

LIFI™: A Long Life, Full Spectrum Light Source for Projection Display

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Abstract

This article presents a new long life, full spectrum and responsive light source called LIFI™. The first implementation of this lighting technology is in projection display but it can benefit other applications readily. Projection display, particularly micro-display projection HDTV and home theater front projectors, currently implement high-intensity-discharge (HID) light sources that transmit energy into gas plasma via metal electrodes. However, it is the electrodes that generate some failure modes for HID sources. LIFI™ presents a novel design where the light source gas is energized by an RF generated electric field. The result of this design is a stable light source that potentially lasts for the lifetime of the display. Furthermore, the flexible properties of the gas fill result in full spectrum and fast start time.

Introduction

Most modern projection display systems fall into two broad classifications. The first are micro-display HDTV products and the second are front projectors used for home theater entertainment, business presentation and education. The light sources required for these applications are characterized by high light output and low etendue. It is well known that these applications currently implement specialized HID sources since they possess the qualities of high intensity along with low area and angular extent.

However, due to the construction of HID sources, they have three major limitations that LIFI™ addresses. These are the lifetime of the HID sources in current use, their color range and the time required to rise to full brightness after application of power[1]. HID light sources are constructed by inserting or embedding metal electrodes inside a quartz enclosure. The current is discharged between the electrodes and thus energizes the gas and metal halide fill. While this mechanism generates high light output in a projection system initially, it promotes degradation phenomena that result in rapid loss of throughput, change in spectrum and lamp failure in several thousand hours. The electrodes lose material increasing the arc distance resulting in loss of throughput. The electrode material transfers to the walls of the enclosure resulting in filtration of various wavelengths. Finally, stresses induced at the electrode interface with the enclosure promote lamp failure over a wide span of time in unpredictable fashion. Thus, generating an intense lamp without metal electrodes has benefits for projection systems.



Figure 1: Image of LIFI™ model 4000

LIFI™ introduces a high intensity light source of novel construction that does not have electrodes inside the emitting enclosure. See figure 1. The enclosure is sealed and thus removes the dominant promoter of low lumen maintenance and lamp failure. Furthermore, LIFI™ has significantly higher spectral stability than other high intensity light sources. Finally, the LIFI™ system enables other significant benefits including rapid time to brightness and the ability to modulate the intensity dynamically.

Structure and Mechanism

The LIFI™ product consists of 5 primary sub-assemblies as seen in figure 2:

- Printed circuit board (PCB)
- RF power amplifier (PA)
- Bulb
- Optics
- Enclosure

The PCB controls the electrical inputs and outputs of the lamp and houses the microcontroller used to manage different lamp functions. An RF (radio-frequency) signal is generated by the PA and is guided into an electric field about the bulb. The high concentration of energy in the electric field vaporizes the contents of the bulb to a plasma state at the bulb's center; this controlled plasma generates an intense source of light. A set of optics is used to deliver the appropriate light beam to the application. All of these subassemblies are contained in an aluminum enclosure.

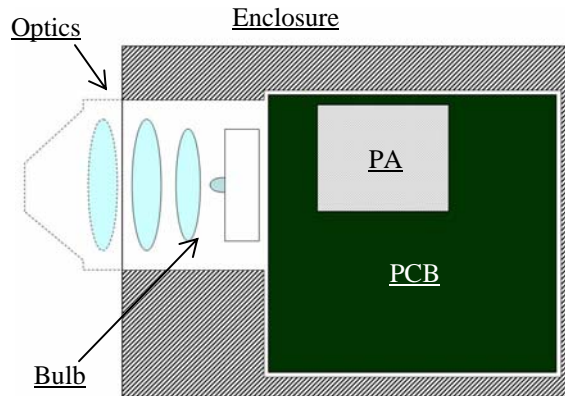


Figure 2: LIFI™ Block Diagram

Function of the Bulb Sub-Assembly

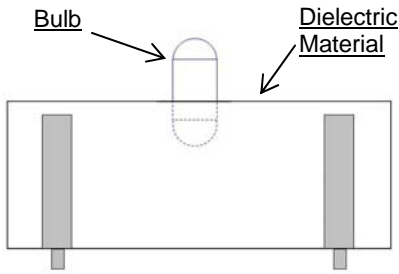


Figure 3: LIFI™ Bulb Sub-Assembly

At the heart of LIFI™ is the bulb sub-assembly where a sealed bulb is embedded in a dielectric material as diagramed in figure 3. This design is more reliable than conventional light sources that insert degradable electrodes into the bulb. The dielectric material serves two purposes; first as a waveguide for the RF energy transmitted by the PA and second as an electric field concentrator that focuses energy in the bulb. The energy from the electric field rapidly heats the material in the bulb to a plasma state that emits light of high intensity

and full spectrum[2].

