Application of High Power Light Emitting Diodes for Submerged Illumination

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***Abstract*- High Brightness Light Emitting Diodes (HB-LEDs) are a reliable, efficient, compact, and robust light source for underwater applications including diver, ROV, AUV, free vehicle, and manned submersible platforms. LED lights are capable of single color or full daylight spectrum, offering unique solutions to oil field and other commercial problems. This paper will present differences and similarities between solid state and traditional lighting types, define specialized lighting terms for end users, and suggest near term and future developments. In-house pressure chamber work has shown pressure compensated LED arrays can be successfully operated to depths in excess of that found in ocean trenches. At-sea use of DeepSea Power & Light's LED-SeaLites® by divers, unmanned, and manned vehicles, will be shown.**

DeepSea Power & Light (DSPL) has been involved in advanced underwater lighting since the company's inception 25 years ago, and in severe environment LED lighting for over 10 years in a line of Pipe Inspection Video Cameras.

I. INTRODUCTION

A. Lighting up the Sea

LEDs match or surpass most traditional forms of lighting in terms of total light output and efficiency, and offer several advantages to undersea workers. Despite the initial appearance of simplicity, designers face a number of unique design challenges with optics, heat management, dimming control, and other characteristics before the full benefits of solid state lighting can be realized.

DeepSea Power & Light, known for adaptation of the most advanced lighting technologies to professional undersea applications, has developed and tested a new line of underwater LED-SeaLites® on manned vehicles, ROVs, and diver helmets.

B. LEDs versus traditional lighting

LEDs offer significant advantages over incandescent or gas discharge lighting, including: 1) rapid on-off switching without damage; 2) increased efficiency to maximize battery life and decrease umbilical size; 3) dimming without changing their emitted color, 4) ruggedness, vibration and shock resistance; 5) very long operating life (reduced total cost of ownership); 6) pressure tolerance; 7) choice of emitted spectrum; 8) unconstrained light array shape; 9) ability to operate in air without risk of damage to the fixture; and 10) smaller, lighter fixtures.

Figure 1. DeepSea Power & Light's LED Mini-SeaLite® combines the safety of low voltage DC with the high brightness of HB-LEDs, in lightweight, black anodized aluminum housing. Photo by Jennifer Crouch, DSPL

Adequate ability to remove heat from LEDs remains the biggest hurdle to high density LED arrays. Pressure compensated designs require components tolerant of direct exposure to the compressive squeeze of the deep sea. Some materials within some LEDs have been shown to react to pressure compensating fluids over time. LEDs and their driver circuits may cost more initially than traditional incandescent or gas discharge lamps of equal light output, but LED lights can provide significant cost savings compared to HID or halogen lamps when the total cost of ownership is considered. Well designed LED fixtures avoid the recurring costs associated with HID or halogen lamps including: routine replacement of the lamp; training technicians on the intricacies of seals, o-rings, and lubricants during lamp replacement; high cost of repair for damage caused by accidental air burn; and operational down time while a lamp is being replaced.

II. About LEDs

A. How LEDs work

An LED is a diode consisting of layers of semiconductor material. Light is generated when electrical current is driven through the LED, where bound electrons capture, then release electrical energy as a narrow spectrum or monochromatic light, in a phenomenon known as "electroluminescence." Different doping materials in the semiconducting material produce different colors of light. Most white LEDs are really blue LEDs with a coating of a single phosphor compound that absorbs the blue light and reradiates it as broad spectrum white light.

B. Power measurement

Technological advances have allowed creation of lighting fixtures with significantly higher efficiencies than in the past. The amount of power going into a lighting fixture, measured in "watts", was once a good indication of how much light you could expect to get out. Today, light output depends on the combined efficiencies of the control electronics + lamp + optics, specifically in the case of LEDs: drivers + LEDs + optics. LEDs make light from electricity, a phenomenon known as "electroluminescence," while traditional lamps make light from heat, a phenomenon known as "incandescence." Using different physics, LEDs produce the same amount of light using far less power than traditional incandescent light sources.

