

AN001 - LIFI™ Design Considerations for Projection Display

Abstract

This application note introduces the LUXIM LIFI™ technology and describes its integration into projection display systems. This document is intended for system integrators of projection televisions (PTV), front projectors and video walls.

This document refers to the LIFI-PRJ-20 Series (LUXIM part order codes LIFI-PRJ-20-02 and LIFI-PRJ-20-03).



The LIFI^ä Advantage

LIFI™ is a high intensity light source of revolutionary design. LUXIM uses a patented electrode-less lamp technology to create an ideal light source for projection display applications. Electrodes are the primary cause of failure in most high intensity discharge (HID) lamps used in projection display due to the degradation of the metal-glass seal in a high-pressure environment and the eroding of electrodes by the heated gas in the lamp.

Without electrodes in its design, LIFI™ offers long life (**20,000 hours**) and unprecedented survival rate to the system integrator. LIFI™ overcomes many shortcomings of conventional lamp technology, such as explosions and expensive lamp replacement schemes, while enabling large screen sizes in both televisions and home theaters.

Other benefits of LIFI™ include:

- Wide spectrum over the visible wavelength range
- Extremely high color fidelity
- Instant start-time
- Dynamic Dark - Brightness modulation of lamp output to enhance video contrast
- Easy thermal management
- Trouble-free integration into existing light engine platforms.

Table of Contents:

Abstract	1
The LIFI^â Advantage	1
Summary of LIFI^â Construction	3
Optical Performance	3
<i>Illumination and Collection Efficiency</i>	3
<i>Lamp Spectrum and Collection Efficiency</i>	4
<i>Color Management for DLP^â systems</i>	5
<i>Color Wheel Design Considerations</i>	5
<i>Color Management for LCoS/LCD systems</i>	5
<i>Time to Brightness</i>	8
Mechanical and Thermal Design	8
<i>Mounting and Alignment to Light Engine</i>	9
<i>Lamp Cooling</i>	9
<i>Bulb Cooling</i>	10
Electrical and Interface Requirements	11
<i>Connections to Light Engine and Lamp Controller</i>	11
<i>Input Power Requirements</i>	12
<i>Brightness Lock and Dynamic Dark Intensity Modulation</i>	12
Certification and Compliance	12
<i>Safety and Hazardous Materials</i>	12
<i>Electromagnetic Compatibility (EMC)</i>	12

Summary of LIFI[®] Construction

LIFI[™] offers an integrated light source that is straightforward to integrate into a projector. In this example LIFI[™] consists of 5 primary sub-assemblies:

- 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 and amplified by the PA and resonates about the bulb. The high concentration of RF energy energizes 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 this light to the projector; the arrangement of these lenses provides either a collimated or a focused beam of light. All of these subassemblies are contained in an aluminum enclosure.

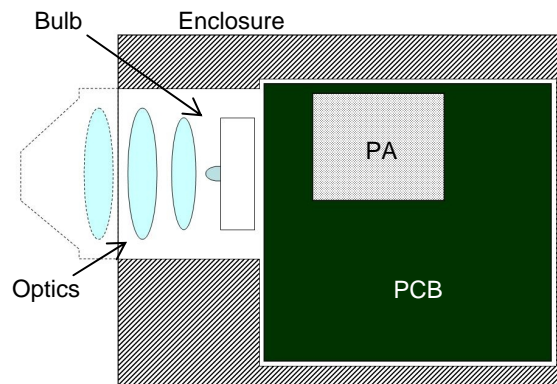


Figure 1: LIFI[™] Block Diagram

Optical Performance

Illumination and Collection Efficiency

In LIFI[™], a set of optics is used to convert light into an output that is efficiently accepted by the projector. For typical DLP[™] projectors, three lenses are used to focus the light. For typical x-LCD/LCoS projectors that require collimated light entering the first fly's eye homogenizer, a set of two lenses are used. The optical design of LIFI[™] allows the system integrator to convert between collimated output and focused output. This flexibility allows the use of the same lamp for most projector types.

