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Fiber Optic Based Lighting for Aircraft

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Technical Paper

Lighting and illumination systems using visible Lasers light sources are being developed under a number of US Navy programs to reduce the ship's costs including acquisition, installation, operation, and maintenance. Recent advances resulting from research initiatives funded thru the Office of Naval Research Mantech program and a Navy SBIR project are making broader applications of this technology feasible, including possible transition into aircrafts for position, landing, anti-collision, cargo loading, wing icing detection, and interior lights. The development of these lasers is being driven by the high definition projection industry, with substantial investments made to bring the technology to broad scale implementation, and with the anticipated increase in product availability and decrease in costs.

The laser systems offer significant advantages over fiber optic systems using other light sources including metal halide and LEDs. A laser prototype has provided from a single fiber five times the intensity of an LED from a 37 fibers cable. With a laser system the fiber cable cost is reduced by ~80% and the cable size and weight by ~70%. Lasers are fully compatible with Night Vision Imaging Systems (NVIS) without necessitating the use of filters, allowing white light illumination while not affecting the pilots' ability to perform NVIS aided operations.

The overall benefits that these fiber optic lighting systems may offer to the aircraft industry include weight reduction, all dielectric light transport cables, minimal interference with the aircraft structure, reduced maintenance, increased durability of the external components, and longer light sources life.

INTRODUCTION

Fiber optic illumination systems offer advantages over conventional lighting systems in situations where the lights are difficult to access and maintain, the luminaires and cables have to be located next to sensitive electronic equipment that may be affected by the electrical emissions, where the space for the lighting device is very limited, where the lights will experience extreme mechanical and environmental stresses, and in any other application where reduced weight, small size, and durable, electricity-free lighting is desirable.

Fiber optic lighting has been used for the navigation and signaling lights on the USS San Antonio LPD 17 class since 2005 and is being installed on the new class of DDG 1000 destroyers for all topside navigation, signaling, and illumination lights. These systems use a proven technology consisting of a light engine (illuminator) with high intensity metal halide lamps coupled to a fiber optic cable with 37 optical fibers. The cable transports the light to a luminaire that shapes and diffuses it in the required pattern. Although suitable for many shipboard applications, the size of these illuminators and cables makes them too large and bulky for avionics applications.

Recent advances in the luminous efficiency of LEDs have made them a feasible alternative to metal halide lamps, increasing the longevity of the light by over 20 fold, from 2,500 hours of metal halide to more than 50,000 hours for LEDs. LED based systems however require the use of the same 37 fibers optical cable to insure that sufficient light energy is transported to the luminaires. Fiber optic lighting systems using LEDs are being installed on the new Italian FREMM Frigate class for navigation and signaling lights and will be installed on the LPD 17 class to replace the metal halide illuminators.

High power lasers coupled into optical fibers have been utilized for many years in manufacturing for cutting, welding, and other functions, proving that high levels of photonic energy can be coupled and transported efficiently and safely in glass fibers. Recent advances in the areas of visible lasers driven primarily by the high definition projection industry have opened the possibility of coupling the laser and fiber optic technology to illumination, reducing the overall systems' costs, size, and weight, while retaining the combined benefits of fiber optic illumination and the longevity of solid state light sources.

In a trade study[(1)] being performed for the US Navy Office of Naval Research, it is estimated that Laser based illumination systems will provide a reduction in weight of 30% from the metal halide and LED systems and an acquisition cost reduction of over 50%. Additional cost reductions will be realized thru the lower weight and the smaller cable, about 1/3 the size of the existing illumination cable, thus easier to install.

This paper examines the advances made and the ongoing efforts in laser based fiber optic illumination systems and their possible application on aircrafts for position, landing, anti-collision, cargo loading, wing icing detection, and interior lights. The three position lights will be used as an example to describe the possible advantages of implementing this technology.

TECHNOLOGY OVERVIEW

A fiber optic illumination system consists of three basic components: 1) illuminator, 2) fiber optic cable assembly, and 3) luminaire.

Illuminator

The illuminator contains the light source and is the only electrical component of the system. The light is generated by a high intensity light such as a metal halide lamp, LED, or lasers. The light is coupled into the optical fibers utilizing a system of optics. The illuminator provides mechanical and environmental protection to the light source and is controlled via an interface to the applicable control system. Functions including flashing, dimming, and color changing are incorporated into the unit. An active cooling mechanism insures that the light sources operate in the optimal range regardless of the external temperature.

Illuminators are designed to meet the specific requirements of the application where they will be installed. Illuminators used on US Navy vessels meet all the requirements imposed on electrical equipment including shock, vibration, EMI, E3, and water resistance while those designed for use on coal mining equipment comply with MSHA safety standards.

