RSL®
Advanced Lighting Technologies

September 2012

Fiber Optic Systems for Avionics Illumination

Giovanni Tomasi, CEO/CTO

Technical Paper

ABSTRACT

Fiber optics has been a viable technology for data communication applications in many environments including aircrafts, providing higher bandwidth, longer transmission distances, EMI/RFI immunity, and lower weight than copper cables. Until recently however fiber optics was not a viable transmission medium to efficiently distribute light for illumination on aircrafts.

Fiber optic lighting systems, referred to as the Remote Source Lighting technology have been installed on US Navy vessels including the LPD 17 class, the Italian Multi-Mission Frigate FREMM class, and the DDG 1000 class. Optical fibers can offer advantages over conventional lighting systems that use copper cables due to safety, lower maintenance, EMI/RFI immunity, no possibility of short circuits or sparks, lightweight, and low operating costs. Higher procurement costs, primarily driven by the 37 fibers optical cable, have prevented a broader usage on naval vessels and for other applications including aircrafts.

Systems utilizing visible Lasers as light sources are being developed under a number of US Navy sponsored programs, enabling the use of single fiber cables to transport light. This critical transition to a laser system capable to couple more light into a single fiber can drastically change the way lighting systems are designed on aircrafts. The single fiber cable will provide significant benefits including 70% lighter weight than copper cables, 80% lower cost than the existing Navy cables, immunity to EMI/RFI, and the possibility to adapt fiber optic components and procedures developed for fiber data transmission applications, such as switches, connectors, installation procedures, and methods to illumination applications.

INTRODUCTION

Silica fibers have the potential to transport more energy than equivalent sized copper cables. A 100µm core fiber could theoretically transport over 25,000 Watts of energy.

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, 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 bundled 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 practical avionics applications.

Recent advances in LED's have made them a feasible alternative to metal halide lamps, increasing the longevity of the light from 2,500 hours of metal halide to more than 50,000 hours for LED's. 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 LED's 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 and welding, and in defense for target illumination, 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. Given that each one (1) additional pound of cable on a Boeing 747 costs an additional $300 per year(2) , replacing 1,000 feet of 14 AWG wire per MIL-W-16878/4 with a fiber optic cable could save over $3,000 in fuel cost per year.

This paper examines the benefits that would be derived thru the implementation of a fiber optic lighting network on aircrafts in areas of weight savings, installation cost reduction, and lower maintenance.

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, LEDs, 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 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

The fiber optic cable transports 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. These 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.

The laser based systems will utilize single fibers, reducing the cost, size, and weight of the cables.

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.

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

LASER BASED SYSTEMS

Laser light sources are the critical enabler that will allow the utilization of optical fibers for lighting networks on aircrafts, marine vessels, and eventually commercial and industrial facilities.

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. 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.

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

Lasers are very temperature sensitive however systems coupling upwards of 180 Watts of laser energy into a 100µm core optical fiber have been successfully implemented. Based on 1 Watt equating to 683 lumens of white light, over 100,000 lumens could potentially be coupled into a single optical fiber, enough light to illuminate 4,000 square feet of working space, and the same luminous output as twenty Q4681 450W aircraft landing light bulbs. Table 1 references the fibers used for the visible laser system comparison with a core size of 600µm and 1,000µm. These larger fibers are used to facilitate the coupling efforts and to avoid the necessity for coupling optics and heat management and dissipation at the coupling point.

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, with the trend is expected to continue for several years.

Antenna Tower SBIR

The SBIR(3) 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, enabling the use of a plane-wide fiber optic illumination network. 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 to 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 intent of Phase I 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.

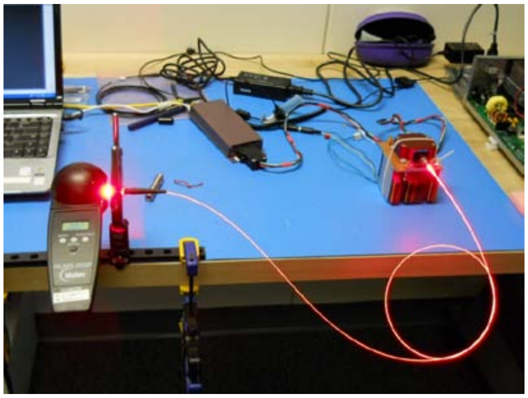


Figure 1: Red Laser Luminous Flux Test Set Up

Test Conditions

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.