C. Lumens

Within the lighting industry, the preferred method of classifying light output of a luminaire, or light fixture, is by its visible energy output, typically called out in "lumens" (L).

A "lumen" is a measure of light that can be perceived by the human eye. Other familiar light appliances, including liquid crystal display (LCD) projectors, describe their products in lumen output, that is, their total projected visible light. Other metrics, including "lux" and "candlepower" are directional intensity measurements and don't measure a light's entire useable output. The same lamp, fitted first with a spot reflector, then a flood, will have the same number of lumens, but different lux values depending on where the measurement was taken in the beam and the distance from the light source. The best way to measure total lumens is with an integrating sphere, such as those manufactured by SphereOptics (Concord, NH). (Figure 2) An integrating sphere captures all the light emitted from a fixture inside a highly reflective sphere, removing any affect of reflectors or optics, producing a measurement of total light (including the visible spectrum) known as "Radiant Flux." The human perceptible portion (lumens) of the total radiant flux is then derived, usually by software, from the measured radiant flux.

D. Efficacy and Efficiency

The lighting industry defines efficacy as the ratio of the amount of visible light (L) produced by a light source, measured in lumens, to the energy used to produce it, measured in watts (w), and expressed as L/w. [1]

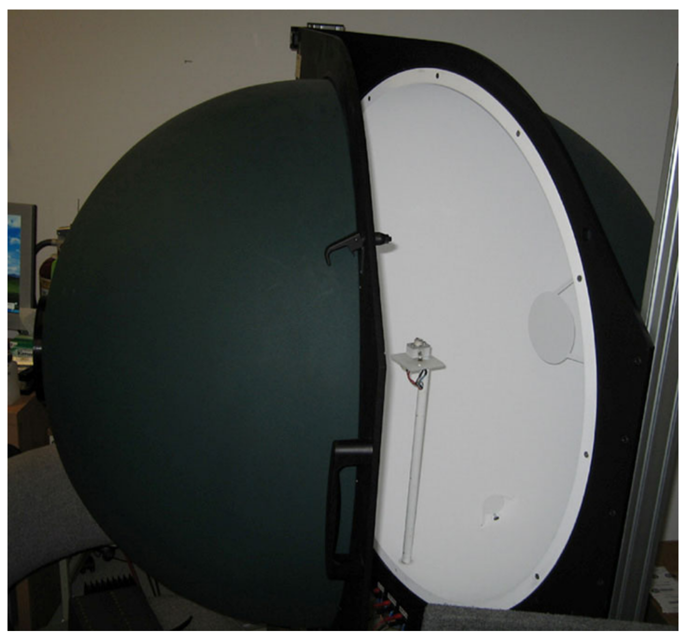

Figure 2. An Integrating Sphere provides a precise and repeatable measurement of total light and color emitted from a lamp.

The theoretical maximum efficacy of an LED light source is 683 L/w for pure monochromatic 550nm, yellow-green light.

The maximum luminous efficacy of an "ideal" white source, defined as a radiator with a constant output over the visible spectrum and no radiation in other parts of the spectrum is approximately 220 lumens per watt. [2]

Efficiency of a light source is calculated by dividing the total visible energy output in watts, by the electrical energy input in watts. This equation produces a result that has units in watts/watts which cancel each other out, and thus becomes a dimensionless number.

Efficacy and efficiency are sometimes interchanged in published sources, generating some confusion.

Even among LED manufacturers, there is disagreement on how to measure and report efficacy. Most prefer to report maximum light output from a single LED under ideal circumstances, optimized with a short electrical pulse and an instantaneous light measurement. DeepSea Power & Light prefers to measure the total output of the entire fixture after allowing the LEDs to reach thermal equilibrium. The latter method records less light, but is a more honest measurement that takes the net efficiency of the total system into account and is consistent with how the LEDs will be operated in the field.

Using the latter method, the efficacy of the current generation of LED fixtures is about five times greater than incandescent fixtures and is on par with all but the highest efficacy fluorescent sources.