Fiber Optic Cable Assembly

A fiber optic cable is used to transport the light energy from the illuminator to the luminaire. Most commercial fiber optic illumination systems utilize plastic optical fibers that limit the transmission distance to under 15 meters. The fiber optic illumination systems used on US Navy vessels utilize cables manufactured with glass optical fibers, allowing for distances over 300 meters. The Navy cables consist of 37 fibers each with a core/clad size of 600/630µm and a low smoke, zero halogen outer jacket. The high fiber count is required to insure that sufficient light energy is coupled from the illuminator into the cable. Special connectors are applied utilizing the epoxy and polish method similar to what is used for standard fiber optic communications cables. The cable is designed to withstand mechanical and environmental stresses similar to other fiber and copper cables installed on Navy ships. The cables are completely non-metallic.

Luminaire

The luminaire receives the light from the illuminator via the fiber optic cable and shapes it into the pattern required by the application. Since the luminaires do not contain the light source and the related power and thermal management hardware, they can be very small and constructed entirely of non-metallic components. Most luminaires designed for use on Navy vessels and other exterior applications are hermetically sealed and Nitrogen charged to prevent contamination of the internal optical components. Luminaires have been designed completely flush to the ship's hull with a hull penetration as small as 0.5 inches (1.25 mm) in diameter. The existing lighting systems allow up to four (4) luminaires to be connected to one (1) single illuminator.

LASER BASED SYSTEMS

Fiber optic illumination systems on US Navy vessels and in mining applications utilize illuminators using either metal halide lamps or high power LEDs as light sources. Both metal halide sources and LEDs require utilizing cables comprising multiple fibers to insure that sufficient light from the illuminator reaches the luminaire. The cable is a major cost driver of the system, representing from 20% to 50% of the total system cost depending on the configuration.

In the last three years visible lasers have become available providing light intensity levels surpassing those of the metal halide and of the LED sources. Table 1 compares a fiber optic illumination system using the different light sources.

Table 1: Light Sources Comparison (White Light)

	METAL HALIDE	LED	LASER
Fibers in Cable	37	37	1 or 3
Fiber Size - core/clad (µm)	600/630	600/630	1000/1040 or 600/630
Flux at Luminaire (lumens)	- 1,000	~ 400	> 2,000
Source life (hrs)	~2,500	≥50,000	≥50,000
Brightness (W / mm^2 str)	~ 1	~ 1	~ 10^5
Coupling Optics Required	Yes	Yes	No

A significant advantage of lasers is the high brightness, allowing to efficiently couple high levels of luminous flux into a single fiber.

The output efficiency of visible lasers is increasing and the costs are decreasing. Necsel, a manufacturer of visible lasers anticipates a cost decrease of 60% over the next 24 months while the output will double. The trend is expected to continue for several years, making the technology very attractive for military and commercial applications. To date, all of RSL's activities have been focused on military shipboard and other Navy applications such as antenna towers' lights, but many of the products being developed could be adaptable to aircraft applications.

Antenna Tower SBIR

The SBIR[(2)] sponsored by the US Navy Naval Facilities Command in Port Hueneme, CA provided a good baseline for the design of a single color laser system that can be transitioned into the aircraft environment. The objectives for antenna tower lights are similar to what is desirable in many aircraft applications:

- Reduced light source maintenance costs. The laser sources provide 50,000 hours life and, when maintenance is required, the sources are in easily accessible locations.
- Reduced or eliminated luminaire and cable maintenance. The luminaires are fully sealed and pressurized, designed to require no maintenance throughout the system's life. The fiber optic cable is all dielectric with a jacketing system resilient to the environmental and mechanical stresses.
- All dielectric lighting system. The only electrical component of the system is the laser illuminator that can be located in protected areas. The cables and the luminaires are non-electric and can be made primarily of non-metallic components.

The activities of Phase I consisted of the following:

1. Evaluate existing technologies that could be applied to the fiber optic lighting system;
2. Evaluate applicable developments from parallel programs under way at RSL Fiber Systems;
3. Evaluate applicable developments from parallel industries;
4. Determine the development efforts required to adapt these technologies to the application;
5. Assemble a system prototype and take initial measurements.

The intent of the program was to identify and utilize technologies and products already available or anticipated to be available when the final lighting system will be designed and assembled to minimize development costs and expedite the system implementation. Similarly, there are many existing technologies that can be readily applied to expedite the implementation of laser lighting systems on aircrafts.

Lasers, like LEDs, are temperature sensitive where the optimal output is within a certain temperature range. A Thermo-Electric Cooler (TEC) is required to maintain a laser source within the optimal operating range of 19°C to 25°C. One of the tests performed by RSL was to operate the red laser with the TEC connected in a way to allow gradual heating of the laser unit. To prevent damage to the laser, the controller was programmed to shut off the unit at temperatures above 30°C and below 18°C.

