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The Application of Remote Source Lighting in Unmanned Aerial Vehicles

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Technical Paper

Introduction

Remote Source Lighting is widely used in Naval ships for a variety of applications including Navigation Lights and Task Lights as well as illumination of work areas such as mission bays, decks, and access ramps. The key advantages of the system over conventional lighting include:

- Increased reliability
- Elimination of EMI/RFI interactions
- Corrosion mitigation
- Radar Cross section reduction
- Elimination of maintenance in hazardous locations
- Energy conservation

These same attributes will be advantageous to Unmanned Aerial Vehicle (UAV) installations. Additional characteristics such as reduced thermal signature and an increased tolerance to lighting strikes will likely provide additional system robustness and benefit.

System Description

As shown in Fig. 1 the basic system components are a Light Engine (illuminator), fiber optic cable, and optical diffuser (luminaire). Outside of the Light Engine, the entire system is passive with no electricity within the system. The optical fiber is constructed of dielectric materials, eliminating any possible conduction path for EMI/RFI. Luminaires are constructed of materials appropriate for the application with extensive use of composite materials to mitigate corrosion issues. For each of the three major system components there is a suite of products available. The specific application drives the make-up of the final system configuration.

An example of a ruggedized Light Engine designed for harsh environments is shown in Fig. 2. This design utilizes a LED as the light source. The Light Engine is fully encapsulated. This creates an inherently robust component, which is compliant with Mil-Std 810 for environmental, vibration, and shock requirements. The Encapsulated Light Engine is available in redundant and non-redundant configurations. Mean time between Failure (MTBF) for a single source non-redundant model is 30,000+ hours. Values for redundant configurations are correspondingly increased.

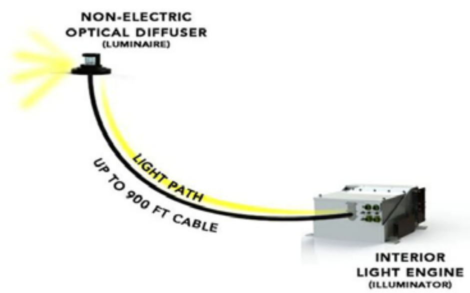

Fig. 1 – Graphical system representation

Fig. 3 – Glass fiber low loss cable with Mil-Spec connector

Fig. 2 – Encapsulated Light Engine

Fig. 4 – Side Emitting Fiber

Two basic styles of fiber are used. The first style is an end emitting cable which transmits the light from the Light Engine with no light emission along the length of the cable; essentially all of the light is accepted at the light engine end and emitted from the opposite end into an optical diffuser. The second style of fiber is a side-emitting design which accepts the light at the light engine end and distributes the light along its length; essentially the fiber is the optical diffuser. Within these two categories there are a number of different designs employed depending on length of cable run, environmental conditions, and illumination requirements. An example of a glass fiber based end emitting low loss cable used for longer runs is shown in Fig. 3. An example of a side emitting fiber is shown in Fig. 4 (as well as in Fig.2 connected to the encapsulated Light Engine).

Within the suite of optical diffusers there are several broad categories of product including navigation lights, task illumination, area illumination, visibility systems. Within these categories the specific optical system and components used are tailored for the light pattern needed for the specific application.

Fig. 5 – Composite Optical Diffuser – Navigation/Task Lighting

All composite optical diffusers used for Navigation/Task Lighting and Area lighting are shown in Fig, 5 and Fig. 6 respectively.

In Fig. 7 a flush mounted optical diffuser is depicted. This design has some unique properties, including:

- Flush mounted to surface with no adverse impact on Radar Cross Section
- Minimal penetration through structure (1/2")
- Can be configured to be utilized with RAM application
- Wide variety of light distribution patterns available
- Inherently robust mechanical design

From our initial reviews based primarily on the review of public domain articles, technical papers, and design references, the following system configuration would appear to be an appropriate design basis for both the navigation and strobe lights on a UAV.

- Encapsulated redundant LED Light Engine, similar to product shown in Fig. 2
- Low loss end emitting glass fiber cable suitably jacketed for environment
- Flush mounted optical diffuser constructed from composite materials, similar to product shown in Fig. 7

Fig. 6 – Composite Optical Diffuser – Area Lighting

Fig. 7 – Flush mounted Optical Diffuser – Variety of applications

Technology Development- Laser Based Systems

Current 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.

	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

Table 1: Light Sources Comparison (White Light)

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.

In addition to the cable cost savings achieved by moving to a single fiber with the laser based system, significant weight savings are realized as well. With the improved efficiencies of the laser system overall energy consumption will be reduced below current LED based systems.

Testing on a red laser system performed as part of a Naval Facilities Command funded SBIR indicated that the requirements for the red and the green navigation side lights per FAA 14 CFR 23.1389 could be met with a red laser with a luminous emission of 0.5 Watts and a green laser with 0.25 Watts, coupled into a 200µm core, 230µm cladding fiber. Given the low power requirement of the lasers, the laser cooling system will be simplified in comparison to the 5 Watts unit tested under the SBIR.