	Collimated config.	Focused config.
# of lenses	2	3
f/#	8.0	1.0
Beam Diameter (mm)	40	NA
Focal Distance (mm)	NA	31

Table 1: Illumination condition for LCD and DLP[™] configurations

Figure 2: Optics arrangement for collimated output

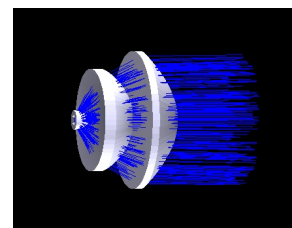
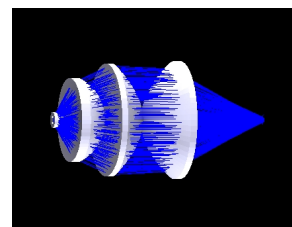


Figure 3: Optics arrangement for focused output



Lamp Spectrum and Collection Efficiency

LIFI™ is a high-efficacy light source with a broad spectrum over the visible wavelengths. The advantage of the LIFI™ spectrum derives in part from stronger emission in the red wavelengths allowing for a saturated red image and natural hues.

The broad spectrum also eliminates speckle or scintillation in the image, interference artifacts created when narrow-band coherent light sources are used for projection. Projector designs that use a coherent or narrow band light source, like a laser, require additional moving parts in the illumination path to reduce temporal coherence of light and reduce speckle.

Unlike laser and LED sources, the LIFI™ spectrum supports the implementation of Brilliant Color™ technology from Texas Instruments, Inc. Brilliant Color™ enables the use of secondary colors (Cyan, Yellow, and Magenta) to define the system color gamut in addition to the primary colors (Red, Green and Blue). This enables the system integrator to engineer a wide color palette and high quality image reproduction.

While the LIFI™ application discussed here is optimized for etendue ranges of 15 to 30 mm²sr, Figure 5 shows the etendue curve that characterizes the bulb source itself, showing a very high level of intensity.

The limiting etendue of the projection system is determined by the size (area) and acceptance angle of the imager:

$$E_{system} = \frac{p \cdot Area}{4 \cdot (F/\#)^2}$$

For typically available imager sizes in projection display, table 2 shows the amount of light available to the system designer using LIFI™. The amount of light that exits the projection lens for image brightness is a function of collected lumens, the transmission efficiency of the optics, the geometric loss in the system such as overfill and vignetting and the color balancing of the system.

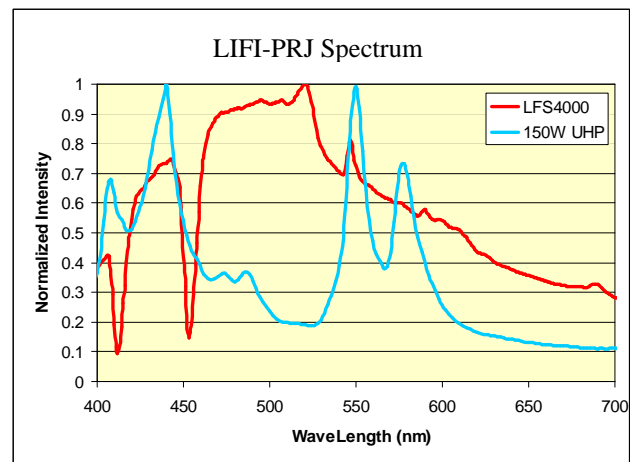


Figure 4: Chart comparing LIFI™ spectrum and mercury HID lamp typically used in projection display

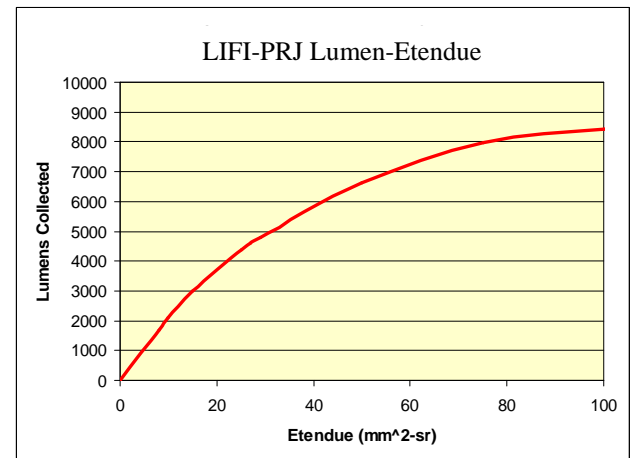


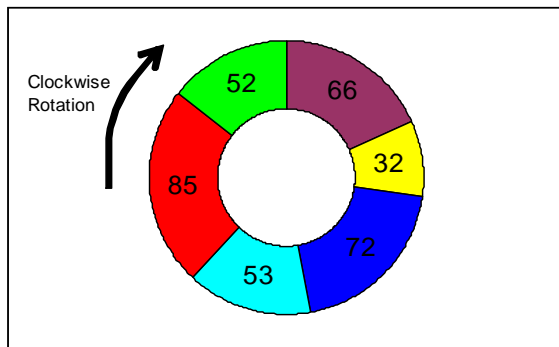
Figure 5: Lumens Collected vs. Etendue

Imager	Diagonal (in.)	f-number	Etendue (mm ² -sr)	Collected Lumens
LCoS	0.61	2.2	16.6	3250
DLP™	0.66	2.4	16.4	3200
LCD	0.74	2.2	24.5	4329