Advantages over Alternative Lighting Systems

The following discusses the advantages of LIFI™ compared with alternative light sources potentially implemented in projection systems. In addition to the HID lamps typically used in projections systems, comparisons are made to Light Emitting Diode (LED) solutions that are also implemented in projection systems.

Lifetime and Lumen Maintenance

The apparatus for lifetime test of LIFI™ is composed of complete LIFI™ assemblies with PA, bulb and optics included. The assemblies are operated in a temperature controlled chamber at 25 °C ambient. At regular intervals, the assemblies are removed from the chamber and measured for lumen output by an integrating sphere.

LIFI™ shows stable lumen maintenance and the trend is projected to a typical value for the sample of 80% at 25,000 hours as shown in figure 4. This performance exceeds the lumen maintenance of the HID type lamps of comparable lumen output typically used in projection display. In addition, no failures of the bulb sub-assembly are observed. Initial failures due to faulty construction of the apparatus are removed from the sample. The bulb sub-assembly when re-constructed with the electronics typically produces full lumen output. Within the test duration exhibited a fraction of HID type lamps fail to operate[3].

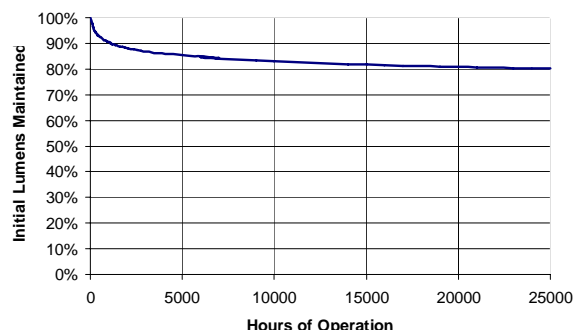


Figure 4: Lumen Maintenance vs. Operating Time

LED sources have longer lifetime than HID sources and do not typically exhibit lamp failure. However, lumen maintenance is typically a reduced value when LEDs are operated at high temperature and high drive current in projection display application[4]. Moreover the lumen maintenance differs between the red, green and blue LEDs in the system and this differential must be managed by sensors and electronic control. LIFI lumen maintenance retains its performance at high source temperatures typical in projection display and the color distribution maintains stability.

Color Spectrum and Chromaticity Maintenance

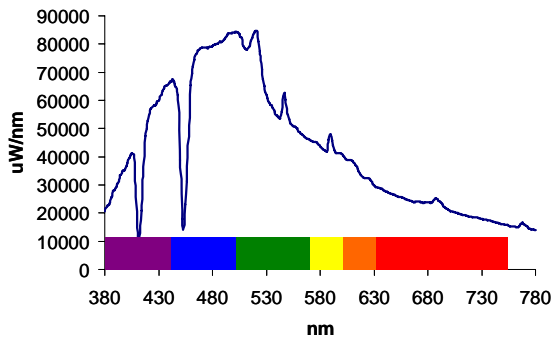


Figure 5: LIFI™ Spectral Power Distribution

The LIFI™ spectrum covers the wavelength range from 380nm to 720nm with relatively few discontinuities as figure 5 shows. The result of this comprehensive spectrum is that color gamut is increased in the projection display application. In particular the additional radiation in the red, green and cyan color range enhances color gamut. The resulting color performance of the display compares favorably against that produced by alternative light sources that do not produce a complete spectrum.

In addition, chromaticity stability is measured after 4252 hours of continuous operation. The relative change in chromaticity over the period examined is exhibited in figures 6 & 7. The change in Correlated Color Temperature (CCT) typically observed is less than 650K in 4252 hours.