Legacy Products

Representative strobe light product and Navigation Light products are shown in Fig.8 and Fig. 9 respectively. The products are LED based products. The LED's can be seen under the shaped windows. The products are shown strictly as representative legacy products and to compare conceptual design aspects of this type of product versus a remote source lighting product.

Fig. 8 – Commercial Legacy LED Strobe - www.aveogroup.com

A comparison of design elements between a legacy conventional lighting approach and a remote source approach is summarized below:

- Flush mount profile of remote source solution provides a reduced Radar Cross Section when compared to the conventional lighting solution
- From an EMI/RFI standpoint the conventional solution provides an electrically transparent barrier to the LED network.
- The remote source solution electrically shields the LED both from an emissions and susceptibility standpoint.
- The remote source solution provides much greater protection for vulnerable LED, circuits, and electronics.
- In the remote source solution these vulnerable components are inside the skin of the vehicle, protected from temperature gradients, lighting strikes, and damage from object impacts.

Fig. 9 – Commercial Legacy LED Navigation Light - www.aveogroup.com

EMI/RFI

There is a significant complement of sophisticated electronic gear in a UAV, including digital/RF type systems for electronic warfare, communications (SATCOM, Line-Of-Sight, etc.), and radar. Many of these systems operate in the 2-18 GHz, which is particularly susceptible to LED and other broadband sources. Along with this hardware come more complex antenna array systems with their increased sensitivity. This increase use of digital/RF hardware results in the greater potential of having electromagnetic interference/compatibility (EMI/EMC) issues that can degrade or damage overall system performance. In addition, reducing the overall RF signature and Radar Cross Section (RCS) in an attempt to become more stealthy is an important initiative. So, it is important to minimize RF signatures and reduce noise sources.

Legacy LED type lights can have their own issues in that typically these LED lights require DC power and so, again a voltage converter (AC-DC or DC-DC converters) is integral to their operation which is also a potential broadband noise source. Usually, when these voltage conversions are necessary, added filtering is necessary to prevent any noise generated by the conversion process from being "transmitted" (i.e. conducted and radiated) to the main power grid and to other potential susceptible hardware with increased cost, space, and weight. Figure 10 (11) shows the typical noise coupling paths that could occur.

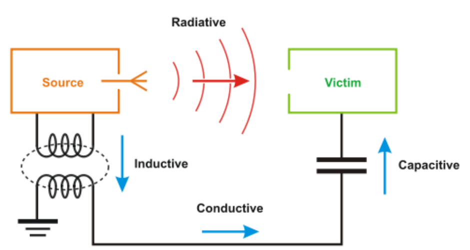

Fig. 10 - Typical EMI coupling mechanisms with source being a "noisy" navigation or strobe light and victim being a nearby sensitive digital/RF hardware or antenna.

Broadband noise source is of concern since their energy is spread across a wide frequency range (reference Figure 11(11)), with no particular frequency accentuated. Reducing broadband noise sources also, of course, improves the RF stealth signature of the ship.

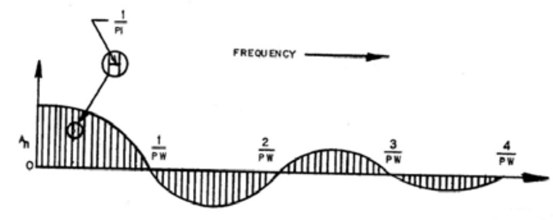

Fig. 11 - Typical Broadband Signature

An alternative to the lighting systems described above is a remote source fiber optic system. In this system the light engine is placed inside the skin of the vehicle in a fully shielded enclosure without the need for EMI transparent windows to allow the light to be emitted. The system component that actually emits and distributes the light specific to the required application is a passive composite luminaire. Connecting the light engine and luminaire is a non-metallic fiber optic cable that transmits the light from the light engine to the luminaire. Since all components outside of the light engine are of non-metallic or composite construction, corrosion issues are effectively eliminated. Similarly, with no electricity (and no conductive components) in the system outside of the light engine, EMI/EMC issues are also effectively eliminated.

Lighting Protection

Many of the same characteristics that make the remote source solution a preferred choice in the context of EMI/RFI emissions and susceptibility improvements also provide a benefit when reviewing susceptibility to lightning strike damage. Eliminating conductive elements (conventional wiring from power source in fuselage to wing mounted navigation lights, as well as the lights themselves) will reduce the likelihood of a strike in a susceptible area (see area 1a and 1b in Fig 12(10)) causing catastrophic damage to the lights and associated circuitry.

