Defense Systems Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Aircraft Display Panel Light-Emitting Diode (LED) Specifications

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ABOUT DSIAC

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ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information on specifications or requirements for light-emitting diodes (LEDs) on aircraft display panels. In a follow-on inquiry, the inquirer requested information on LED component requirements. DSIAC contacted a subject matter expert (SME) at Georgia Tech Research Institute to help respond to the inquiries. The SME described LED dimming methodologies, compared various approaches, summarized relevant military specifications, and offered recommendations for developing requirements. The inquiry response was compiled into a report and delivered to the inquirer.

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1.0 TI Request

1.1 INQUIRY

What information is available on requirements for light-emitting diodes (LEDs) and associated components used in aircraft display panels?

1.2 DESCRIPTION

This report is the result of two related inquiries. The original inquiry requested information on specifications or requirements for night vision imaging system (NVIS)-compatible LEDs on aircraft display panels. A follow-on inquiry requested information on LED component requirements. The inquirer noted that there can be issues with dimming as it could possibly cause the cockpit display panels to blink erroneously.

2.0 TI Response

The Defense Systems Information Analysis Center (DSIAC) contacted a Georgia Tech Research Institute (GTRI) Electronic Systems Laboratory (ELSYS) subject matter expert (SME) for help responding to the inquiries. The SME provided a response based on Department of Defense (DoD) Crew Systems community practices and standards. The SME also provided recommendations for the specifications and employment of LED panels in the design of fixed- and rotary-wing aircraft (new and retrofit).

2.1 AIRCRAFT DISPLAY LED SPECIFICATIONS

The advent of blue or white LEDs enabled suppliers to meet DoD requirements for instrument panel lighting; as a result, the use of LEDs in aircraft instrument panel design (and on other aerospace applications such as for external anticollision or other lighting) has dramatically increased over the past two decades. Colors such as "IPL White" (Instrument Panel White) and "AF Blue White" (Air Force Blue White) were formerly only available in incandescent filament-based lamps. Advances in LED technology since the mid-1990s have enabled designers to substitute LEDs in new and modification/retrofit kits, reducing power requirements, reducing the resultant thermal output due to improved LED efficiencies, and dramatically improving supportability footprints due to generally far better mean times between failures. Yet, the use of LEDs has presented some challenges in terms of lighting balance and control and NVIS compatibility. This TI response presents some current and applicable specifications, and discusses factors typically addressed in the use of LEDs for aircraft instrument panel applications.

2.1.1 Joint Service Specification Guide (JSSG) 2010-5, *Crew Systems Aircraft Lighting Handbook*

Every section of the *Aircraft Lighting Handbook* applies to LED-based display panel technology; for instance, section 3.5.2.1.8.5.2, "Electronics and Electro-Optical Displays," states the following [1]:

> Electronic and electro-optical displays shall provide sufficient luminance and contrast for operation in all anticipated ambient environments (0.0 to 10,000 fc). Each individual electronic and electro-optical displays shall have its own luminance and contrast control. The minimum acceptable high ambient contrast requirements for display readability are presented in table V. The luminance range of surfaces immediately adjacent to scopes shall be between 10% and 100% of screen background luminance. With the exception of emergency indicators, no light source in the immediate surrounding area shall be of a greater luminance than the displayed signal. The ambient illuminance in the display area shall be appropriate for other visual functions (e.g., setting controls, reading instruments, maintenance) but shall not degrade the visibility of signals on the display. When a display is used in a variable ambient illuminance, illuminance controls, shall be provided to dim all light sources, including illuminated panels, indicators and switches in the immediate surround. Automatic adjustment of brightness may be used if the brightness is automatically adjusted as a function of ambient illuminance and the range of automatic adjustment is adequate for the full range of ambient illuminance.

The following excerpt from the section, "Requirements Lessons Learned," provides information to flat panel display and LED NVIS compatibility [1]:

> Liquid crystal displays (LCDs), whether monochromatic or color, typically can easily and cost effectively meet NVIS chromaoticity [sic] and spectral radiance requirements if a proper lights source is chosen (e.g., fluorescent tubes) and appropriate filters are used. Typical monochromatic (i.e., green) light emitting diodes (LEDs) can be readily purchased off the-shelf which are NVIS compatible.

The remaining sections of the *Aircraft Lighting Handbook* apply equally to LED-based panel indicators and light plates as they do to non-LED-based lamps [1].

JSSG 2010-5, the *Aircraft Lighting Handbook*, dated 30 October 1998, supersedes AFGS-87240A (31 December 1987), MIL-L-85762A (26 August 1988), and MIL-STD-1776A (U.S. Air Force) (25 February 1994) [1].