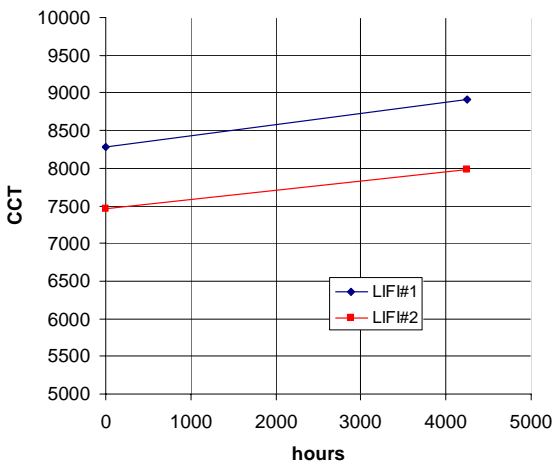


Figure 6: Change in CCT vs. Operating Time

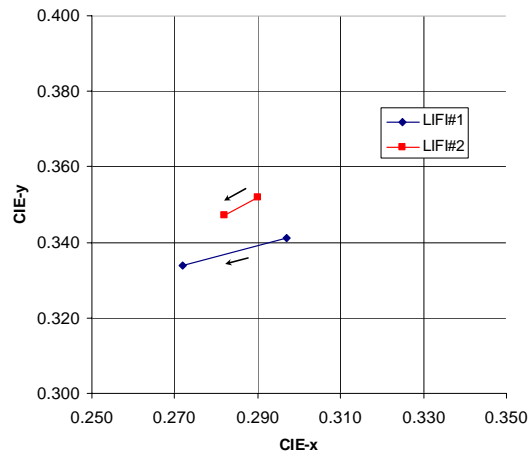


Figure 7: Change in Chromaticity in 4252 Hours Operation

LIFI's full color spectrum and chromaticity stability result in wide color range capability in projection display systems and the potential maintenance of the color quality for the life of the display system.

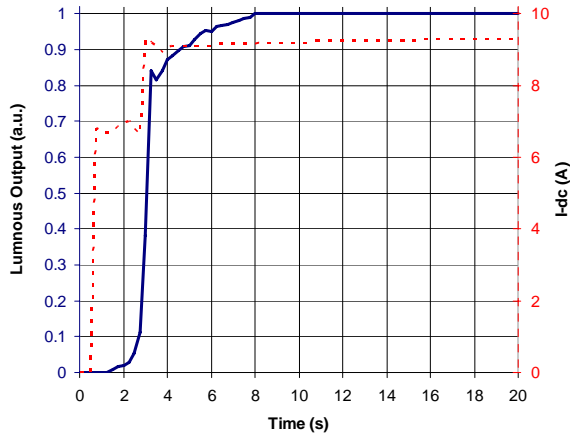


Figure 8: Time to Illuminate to Full Brightness

Start Time

The LIFI™ lighting system operates at relatively low pressure in a relatively low volume enclosure. Thus the time required to energize the plasma is typically less than 10 seconds. The time to full brightness curve is illustrated in figure 8. For practical purposes, the fast start time results in responsive projection display performance. The re-strike time for LIFI™ is typically less than 20 seconds from power shut down.

Dimming Response Time for Dynamic Contrast Improvement

A common technique to improve contrast and black levels in projection display consists of dynamically controlling the light output of the projection system. The brightness content of the video signal is continuously sampled and the light output is adjusted every few frames. In typical HID applications this is achieved by opening or closing a mechanical iris. With LIFI™ it is possible to achieve similar performance by varying the light output of the lamp itself. The light output is controlled by adjusting the frequency of the RF feedback loop. Lowering the frequency changes the feedback of the system. This results in less power to the bulb and therefore less light output. The response of the plasma is rapid enough for the dynamic darkness adjustment needed in projection display. The response time to go from 100% to 25% brightness is typically 50ms as exhibited in figure 9. Due to the thermal response of the bulb the time necessary to go from 25% to 100% increases slightly from this value. However, wide ranging transitions from the maximum to the minimum light output as discussed here are not typically required in the projection display application to achieve favorable contrast ratio. Thus, the practical response time for the dynamic brightness modulation is more rapid than the maximum case illustrated