Table 2: Typical imager size, acceptance angle and amount of light that can be coupled into the projector system

Color Management for DLP^{ai} systems

RGB implementation enables acceptable projector functionality. However, LIFI's properties particularly enhance a Brilliant Color™ DLP™ system. Brilliant Color™ efficiently utilizes the LIFI™ spectrum in order to display with high brightness and wide color gamut. Using a 6 segment color wheel described in figure 6, the color balanced efficiency of 28.5% can be achieved. The resulting color gamut has saturated primaries and is 130% bigger than the SMPTE color gamut as shown in figure 7. With a single panel DLP™ light engine using a 0.66" xHD5 imager, greater than 340 lumens at 10,500 Kelvin can be realized as shown in table 3. This corresponds to greater than 560 nits on a 57" TV with a gain 4.7 screen.



	50% point	50% point	Slope	
G1	490	G2	580	<20
R	595			<20
C	570			<20
B	490			<20
Y	490			<20
M1	490	M2	590	<20

Figure 6: 6 primary color wheel design

Color Wheel Design Considerations

When designing a color wheel for a LIFI™ source, a few simple design considerations must be followed. Firstly, the 50% points of the dichroic filters must be changed to achieve the desired color gamut. This is due to the fact the LIFI™ provides a different light spectrum than a conventional HID lamp. Figure 6 shows a reference design for a 6 segment color wheel designed for Texas Instrument's BrilliantColor™ technology. In this design, yellow is used as a 'boost' segment only and Brilliant color matching and PWM artifact issues are minimized. The second consideration that must be followed is that

the dichroic filter must be designed with a weighted angle of incidence of 17 degrees to accommodate the LIFI™ angular distribution. This ensures an accurate resulting 50% point after the light passes through the color wheel filter.

Color Management for LCoS/LCD systems

In a 3-chip LCD/LCoS application, light is split into 3 colors with an imager dedicated to each of the colors. This allows higher color balance efficiency since all three imagers are 'on' during the full video frame rather than a single imager sharing a frame with all of the color primaries. However, the polarization requirement in LCoS and LCD systems renders about half the light non-usable. These two conditions roughly balance each other resulting in LCoS and LCD systems being roughly as efficient as DLP™ systems.

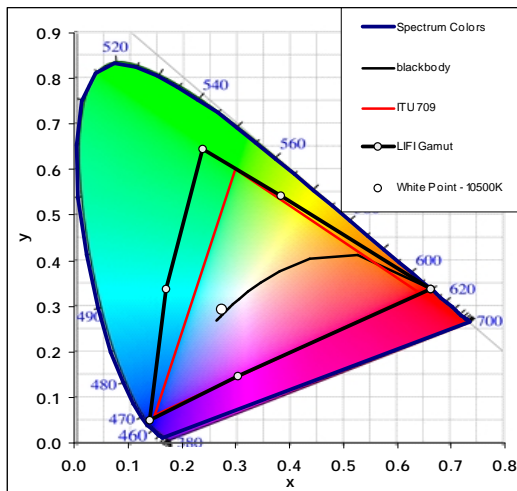


Figure 7: Color gamut for Brilliant Color™ projector illuminated by LIFI™

Input Lumens	2891
UVIR	96.0%
LP	96.0%
Relay Lens	96.0%
TIR_in	96.0%
DMD	65.0%
TIR_out	92.0%
PJ Lens	85.0%
Color Balancing	27.9%
Output Lumens	348
Screen Diag	57
Screen Gain	4.7
Nits	564

Table 3: Lumens budget for a DLP™ projector at 11,000 Kelvin using LIFI™

While specific system designs vary, LCD/LCoS architectures use shortwave wave pass (SWP) and long wave pass (LWP) dichroic filters at 45 degrees to split light into three colors. Trim filters are used to tune the color gamut. An example of 3-chip LCoS architecture is shown in figure 8. The blue color point is defined by the lower 50% point of the UVIR filter and the blue trim filter, the green color point is defined by the SWP and the green trim filter and the red color point is defined by the red trim filter and the upper 50% point of the UVIR filter. In this particular example, a color balancing efficiency of 48% can be realized. This allows greater than 330 lumens to reach the screen at 11,000 Kelvin as shown in table 4.