2.1.2 U.S. Air Force Guide Specification (AFGS) 87240, *Lighting Equipment Airborne, Interior and Exterior*

AFGS 87240 was cancelled and is now included in JSSG 2010. Provided for reference, this guide specification (now superseded by JSSG-2010-5 - Aircraft Lighting Handbook) provides original source LED readability requirements, as identified in the following excerpts [1]:

> Appendix A, 3.2.1.1.8 Sunlight readability. All self-luminous displays that must be viewed in high ambient illumination environments (10,000 fc) shall be readable when energized and shall not be readable nor have ghost images when not energized.
>
> REQUIREMENT RATIONALE (3.2.1.1.8). Self-luminous displays must be designed to assure readability in very high ambient illuminations encountered at high altitudes.
>
> REQUIREMENT GUIDANCE
>
> Invoke this requirement for all self-luminous displays for cockpit such as incandescent and light emitting diodes (LEDs) alphanumeric or transilluminated types to be used under high ambient illumination. Warning, caution, and advisory are special cases also having this requirement, and are specifically covered in the general warning and caution section. Modern, one-piece bubble canopies allow worst case, direct sun illumination at high altitudes. All self-luminous displays must be readable under those extreme conditions which can reach 10,000 fc ambient illumination. Illuminated segments require a minimum of 500 fL with continuous dimming to zero. Illunimated [sic] indicia on panels are an exception to this requirement. Panels must be sunlight readable without being energized, since they are illuninated [sic] only for night visibility.
>
> REQUIREMENT LESSONS LEARNED
>
> Improperly designed LEDs are easily washed out by the sun. Contrast enhancement filters, increased luminance, and microlouver materials can be used to increase readability.

2.1.3 MIL-STD-3009, *Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible*

MIL-STD-3009, *Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible*, dated 2 February 2001, superseded MIL-L-85762A as the single MIL-STD specification used to "define the requirements and quantitative testing methodology for NVIS-compatible lighting" and display technology. It was reverified as an additional standalone MIL-STD specification alongside JSSG-2010-5 - Aircraft Lighting Handbook. All passages specifying lamp and display characteristics apply to LEDs as equally as with other lamp technology. For example, section C.3.4, "NVIS Background," states the following [2]:

> For instrument lighting, successful methods include floodlighting as well as external bezel and integral lighting using filtered incandescent lamps and filtered electroluminescent (EL) lamps. For light plates, filtered incandescent lighting, filtered EL lighting, and filtered light emitting diodes (LED's) have been successfully used.

Further, section C.5.3, "Light Sources," remains neutral on the lamp technology used, as identified in the following excerpt [2]:

> MIL-STD-3009 does not specify the type of lighting source (e.g., incandescent, Electroluminescent (EL), or Light Emitting Diode (LED)) because, depending on the application, one technology may be better than another. For example, when an aircraft equipped with incandescent lighting is being retrofitted, it is usually easier to retrofit with incandescent lighting than to convert to EL or LED lighting.

Section C.5.10, "Daylight Legibility and Readability of Electronic and Electro-Optical Displays," similarly states that "CRT's, LED's, and LCD's are all considered to be electronic and electro-optical displays," and section C.7.11.3, "Chromaticity measurements," states that LEDs are called out alongside other lamps [2].

2.2 UNSPECIFIED LED DISPLAY FACTORS

LED display factors that are not explicitly specified are derived requirements for LED-based display panels, which were never codified in JSSG 2010-5, AFGS 87240, or MIL-STD-3009 [1–3], and have evolved since their formation in the CY2000 time frame. The most significant of these requirements is the methodology to provide continuous dimming functionality. MIL-STD-3009 states that "continuous intensity control of the above lighting from full bright to 0.02% of full bright and 'off' is required." LEDs, as diodes, provide a constant, luminous output; therefore, this requirement is harder to meet as opposed to other filament-based lamp technology wherein input voltages can simply be trimmed via a potentiometer to provide a dimming function which is continuous to full "off" [2].

The solution (not mentioned in any of the available guide specifications) is to incorporate a pulse width modulator (PWM) into an LED lighting control circuit. The PWM, controlled either manually by the pilot or via an automatic brightness control (ABC), varies the peak-to-peak voltage of the LED circuit to valve the effective brightness of the activated diode. Thus, with very wide pulses, the diode is barely activated and emits very little light over time, meeting the MIL-STD-3009 requirement.

2.3 CASE EXAMPLE

A case example was provided to illustrate the source rationale behind the dimming section of the specification, and/or to provide guidance on requirement implementation.