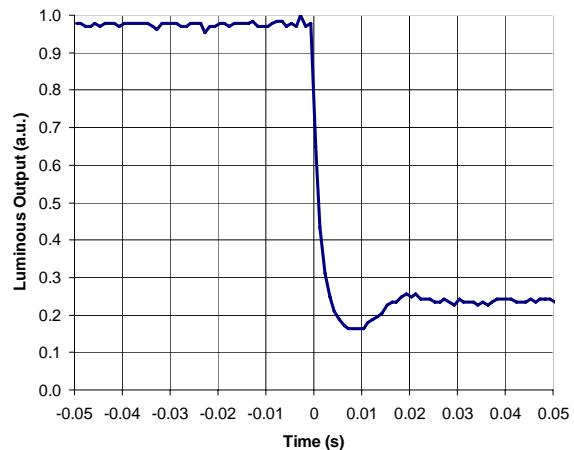


Figure 9: Response Time to Change Light Output Through Full Range

in figure 8. An additional benefit is the reduction in average power consumption when dynamic brightness control is implemented since the RF feedback loop draws less current. The power consumed is typically reduced to 58% of full power consumption when the LIFI™ is dimmed to 25% of full brightness.

Performance of LIFI™

LIFI™ in current production is the product LIFI™ model 4000 and its typical performance is contained in the chart below.

Chart 1 – LIFI™ model 4000 performance

Product Version	Lumen Output (typical)¹	Power Consumed (W)	Focused Spot size (mm)
Collimated beam	4000	270	-
Focused beam	4000	270	3

¹ Lumen output is measured by light captured in a reference cone of 27 mm²sr

Future Development Schedule

There are several areas of future development that may be addressed to increase the light output and efficiency of LIFI™ in projection display applications.

Optical Collection

In the current implementation lenses are used to collect the light from the bulb source and direct it to the projection engine. Future development addresses the collection optics by using different geometries or reflectors in order to increase efficiency.

RF Power Amplifier

Increasing the efficiency of the power amplifier module increases the efficiency of the overall lighting system. New power amplifier technology can be applied to increase the performance of LIFI™

Bulb Design

The sealed bulb has the advantage of enabling flexibility in the materials used to fill the bulb and contribute to the plasma source. Seeking materials with improved light output properties in the ionized state improves the light output efficiency and spectrum.

Thermal design

Improved cooling mechanisms applied to the bulb and the PA generates new designs that may have smaller or different form factor. For projection display applications, providing more light from a smaller assembly is explored.

Applications and Markets

The current LIFI™ implementation addresses the needs of micro-display projection television. The benefits of LIFI™ in this application are improved life and reduction of requirement to replace lamps during the lifetime of the display. In addition, display color range and time to full brightness are improved. Finally, the dimming of LIFI™ in responsive fashion results in increase to the dynamic contrast ratio of the display.

In order to implement LIFI™, the system requires a 28V power source and two cooling fans. One blower regulates the bulb temperature and one axial fan regulates the temperature of the heat sink base and PCB. This system is similar to the system currently implemented for HID light sources.

Additional applications for the current LIFI™ implementation are in fiber optic lighting. The ability to concentrate the light in a small spot size readily enables applications that distribute light in fiber of light pipe. These applications include medical lighting and imaging systems lighting.

As improvements are made in the future development schedule to the light output, efficiency and form factor of LIFI™, new applications are addressed. Front projectors benefit from the long life, color spectrum and responsiveness of LIFI™. Currently these applications use HID light sources that must be replaced each few thousand hours. In general, front projectors require light sources with more illumination power. The HID lamps used in current front projectors have light power between 20% and 100% higher than those used in micro-display projection HDTV.

Conclusions

In summary, LIFI™ presents a novel mechanism for intense light output for projection display applications. By removing electrodes, a dominant failure mode of HID, lifetime in the projection application is increased several fold. In addition, color spectrum is improved for more color range in the display. Finally, time to full brightness is reduced to provide a more responsive viewing experience and dimming dynamically increases the contrast capability of projection display.

Acknowledgements

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References

- [1] J. F. Waymouth, *Electric Discharge Lamps*, The MIT Press (1971)
- [2] M. Espiau, C. Joshi and Y. Chang, "Plasma Lamp with Dielectric Waveguide," U.S. patent no. 6,737,809 (2004)
- [3] Royal Philips Electronics N.V., "UHP-Control Room Segment", Dec 2003
- [4] Osram Opto Semiconductors, "Life Expectancy of LED Modules", 8 Feb 2005