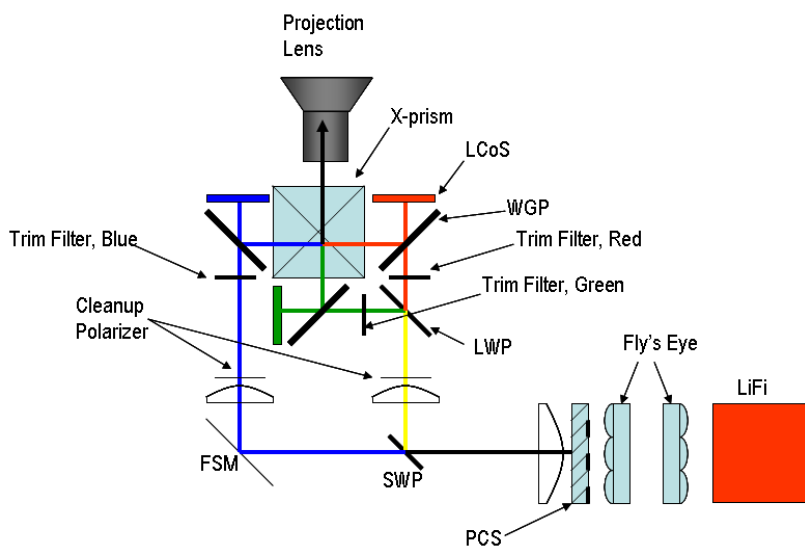


Figure 8: Schematic of LCoS architecture.

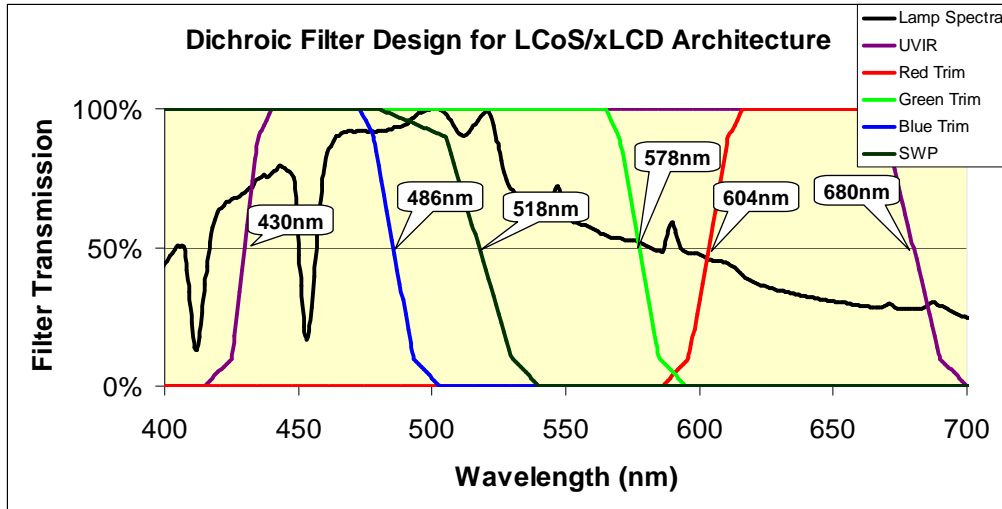


Figure 9: Dichroic filter reference design for LCoS/x-LCD system.