Table 2 shows the output from a 2 meters jumper cable with a single 600/630µm fiber, the same type as used in the 37 fibers Navy cable. The fiber is terminated into an industry standard SMA 905 series connector. The luminous flux values obtained are slightly below the value of 652 lumens specified by the laser manufacturer Necsel since the SMA connector did not have anti-reflective coating, losing about 10% of the light.

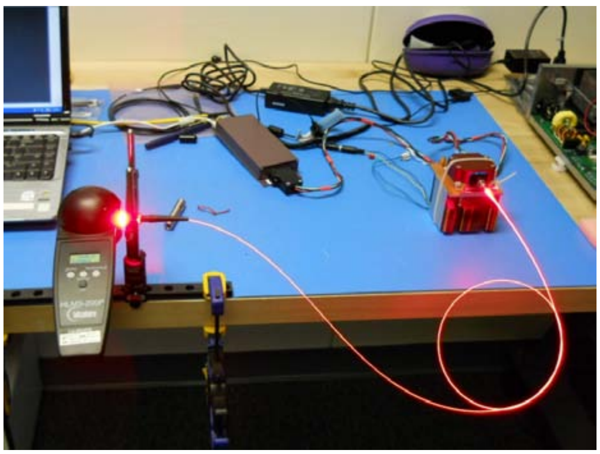


Figure 1: Red Laser Luminous Flux Test Set Up

<u>Test Conditions</u>

Ambient temperature:	23°C (73°F)
Test Equipment:	Labsphere HLMS 200P
Fiber Cable:	600/630µm, doped silica core, polymer clad, 0.47 N.A.
Cable Length:	2 meters
Optical Connectors:	SMA 905 (no anti-reflective coating)
Coupling Method:	The SMA connector is coupled directly into the laser SMA receptacle. No coupling optics used.

The typical efficiency of the luminaires used for navigation and signaling lights varies from 20% on the earlier designs to upward of 60% on newer designs. Part of the relatively low efficiency is that blockers are used to limit and control the light emission within the prescribed pattern. Higher efficiencies upward of 90% are obtained with luminaires for general illumination where blockers are not used to limit the emission.

Table 2: 5Watt Red Laser Flux vs. Temperature Test

Current (A)	Flux (lm)	Time (sec)	Temp (°C)
9	595.0	10	19.7
9	566.0	30	21.4
9	540.0	60	22.6
9	520.0	90	23.8
9	484.0	150	25.6
9	470.0	180	26.3
9	456	210	27
9	437	270	28
9	416	360	29

Laser Application for Aircrafts Position Lights

<u>Red and Green Lights</u>

The requirements for the red and the green navigation lights per FAA 14 CFR 23.1389 are used to calculate the luminous flux needed from the optical fiber cable into the luminaire, providing an average intensity of 30 candelas thru the entire emission pattern. Given a luminaire efficiency of 30%, the flux required from the fiber optic cable into the luminaire is ~50 lumens. Since over 500 lumens were obtained from a 5 Watts red laser, a red laser with a luminous emission of 0.5 Watts and a green laser with 0.25 Watts could be used for the side lights. Given the low power requirement of the lasers, the laser cooling system will be simplified in comparison to the 5 Watts unit tested. A fiber with a 200µm core, 230µm cladding with a polyimide outer coating in a cable configuration similar to the product from General Cable Corporation illustrated in Figure 4 can be used to transport the light to the luminaires.

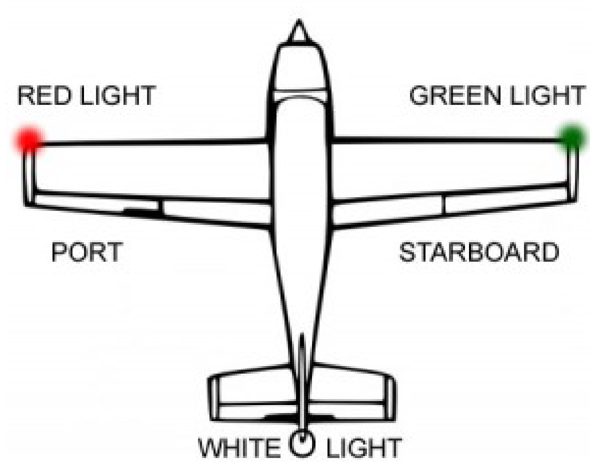
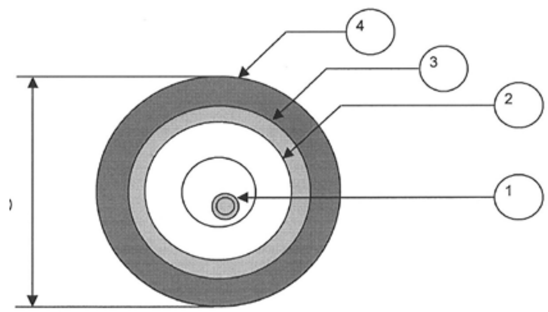