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

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.

Laser Application for Aircraft Position Lights

Aircraft position lights were selected to evaluate if a single color laser source coupled into an optical fiber cable could be utilized to replace the conventional lights.

The intent of this analysis is to determine if sufficient light intensity can be generated, transported via optical fiber, and shaped by a luminaire to be in compliance with the position lights requirements.

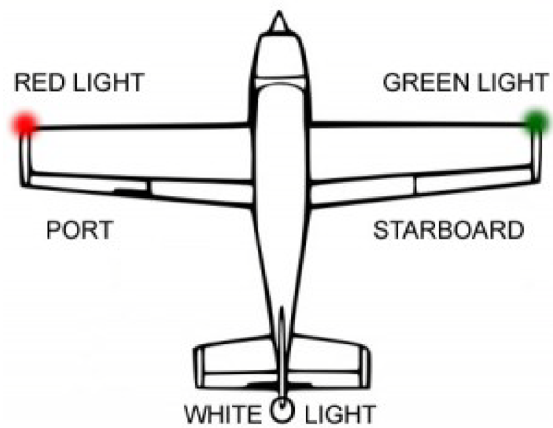
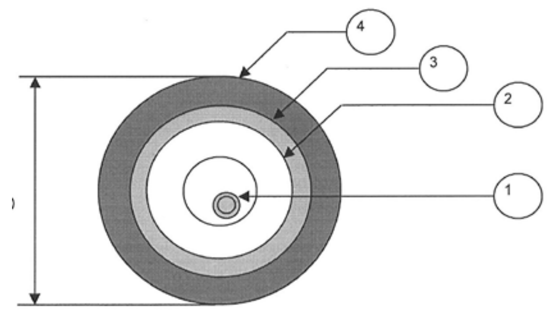


Figure 3: Aircraft Position Lights [4]

Red and Green Lights

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. Using a luminaire efficiency of 30%, the flux required from the fiber optic cable into the luminaire is ~50 lumens. Over 500 lumens were obtained from a 5 Watts red laser indicating that 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 for the SBIR efforts. 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.



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 [5]

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.). A luminaire for aircraft applications 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.

Figure 5: Navigation Luminaire Flush with Exterior Surface

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.

Laser Based Aircraft 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)**

For comparison, using two (2) 16 AWG MIL-16878/4 PTFE jacketed wires would result in a cable assembly weight of 1.5 Kg (3.3 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.

SUMMARY/CONCLUSIONS

Laser based fiber optic illumination systems distributed via a plane wide fiber optic network 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. Fiber optics have demonstrated the ability to transport high levels of photonic energy providing a light weight option to heavier copper cables even in applications where high intensity lights are used, including aircraft landing lights.

Although no laser based systems have yet been 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.

REFERENCES

1. J. Farmer, Next Generation Remote Source Lighting Trade Study, ONR Subcontract Number 0145-SC-20426-0253, 2012
2. J. Dunn, D. Slutz, Weight Reduction and Space Savings in Wire and Cable Design and Their Contribution to Aerospace Design and Operational Efficiency, White Paper, 2011
3. G. Tomasi, Final Report, Innovative Lighting System for Base-Insulated Transmitting Antenna Towers, SBIR N111-086-27, 2012
4. Aircraft Navigation Lights, Web Site http://www.learntofly.ca/aircraft-navigation-lights/, accessed 6 June 2012
5. General Cable OC-1260 100/140 High Temperature Flight Light Fiber Optic Cable, 2003

CONTACT INFORMATION

Giovanni Tomasi, RSL Fiber Systems, LLC, 860-282-4930
gptomasi@rslfibersystems.com

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