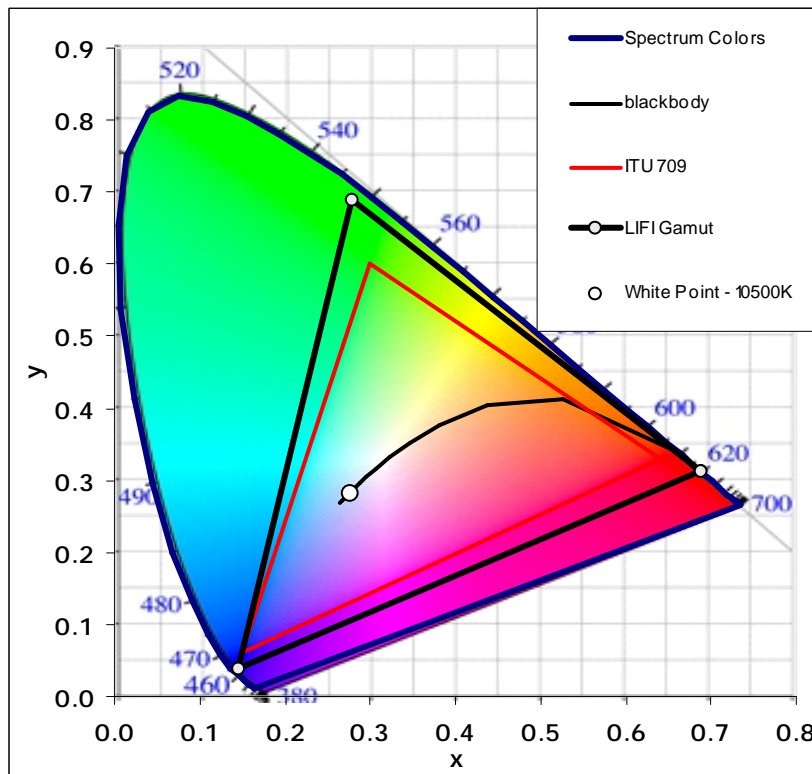


Figure 10: Color Gamut for LCoS/x-LCD projector using LIFI™.

xLCD	
Input Lumens	3771
UVIR	96.0%
Fly's Eye/PCS	60.0%
Fold Mirror	97.0%
Relay and Cleanup	90.0%
xLCD	55.0%
Cleanup/X-Cube	85.0%
PJ Lens	85.0%
Color Balancing	48.0%
Output Lumens	362
Screen Diag	57
Screen Gain	4.7
Nits	586

LCOS	
Input Lumens	2912
UVIR	96.0%
Fly's Eye/PCS	60.0%
Fold Mirror	97.0%
Relay and Cleanup	92.0%
PBS_in**	95.0%
LCoS	65.0%
PBS_out/X-Cube**	88.0%
PJ Lens	85.0%
Color Balancing	48.0%
Output Lumens	332
Screen Diag	57
Screen Gain	4.7
Nits	538

** 3M Vikuiti Core

Table 4: Lumens budget for an LCoS/x-LCD projector at 11,000 Kelvin using LIFI™.

Time to Brightness

Another advantage that LIFI™ technology offers over HID lamps is the rapid turn-on time. Electrodes in HID lamps limit the amount of current and power that can be delivered to the bulb causing slow mercury evaporation lengthening time to brightness. In an electrode-less design, the amount of power delivered to the bulb at start is not limited. Therefore, the gas fill in LIFI™ enables fast start time and almost 'instant' on capability. In a 'cold' state, a typical LIFI™ lamp reaches 90% of full brightness in less than 10 seconds. In a warm state, the time to brightness can be more rapid. For system design, LUXIM recommends a 20 second re-strike protection to allow the fill material in the bulb to stabilize.

Mechanical and Thermal Design

Compared to solid state light sources, LIFI™ offers ease of integration into an existing TV or projector platform. The LIFI™ enclosure has straightforward and precise locating features that allow accurate alignment to the optical axis of the light engine as shown in figure 11. LIFI™ thermal design allows the system integrator to use a fan/duct cooling configuration very similar to existing projector cooling schemes.

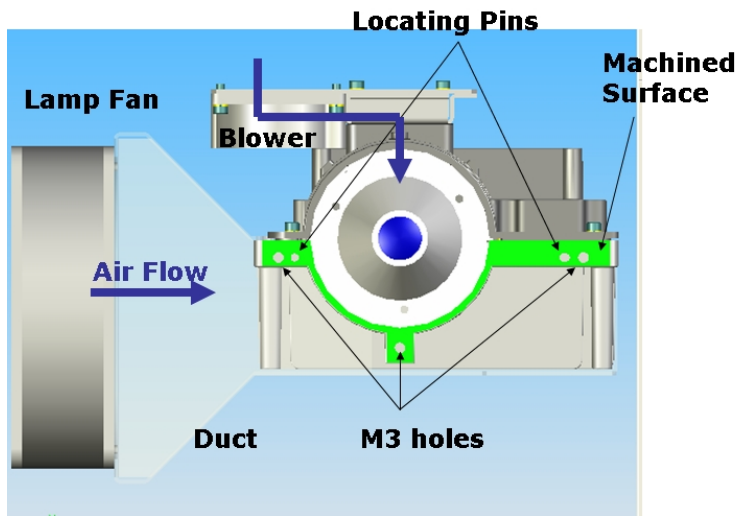


Figure 11: Recommended cooling configuration and mounting features of LIFI™.

Mounting and Alignment to Light Engine

As shown in figure 11, LIFI™ offers mounting and alignment features to provide an accurate interface to the light engine. Mechanical precision is important so the lamp aligns to an interface plate such that the focus of the light is centered. LUXIM advises using metal mounting hardware for LIFI™ to ensure proper grounding of the lamp.