2.3.1 F-16 Data Entry Display (DED) LED Modification

The following is an excerpt from Appendix B of JSSG-2010-1 Crew Systems Engineering Handbook (pg. 94) [4]:

> (13) F–16 Data Entry Display brightness - Unusual technology (LED) not adequately understood, specified, or built properly for use in dark adapted environment. Required redesign of dimming circuitry.

The F-16 advanced DED was integrated in the mid-1990s without adequately understanding that, as integrated, the new LED back lighting was not continuously dimmable to off. This flaw resulted in a deficiency where the pilot was unable to smoothly and continuously dim the DED to off. The DED is mounted directly beneath the heads-up display, directly within the pilot's central 30° field of view (FOV), which magnified the unacceptability of having a bright display directly in the pilot's FOV. This deficiency was eventually mitigated through the incorporation of a PWM, which enables the pilot to vary the peak-to-peak voltage of the diode, allowing the LED to be effectively dimmed to very low levels. This approach has been used in every subsequent tactical aircraft using LED crew station lighting in applications that require NVIS compatibility.

2.4 COMPARATIVE LED DIMMING APPROACHES

The following information on LED component requirements was added to address the follow-on query.

2.4.1 Voltage Dimming

Voltage dimming can be effective through trimming the voltage with a potentiometer. A potentiometer controls resistive loads with a generally linear current/voltage relationship (a straight-line dimming response), as shown in Equation 1.

$$I = (1/R) \times V, \quad (1)$$

where I is the intensity (in amps), R is the resistance (in ohms), and V is the voltage (in volts). Voltage dimming is effective, but it works the best with single LED bulbs.

However, LEDs are nonlinear devices. They have a strongly curved dimming response, where small changes in voltage can equal a huge and sudden change in intensity. With voltage dimming to trim the current as the pilot tries to trim a light plate or panel on a very dark night, the panel may either dramatically jump in brightness from barely perceptible (so that the pilot's tactical night vision and ability to see outside the aircraft are not impaired) to unacceptably bright.

Color shift has been observed as a result of voltage dimming. At lower luminance values, color sensitivity for scotopic (dark) and mesopic (transitional light) vision-adapted pilots and below is marginal, so any loss of color contrast from voltage dimming is significant.

There is also a potential reliability and maintainability issue, as voltage dimming drives the diode at all times, possibly shortening its life.

2.4.2 PWM Dimming

PWMs strobe the LEDs on and off with constant voltage square wave pulses. The longer the duty cycle (i.e., the on pulse lengths relative to the off periods), the brighter the diodes appear to pilots.

Because the voltage is held constant, the relative curved response to voltage changes is eliminated as a factor. The pulse strobes create the dimming effect, providing better apparent dimming at very low light levels with no jumping, and reduced potential for color shifts.

PWMs variably pulse, and they could introduce noise into the circuit, potentially resulting in flicker. Therefore, circuit designers should do the following to prevent LED flickering:

- Design the circuit to separate the control signal (i.e., from the pilot's potentiometer) from the aircraft power input.
- Make sure that aircraft power comes from a conditioned power source, not just the 28-V raw power bus. For example, lighting upgrades to the F-14 Tomcat highlighted its relatively poorly conditioned power, which frequently burned out displays and lights. It cannot be assumed that all customer platforms (particularly the older ones that require modification/retrofit) will have properly conditioned power for drop-in replacements.

- Select the right input voltage; the voltage depends on the LEDs, which have variability.

2.5 LED PART VARIABILITY

As stated in Section 2.4.1, installed individually, an LED may provide a uniform response to voltage trimming. However, when used in groups, the observed variability in LEDs (when used with a current-reduction voltage trimmer) has been widely seen to provide a nonuniform, objectionable response where parts of a panel (or individual panels) all respond differently. In an operational context, a pilot flying an aircraft that is ascending (or descending) during dusk or dawn, or that is penetrating an area of significant cultural lighting, will need to quickly adjust cockpit lighting to be visible and usable while preserving his visibility outside the window. Having an unbalanced, poorly linear LED response increases pilot workload and requires more “tuning” during a higher workload period when the pilot cannot afford to be distracted to tinker with lighting controls.