Figure 3: Aircraft Position Lights [3]

The existing marine navigation light non-metallic mini-luminaire weights 300 grams (10.5 ounces). A similar or smaller, lighter luminaire can be designed for integration into the airframe. The optical design can be comparable to the one developed for the navigation lights on a Navy program requiring the luminaires to be flush with the ship's external structure and having less than 2.5 mm (1.0 inch) penetration thru the hull. The unit shown in Figure 5 is manufactured with a steel housing due to the ship's requirements. The optically active area can be contained in an area 5 mm x 2.5 mm (2 in. x 1 in.). Although the design shown will need to be modified to meet the photometric requirements of aircraft lights, a similar luminaire, flush with the aircraft skin, could be manufactured of non-metallic components, with the only metallic parts being the optical connector and mating receptacle and possibly some of the securing hardware.



Cable Diameter:	2.1 to 2.5 mm
Cable Weight:	5 – 7 grams/meter (5.4 – 7.6 ounces/100 feet)
Outer Jacket (4):	Tefzel or FEP
Strength Member (3):	Teflon Impregnated Aramid Yarn or Fiberglass
Buffer Tube (2):	Tefzel or FEP
Fiber Coating (1):	Polyimide
Optical Fiber:	50/125, 62.5/125, 100/140, or 200/230

Figure 4: Fiber Optic Cable [4]

White Light

White light can be generated either thru the use of a blue laser to excite a layer of phosphor in the illuminator or in the luminaire, or by combining one (1) each red, green, and blue lasers. The advantage of the single blue laser approach is that it is smaller and lighter in weight than the three (3) lasers system. The advantage of the RGB approach is that it is fully NVIS compatible and provides the option to change color if required.

Figure 5: Navigation Luminaire Flush with Exterior Surface

Laser Based Aircrafts Lighting System - Weight

In a fiber optic illumination system the bulkier and heavier component, the illuminator, can be placed where space, weight, and size constraints allow. In an aircraft application, the illuminator can be anywhere within the fuselage with only the very lightweight cables and luminaires at the aircraft extremities. Using a Boeing 777 as an example, one (1) each red, green, and white laser illuminators could be installed at the midpoint of the aircraft, each with one (1) 50 meters (164 ft) of fiber optic cable and with one (1) luminaire. Extra cable length is included to allow for the routing thru the aircraft structure. The estimated weights are as follows. Note that the weight is for a redundant illuminator with two (2) light sources, including power supply and cooling mechanism. A single source illuminator would be about 30% lighter.

Illuminator weight:	4.0 Kg (8.8 lbs)
Cable assembly (50 m):	0.4 Kg (0.9 lbs)
Luminaire:	0.3 Kg (0.7 lbs)
Total:	**4.7 Kg (10.4 lbs)**

The lengths of copper cable required to power and control the illuminator can be kept to a minimum by placing the illuminator in proximity of the power source.

Laser Based Aircrafts Lighting System – Power Consumption

The power consumption per each color is under 100 Watts, including power supply and cooling mechanism. Improvements in laser efficiency are decreasing the power consumption or increasing the luminous output. The red laser system purchased in September 2011 used for the Navy SBIR generated 5 Watts of luminous energy. The same system if purchased in June 2012 will generate 7 Watts of luminous energy with the same total system power consumption.

SUMMARY/CONCLUSIONS

Laser based fiber optic illumination systems can provide significant advantages in areas of weight savings, ease of integration in the aircraft structure with minimal interference, improved reliability, reduced maintenance, and full compatibility with Night Vision Imaging Systems. Although no laser based systems have been yet developed specifically for aircraft applications, many of the efforts currently under way for the US Navy for interior ship's lighting, exterior lighting, navigation and signaling lights, and antenna tower lights can be applied to the aircraft industry to shorten the development and implementation cycle.

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DEFINITIONS/ABBREVIATIONS

EMI	Electro-Magnetic Interference
E3	Electromagnetic Environmental Effects
FREMM	Multi-Mission Frigate (joint Italian-French program)
LED	Light Emitting Diode
NA	Numerical Aperture
MSHA	Mine Health and Safety Administration
NVIS	Night Vision Imaging System
RGB	Red, Green, and Blue
SBIR	Small Business Innovation Research
TEC	Thermo-Electric Cooler