Lamp Cooling

The LIFI™ enclosure is designed such that the RF amplifier module is adequately cooled for very high reliability. The RF amplifier module is heat-sunk to an aluminum base with fin structures that requires 25 CFM (across 18 Pa drop) airflow across it.

In each amplifier module roughly 90 W of power is dissipated as heat and distributed over the surface. Thermal simulations assuming a maximum ambient or fan inlet temperature of 55°C shows that the junction temperature does not exceed 135°C as shown in figure 13:

$$T_{\text{junction}} = T_{\text{test}} + R_{\text{th junction-test}}P$$

$$T_{\text{junction}} = 90^{\circ}\text{C} + (0.5^{\circ}\text{C/W} \times 90\text{W}) = 135^{\circ}\text{C}$$

where R_{th} is the thermal resistance between the test location and the junction. Experiment verifies this temperature is typically less than 130°C at full operating power.

The amplifier used is rated for junction temperatures up to 170°C. For maximum reliability, LUXIM recommends a safety factor such that the junction temperature stays well below 160°C. For qualification of TV cabinet or a projector thermal design, contact a LUXIM applications engineer for measurement modules to verify junction temperature.

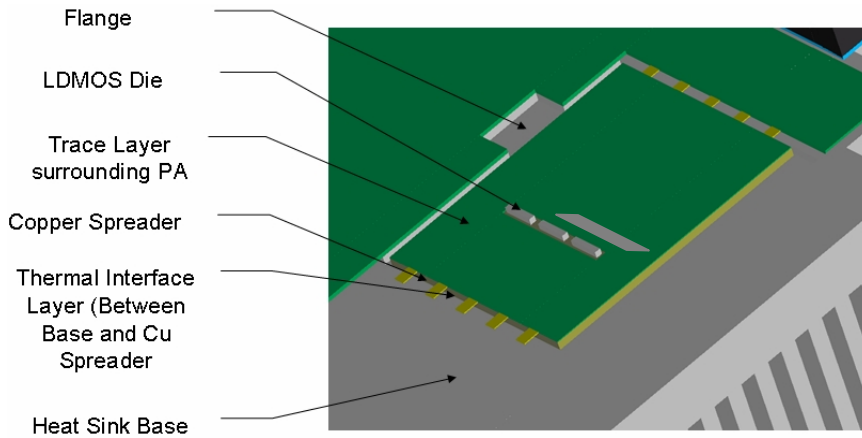


Figure 12: Close up of RF amplifier module showing LDMOS die.

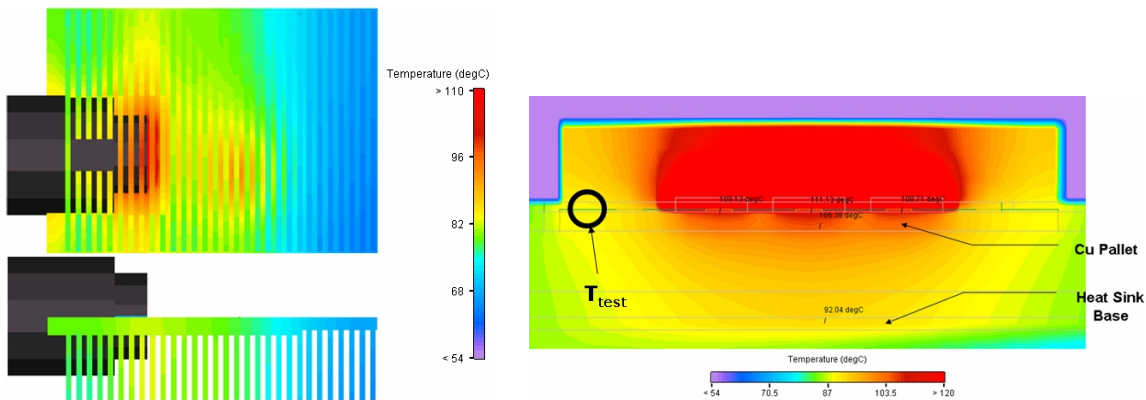


Figure 13: Thermal simulation results show typical temperature distribution on the mechanical enclosure (left) and cross section of the RF amplifier (right).

Bulb Cooling

LIFI™ provides a duct in the enclosure for air flow across the bulb to provide additional margin for bulb reliability. Peak temperature on the outer wall of the quartz bulb with airflow across it measures 800°C at typical operating power. Without airflow, this temperature measures up to 900°C in 55°C ambient conditions. Repeated testing at these temperatures has shown that there is adequate temperature margin for bulb reliability.