E. Heat

LEDs, while very efficient, still produce heat. Unlike traditional sources which radiate heat as infra-red light in the beam, the heat generated by an LED stays inside the semiconductor material and must be extracted via conduction and dissipated to prevent overheating and failure.

Excessive heat within the LED can cause reduced lumen output, color temperature shifts, and lower life expectancies. Fortunately, the sea provides an ideal heatsink. Transferring heat from the back of the LED to the ocean volume must be done through the shortest path and fewest thermal barriers. Metal Core Printed Circuit Boards (MCPCB) are becoming standard practice, and methods to tie those to the housing challenge designers to minimize the thermal path.

F. Reliability

Because LEDs are solid state devices, there are no shock sensitive elements to be broken, such as glass envelopes or thin wire filaments. If designed and manufactured properly, LED arrays are highly reliable and have an extremely long life span.

G. Life expectancy

LEDs can due to fail open or closed circuit, and also due to driver failure. In principle, LED's themselves rarely fail catastrophically, but simply have a degraded output after many tens of thousands of hours. The LED industry group "Alliance for Solid-State Illumination Systems and Technologies (ASSIST)" created a new set of metrics to properly characterize LED life expectancy. They established LED life, or "lumen maintenance," as the time it takes for an LED to reach 70% of its initial light output[3]. In a perfect world, it is more likely that an operator will change an LED light engine to upgrade to a next generation higher lumen output than from failure of the LEDs.

Figure 3. A DeepSea Power & Light LED Multi-SeaLite® illuminates the field-of-view for Los Angeles County's Phantom ROV.

While manufacturers publish estimated life ratings for individual LEDs in enormous numbers of hours, a poorly designed fixture using a large array of LEDs may not have anywhere near this life rating. Individual LEDs can be rated at 50,000 hours or more, running cool in a controlled laboratory test environment. But dense LED arrays can suffer from inadequate heat sinking while left running in air on a hot deck. A good design will include a thermal sensing unit that rolls back the current and dims the LEDs when an elevated temperature is detected, reducing the supplemental heat generated by the LEDs and driver circuit, and insuring long life of the fixture.

H. Color Temperature

A "black body" material, one that totally absorbs any light striking it, will radiate specific visible wavelengths of light corresponding to a particular temperature, measured in degrees Kelvin (K). Hence, the color of light can be referred to as "color temperature". The surface of the sun is about 5880° Kelvin (5605° Celsius) which gives daylight its characteristic "whiteness". A higher temperature white (7000K), emits white light that has a bluer tint to it, while a cooler temperature white (4000K) emits white light that has a redder tint to it.

High power LEDs producing narrow spectrum Red, Green, Blue, UV, IR, and other colors are currently available, giving the designer control of the color output. Colors may be selected for a specific application by choosing an appropriate LED or combination of LEDs, avoiding filters that reduce light output and waste energy.

I. Pressure compensation

Unlike traditional vacuum and gas-based light sources, LEDs are solid-state devices, packaged in epoxy or silicone, making them inherently resistant to pressure affects. DeepSea Power & Light has successfully driven its LED light engines and custom drivers to 20,000 psi. Satisfactory solutions have been found, while advanced research continues to characterize alternative approaches.

J. Drivers

LEDs are best operated as current-driven devices. While voltage remains relatively constant, average current is varied to control light output. DeepSea Power & Light incorporates temperature compensation circuitry to reduce drive current when LED temperatures exceed a critical level which would cause damage or degradation to the LEDs. When operating from AC mains, power factor correction circuitry becomes important, particularly in higher-power fixtures. Power efficiency is paramount in reducing heat and minimizing burden on the power source. DeepSea Power & Light drivers are extremely efficient and support nearly any power source including wide-range DC (Direct Current), high-voltage DC, and universal AC (Alternating Current) mains. Efficiencies exceed 95% in some cases, with power factor correction near unity.