In older aircraft platforms using incandescent lamps (e.g., either class 1 or 2, AF Blue White or IPL White lamps), a trim panel with individual potentiometers would allow a maintenance team to balance out a cockpit to control lamp variability. Today, few modern cockpits support such trimming. Further, some suppliers mix their LEDs from different sources, which has been observed to create variability in display and light plate assemblies, as their dimming curves may not match. For example, one manufacturer from China may supply an LED with a square transfer function, while one from Japan may have a more linear light output function. Using LEDs from different manufacturers in the same cockpit creates an unbalanced presentation. Therefore, a derived requirement for MIL-DTL-7788 [3] might be to require that all LEDs used must have the same response curve within the same application, panel, and platform (cockpit) to ensure a smooth, cohesive response.

2.6 RECOMMENDATIONS

The use of PWM-based dimmers is strongly encouraged and preferred over voltage trimming-based dimmers; however, since this is primarily a detailed design decision left to most program design activities, it can only be recommended strongly in government standards. The remaining recommendation is to consider the adoption of material quality-based requirements for the use of LED lamps in subassemblies, as expressed in the following suggested revisions to MIL-DTL-7788H, *Detail Specification: Panels, Information, Integrally Illuminated*, of 18 October 2011 [3]:

- Section 3.3.3.4.2, “LED Circuit,” could be a possible location to state that LED sources used in the same panel shall be identical in terms of dimming response.
- The statement that LED sources used in the same panel shall be identical in terms of dimming response should cross reference section 3.1.2 of MIL-DTL-7788H, in that having

mismatched LEDs is therein considered a nonqualifying criterion for qualification by similarity. The following excerpt from section 3.1.2 provides additional details:

> Qualification may also be granted for type VII panels on the basis of similarity provided qualification is achieved within the past two years for other type VII panels using the same LEDs and internal circuit design. However, qualification shall not be granted for class 1-NVIS Green A on the basis of prior qualification for other types or classes. Neither shall qualification be granted for type VI panels utilizing different phosphors, nor for type VII panels using different LEDs and different internal circuit design on the basis of prior qualification for types IV or V or for other classes.

- Consider a future equivalent military specification set for LEDs to quantify the requirements of section 3.3.3, “Light Source.” These specifications could be similar in format to MS3338 (Lamp, Incandescent, T-1 Bulb, Based, 28-Volt, Integral Lighting), MS90451 (T-1 Bulb, Short version), or MS90452 (T-3/4 Bulb) to try to control for variability within sourced LEDs. However, this recommendation is not as strong as ensuring that matching LEDs be used internal to panel assemblies.
- Modify section 3.3.3.2.c “Lamp Quantity” to clarify that the referenced minimum two LED assemblies must be of identical part numbers from the same supplier lot with identical dimming characteristics.

There is also a strong argument for gathering the recommended revisions into a single new paragraph and simply referring to it systematically throughout the referenced collateral requirements sections.

REFERENCES

[1] Department of Defense (DoD). *Crew Systems Aircraft Lighting Handbook.* JSSG-2010-5, Aeronautical Systems Center (ASC), Engineering Directorate Systems Integration Branch (ENSI), Wright-Patterson Air Force Base (AFB), OH, 30 October 1998.

[2] DoD. *Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible*. MIL-STD-3009, Department of Defense Interface Standard, ASC/ENSI, Wright-Patterson AFB, OH, 2 February 2001.

[3] DoD. *Detail Specification: Panels, Information, Integrally Illuminated*. MIL-DTL-7788H, 18 October 2011.

[4] DoD. *Crew Systems Engineering Handbook*. JSSG-2010-1, Aeronautical Systems Center (ASC), Engineering Directorate Systems Integration Branch (ENSI), Wright-Patterson Air Force Base (AFB), OH, 30 October 1998.

BIOGRAPHY

JEFF O'HARA is a Senior Research Scientist with Georgia Tech Research Institute (GTRI) and has nearly three decades of experience as a human factors engineer in the defense and aerospace field in both government and industry roles. His experience includes being the senior or team lead on human factors/pilot-vehicle interface engineering assignments on the F-35, F-22, and F-16 fighters, the RAH-66 Comanche, several X aircraft, and a range of other fixed- and rotary-wing aircraft. His experience also includes extensive ground and flight test work in the areas of crew station, Integrated Caution and Warning System (ICAWS), and symbology design and test. A former U.S. Navy Test Pilot School technical instructor, he provides training on advanced cockpit systems development and working with the military user. He currently supports Department of Defense customers as a technical expert in crew systems/pilot vehicle interface design and test. He holds a B.S. degree from Florida Tech and an M.S. degree from Embry–Riddle Aeronautical University. His current research interests include user interface design and design requirements allocation for highly complex systems; visual and auditory performance coupled with symbology and other cueing development; anthropometric accommodation of crew; lighting and aided/augmented vision design, test, and evaluation; and control and display interface design and test.