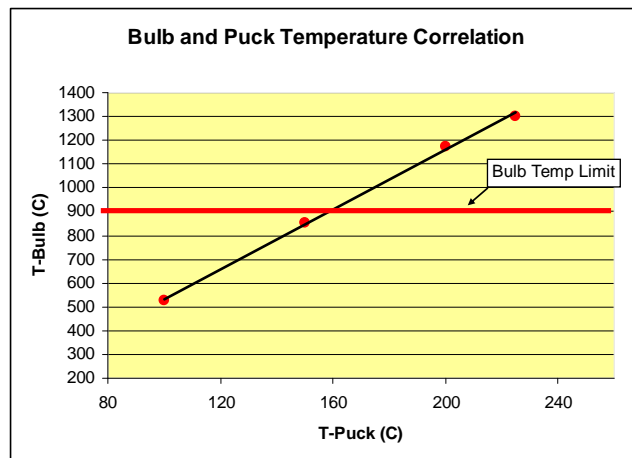


Figure 14: Measured bulb temperature vs. base (puck) temperature

LUXIM has experimentally established a functional relationship between the bulb temperature and its base (puck) temperature as shown in figure 14. The base temperature is measured at a location centered on the outer cylindrical

surface. For qualification of TV cabinet or a projector thermal design, contact a LUXIM applications engineer for measurement modules to verify bulb temperature. For reliability safety factor, LUXIM requires that the bulb surface operate at less than 90°C in the maximum ambient temperature. There are no complicated upper and lower temperature limits at various location of the bulb as in the UHP bulb; Luxim recommends running the bulb wall temperature as cool as possible.

The following chart lists the recommended thermal cooling part numbers for use with LIFI™:

Part Number	Description	Supplier
NMB-MAT FBA12G24L	Lamp Cooling Fan	Panaflo
FAL3F12LH	Bulb Cooling Fan	Minebia-Matsushita (Panasonic)

Electrical and Interface Requirements

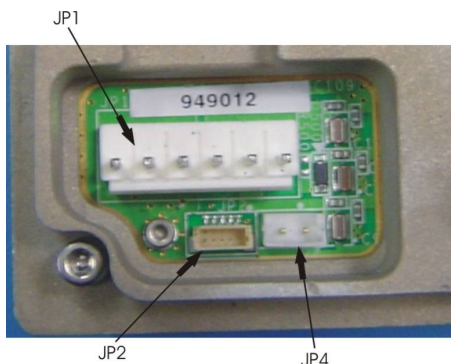


Figure 15: Picture of lamp connection.

Connections to Light Engine and Lamp Controller

LIFI™ incorporates an electrical interface to the light engine. There are three connectors to the lamp. First is the 26 V input (JP1); this provides the power to the lamp unit. The second is the 5 pin connector (JP2) for the lamp controller; this allows communication between the lamp and the projector. The third is a 28 V output power supply for the bulb fan/blower (JP4).

The electrical interface design allows for two modes of communication, manual and UART. In manual mode, the lamp can only be turned on and off using the SCI (serial communication interface) line. In UART mode, advanced commands and queries can be executed using the RxD and TxD lines (you can also turn the lamp on and off in UART mode).

The UART communication is an 8 bit operation at a baud rate of 19,200; this allows a single command to be sent from the light engine to the lamp in 0.5 msec. enabling several commands and responses within a frame of video (60 Hz or 16 msec.). UART mode is used for

- 1) Turning lamp on and off
- 2) Status queries including
 - i) Temperature of lamp
 - ii) Fault modes
 - iii) Firmware version
- 3) Dynamic Dark intensity modulation commands

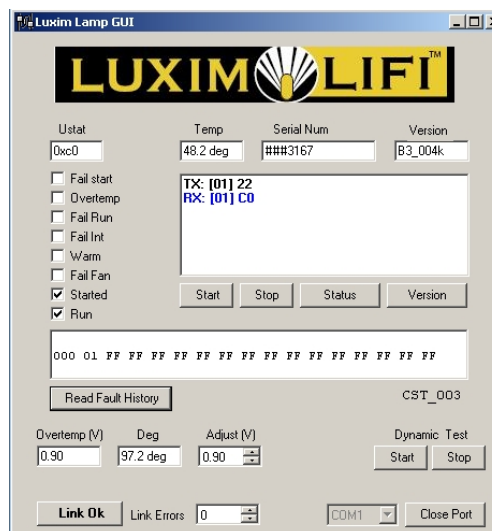


Figure 16: Snapshot of LIFI™ customer GUI

The detailed timing and commands for UART communication can be found in appendix A of the LIFI™ specification sheet.