K. Compact Reflectors

While LEDs intrinsically direct their light forward in a "Cosine" or "Lambertian" distribution, the design of the LED reflector will make the difference between a spotlight for maximum penetration, and the uniform floodlight needed for videography.

L. System Design

A complete LED underwater light design will incorporate housing, window, reflector design, heat sinking, power and control elements to allow for the maximum output and reliability at the lowest cost and power consumption.

III. Future Applications

Advanced designs will pressure compensate both LEDs and driver circuits in architectures completely driven by the form of the craft.

While LED arrays can create near daylight spectrum, their real gift may be in the ability to generate narrow bands of pure monochromatic light. In the UV, oil leaks fluoresce, a powerful observational tool when matched by a camera sensitive to the re-radiated spectrum. Research suggests deep sea animals see primarily in the blue-green, having narrowed their sensitivity through natural selection to favor dominant bioluminescent colors. Red LEDs may not disturb the natural behavior of some species, or attract them to the light source. It may then be possible for ROV operators working on wellheads to avoid being blinded by congregating fish.

Additionally, test dives in June 2007 with the Woods Hole Oceanographic Institution's submersible, ALVIN, showed less backscatter and greater penetration in turbid bottom water using green LED lights compared to white. [4]

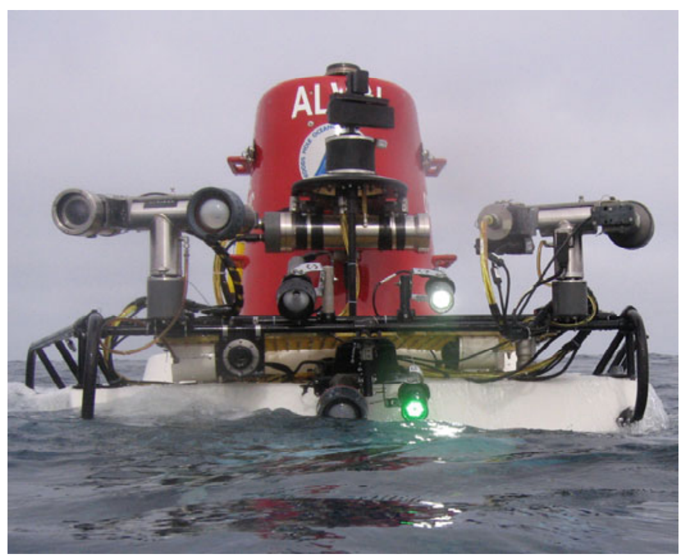

Figure 4. Woods Hole Oceanographic Institution's iconic submersible ALVIN begins a 1-mile dive with DeepSea Power & Light's LED SeaLites®.
Photo by Rod Catanach/Mark Spear, WHOI ALVIN Group.

DeepSea Power & Light has a number of LED projects working their way through Research and Development, including high power flat panel light fixtures for the next generation of deep ocean vehicles. Powered by light weight pressure-compensated batteries, the LED panels can provide light for long term time-lapse remote filming. Not far off, flat panel LED lights will encircle a submersible or ROV. The vehicle pilot can swivel a camera while sequential panels illuminate a sector, following the camera motion. A submersible, maintaining constant course, depth, and speed, can pass a target, filming it with constant illumination as the object approaches, passes, and recedes from view.

Other emerging topside marine applications of LEDs include oil platform, ship, buoys, safety, general lighting, and survival systems. LEDs are well suited for unattended operation, battery back-up, or hazardous environments.

IV. Conclusion

LED lights have created new opportunities for manned and unmanned vehicle designers. As LED technology improves, higher efficacy LEDs will produce less heat for the same light output or more light for the same power input. For the moment, not all traditional lights can be replaced by LEDs. But that day is coming.

Acknowledgment

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Footnotes

[1] http://en.wikipedia.org/
[2] IES reference volume, 1984, Section 2-6, Luminous Efficacy of Light Sources
[3] ASSIST, the Alliance for Solid State-State Illuminations and Technologies
[4]http://www.whoi.edu/page.do?pid=10897&i=2741&x=209

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