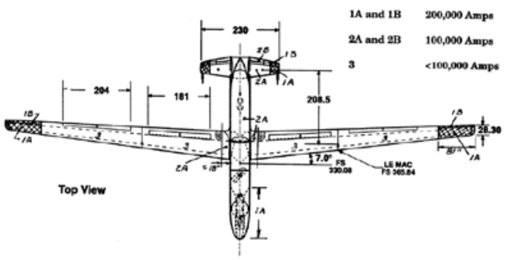

Fig. 12 – Lightning Strike requirements

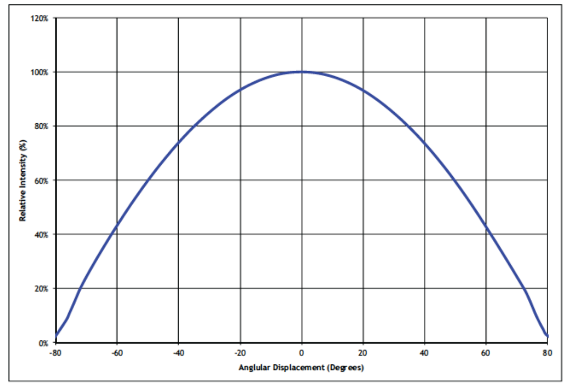

Fig. 13 – LED Angular Distribution

Radar Cross Section/Thermal Signature

As mentioned above when discussing the legacy products, the ability to flush-mount the optical diffusers into the vehicle skin provides a reduction in radar cross section. Conventional lighting fixtures are typically mounted proud to the surface to facilitate the optical distribution required of the application. This is somewhat inherent to the characteristics of conventional light sources. As an example an LED typically has a lambertian distribution as shown in Fig. 13 (3). With the remote source solution the light has been coupled to a fiber in the light engine; when the light exits the fiber in the optical diffuser it is highly collimated and effectively a point source. This enables very efficient shaping of the light with the appropriate optical system.

With the remote source solution the heat produced at the light source is internal to the vehicle and highly modulated by the integral heat management components. The visible optical diffuser essentially produces no heat - from a practical standpoint only light is emitted. This will reduce the overall visible thermal signature.

Reliability

The advantages of the remote source system when compared with the legacy system largely rests with the system architecture and placement of components. The active components themselves (LEDs, circuitry, power supplies) are for the most part the same as the legacy products. The significant difference is the protection offered in the packaging and placement of the active components. Exposure to environmental effects including exposure to temperature extremes, EMI, and mechanical effects (all electronic circuitry including the LEDs are fully encapsulated in the RSL design) are significantly mitigated by the remote source mechanical design basis. A system reliability hierarchy of a typical UAV is shown in Fig. 14(10).

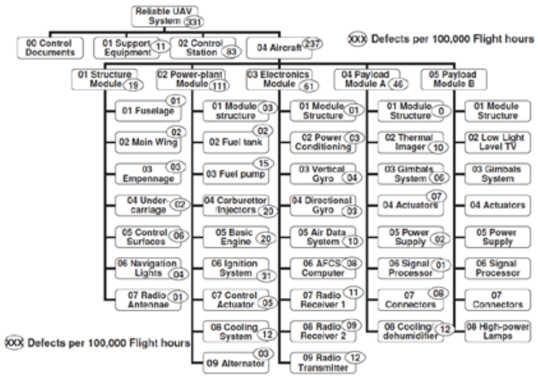

Fig. 14– UAV System Reliability Hierarchy

Fig. 15– Northrup Grumman – Global Hawk (2)

References:

1. Range Commanders Council, US Army White Sands Missile Range, New Mexico**,** supplement to document 323-99 " A Study of Reconnaissance Surveillance Vehicle – Global Hawk" NPS 041003 – Naval Postgraduate School Jan 2010
2. Luminus CBT-90 Product Bulletin, Luminus Devices Inc. 201314 CFR 91 Docket No. FAA-2006-25714 – Unmanned Aircraft Operation in the National Airspace, Department of Transportation, Federal Aviation Administration
3. "Structural Design Aspects and Criteria for Military UAV" EADS Defense and Security, Newbauer, Martin, et al May 2007
4. "Design Methodology for Unmanned Aerial Vehicle (UAV) Team Coordination" Massachusetts Institute of Technology, prepared for Boeing
5. Phantom Works, December 1007 Da Silva, F.B., et al. "Lightweight Low Cost Threat Warning for UAV, Aerostat and other small platforms, Forrest, P.G. Teledyne Defense Limited, Shipley UK 2010
6. "UAV Requirements and Design Consideration" Technical and Project Management Department, Turkish Land Forces Command, Ankara, Turkey Torun, Erdal 1999
7. "UAV Design Activities in a University Environment" School of Aerospace, Mechanical and Mechatronic Engineering, University of Sydney, Wong, K.C. 2006
8. "Unmanned Aircraft Systems – UAVS Design, Development, and Deployment, Wiley Press, Austin, Reg 2010
9. "Potential Navy Mast Light EMI" Nakauchi, E, McFadden, J. RSL Fibersystems 2012
10. "Laser Based Lighting for Avionics" Tomasi, G. RSL Fibersystems 2012

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