact 18W LED lamp currently exists for boating applications, and has an output similar to a 100W spot-light! The only trouble is, it must be immersed 100% in water (under the hull) to aid cooling and avoid an instant death.

I hope that this information is useful when you consider purchasing quality LED products. With a little research you will find that there are just a handful of companies manufacturing and marketing LED clusters with constant-current control that are suitable for our yachts. It is interesting that all of these companies are owned by sailors.

The sad state of affairs right now is that because the marketplace is unaware of the differences between LED products, it is tough for the consumer to differentiate between the various products.

Nigel Calder, the god of everything electrical, wrote a truly comprehensive article about LEDs in the October/November 2008 issue of *Professional Boat Builder*, and said "In skimming through Marine chat sites on the Internet, I have noticed a number of unhappy boat owners who've had LED lights fail within *hours* of putting them into service --and others who've enjoyed years of service with no failures at all. It's clearly important to buy from reputable companies." He ends the informative article two pages later with the line "Again: make sure the product is sourced from a reputable manufacturer."

So how can we tell? Here are some basic rules:

- If the website or dealer doesn't specifically tout that he is selling DC/DC constant-current converter products, then there is a high likelihood he is not. Anyone selling a constant-current LED product will be sure to highlight that fact, and charge accordingly. In otherwords, you get what you pay for. Engage the proprietor and test his knowledge, and then you can be the judge.

- If the "marine" LED products are being sold by an outfit that also sells glow-in-the-dark ice cubes, garden lamps, camping lanterns, tail lights and Christmas lights, it is likely that he has no interest in the higher-cost high quality marine lights with constant-current. Don't go by looks alone, even if the price is tempting! We have counted dozens of websites using a picture of our bulbs to capitalize on the brand, but are then providing a cheap copycat product. See our copycat bulb pictures on the website.

- If the product specification or website just says 12VDC, or 12V-14V, without a range like 8V-30V or similar, it is not a constant-current product. Again buy from someone you trust, as we are seeing many false statements, voltage ranges, lumens, lifespans, etc.

- If it has a big beige, blue or red axial-leaded resistor, it is not a constant-current product.

- If it has a retail price of less than $20, it is likely not a constant-current product.
- If it dims or brightens as you vary the voltage (within its range), it is not a constant current product.

- Look for marine energy dealers or companies that are owned by cruisers. They usually know what they are talking about.

- Ask about the warranty and fitment guarantee, if any.

At Marinebeam we strive to offer a quality product in a useful form factor, at a reasonable price. All our products are CE approved, UV-safe, and most are lead-free.

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