LUXIM supplies a customer GUI that can power lamp on and off, read lamp status, command Dynamic Dark intensity modulation, set temperature limits, and read fault history.

Input Power Requirements

LIFI-PRJ-20 requires 229 W of DC power as shown in table 5. A recommended power supply is part number SP-320-27 by Meanwell.

DC Input Voltage (V)	26
DC Input Current (A)	8.8
DC Input Power (W)	229

Table 5: LIFI™ input power profile

Brightness Lock and Dynamic Dark Intensity Modulation

Using an internal photodiode, the LIFI™ is able to assess the output brightness of the lamp and keep it at a stable level by increasing or decreasing the power to the bulb – this feature is known as Brightness Lock. Therefore, any slight drifts in light output of the lamp can be reduced over its lifetime.

LIFI™ also allows dynamic brightness modulation of lamp output, referred to as Dynamic Dark. The user can command the lamp to increase or decrease its output depending on the video content through the UART interface. The lamp is able to modulate from 100% to 20% brightness in 50 msec. or 3 video frames at 60Hz. This has the impact of making bright scenes brighter and dark scenes darker and thus improving the perceived image depth and contrast of the system. This feature is designed to reduce system cost and complexity by replacing the mechanical iris that is typically placed in the aperture stop of the projection lens. Frame-by-frame modulation of the lamp also reduces the average power consumed by the lamp while retaining full reliability.

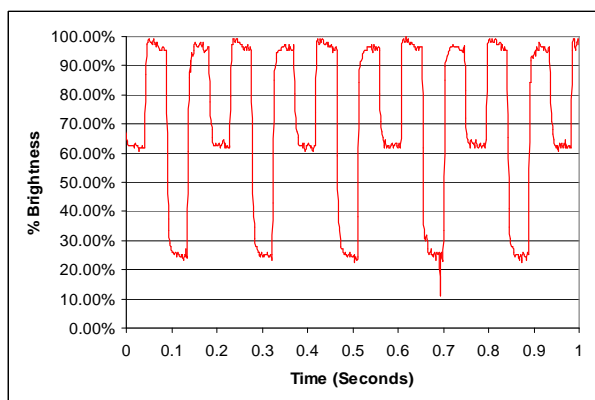


Figure 18: An arbitrary brightness modulation sequence with 50 msec dwell time demonstrating Dynamic Dark™ feature of LIFI™.

Certification and Compliance

Safety and Hazardous Materials

LIFI™ has been designed to meet UL safety standards according to EN60065-7; this UL standard applies to Electronic Equipment and Components: Television Equipment. LIFI™ is also compliant with RoHS (Restriction of Hazardous Substance Directive) testing for Lead, Mercury, Cadmium, Hexavalent Chromium, Polybrominated Biphenyls, and Polybrominated Diphenyl Ether.

Electromagnetic Compatibility (EMC)

LIFI™ limits EMI (electromagnetic

interference) radiation from the lamp. The product complies with FCC Part 15 Class B requirements and completes certification.

Summary

As described in this application note, the LIFI-PRJ-20 offers a bright, color rich and stable light source for projection display. The reliability and simplicity of integration of LIFI™ compares favorably to other light source technologies including HID lamps, LED and laser. LIFI™ brings Light Fidelity™ to projection display with light stability, reliability and fast turn-on times. See the LUXIM website (www.LUXIM.com) or contact a LUXIM sales or applications representative for more information.

DLP™ is a trademark of Texas Instruments
Brilliant Color™ is a trademark of Texas Instruments
LIFI™ and Light Fidelity™ are trademarks of LUXIM Corporation

Author: Apurba Pradhan

About LUXIM

LUXIM is the inventor of LIFI™ bringing the contribution of Light Fidelity™ for long-life, vivid color projection display applications like wide screen high-definition TVs and home theater projectors. A manufacturing company based in the heart of California's Silicon Valley, LUXIM produces in volume an entirely new set of products for high intensity lighting. With unprecedented levels of stable light power, long life, quality color spectrum and ease of implementation, LIFI™ is now possible for lighting applications that need it.

LUXIM Corporation
1171 Borregas Avenue
Sunnyvale, CA 94089
tel: +1-408-734-1096
email: info@LUXIM.com

Printed in USA 6/08

www.LUXIM.com