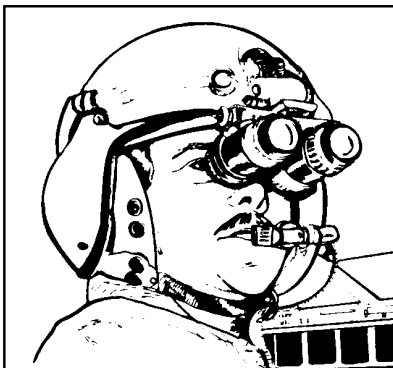


Application Note 1030

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Introduction

The U.S. military services are using night vision imaging systems (NVIS) to allow personnel to see during night operations. Thus, the U.S. military is procuring equipment with lighting specifically configured for use with night vision imaging systems.

Two types of night vision imaging systems are currently in use. These are the GEN II and GEN III night vision goggles, NVG, which differ in their response and gain characteristics in both the visible and infrared regions.

There are three levels of NVIS lighting requirements. The first is for military aircraft cockpit lighting which must be compatible with GEN III goggles per MIL-L-85762A so as not to interfere with their operation. The second is for NVG Secure Lighting for use with GEN II goggles as given in the U.S. Army CECOM Statement of Work (SOW). The third is IR Secure Lighting, which is a reduced requirement of NVG Secure Lighting.

This application note introduces the concept of night vision imaging. It discusses GEN II and GEN III ANVIS and Cat's Eyes night vision goggles. NVG compatibility problems and compatible lighting objectives for aircraft cockpits are discussed. It illustrates the use of NVG filters with high performance green and yellow LEDs to obtain NVG compatibility. Various aspects of MIL-L-85762A, as they apply to LEDs, are discussed. Calculated NVIS Radiance values are presented for high performance green and yellow LED/NVG/DV filter combinations. A discussion of the U.S. Army's NVG Secure Lighting Program and the objectives of the CECOM SOW are included. Information on dimming LED displays is presented. Daylight readability with NVG/DV filters is also discussed.

Avago Technologies military grade LED lamps and displays are ideally suited for use in night vision lighting applications.

Features and benefits include:

- Meet NVIS Radiance with NVG filters
- Dimmable to NVIS lighting levels
- Sunlight or daylight viewable
- Hi-rel screened to either MIL-S-19500 or MIL-D-87157
- -55° C operation
- Meet hermeticity requirements
- Solid state long term reliability

A list of Avago Technologies IR secure hermetic LED lamps per DESC Drawing 87019 and other military grade high performance green and yellow LED lamps and displays for use in NVIS lighting applications is included at the end of this document.

The Concept of Night Vision Imaging

The concept of night vision imaging is to intensify available nighttime near infrared (IR) radiation, (600 nm to 930 nm), sufficiently to be presented to the eye on a miniature green phosphor screen. Nighttime infrared radiation comes from such sources as star light and moon light. Variations in the level of near infrared energy, due to variations in object reflectance, are translated into brightness variations across the face of the monochromatic green visible image, providing the necessary contrast for object recognition. The image is produced with sufficient quality and clarity to discern considerable detail.

Night Vision Goggles

Infrared image intensifier tubes that are currently in use in NVIS optical devices use two different types of

photosensitive materials. The Generation II (GEN II) intensifier tubes use a tri-alkali photocathode, micro-channel. The Generation III (GEN III) intensifier tubes use a gallium arsenide photocathode, microchannel. The GEN II and GEN III intensifier tubes differ in their gain and response characteristics in both the visible and infrared regions.

In Figure 1, the normalized response characteristic of the GEN II AN/PVS-5 goggles and the GEN III AN/AVS-6 ANVIS goggles is shown in relationship to the CIE Photopic Curve and night sky radiation. The GEN II AN/PVS-5 goggles have considerably less gain in the IR region than the GEN III ANVIS goggles. The response characteristic of the GEN II intensifiers in the AN/PVS-5 goggles covers both the visible and IR regions, from 400 nm to 930 nm, but peaks at 550 nm in the visible light region rather than in the IR region. For this reason, considerable difficulty occurs with the use of GEN II AN/PVS-5 goggles in aircraft cockpits due to the incompatibility between cockpit lighting and goggle operation. The response of GEN III intensifiers is from 450 nm to 930 nm and is maximized in the near IR region between 700 nm and 850 nm to take full advantage of nighttime near infrared radiation. Optical filters, termed "minus blue filters," are used in conjunction with the objective lenses of GEN III goggles to restrict their response to visible light. Since the response of the GEN III ANVIS goggles is primarily in the IR region, cockpit lighting in the green and yellow regions is compatible with goggle operation.

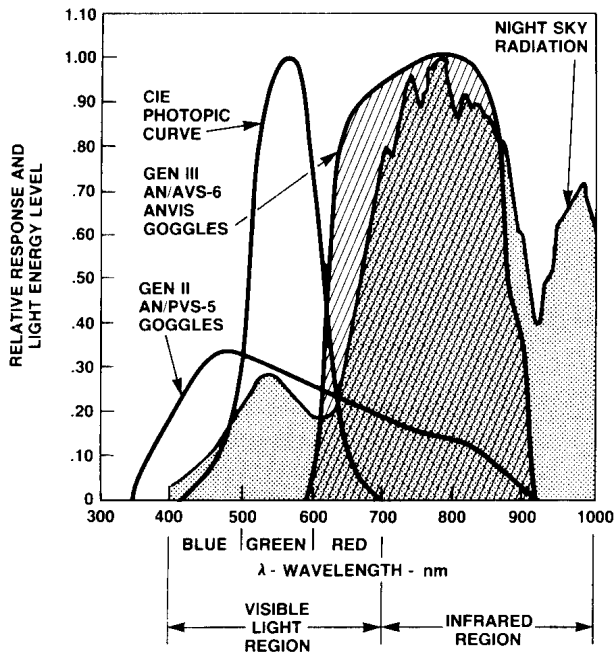


Figure 1. Relative response of GEN II and GEN III Night Vision Goggles with respect to the CIE photopic curve and night sky infrared radiation.

GEN II Night Vision Goggles

GEN II night vision goggles intensify low level visible light and low level near infrared radiation to present an image on a monochrome P-20 green phosphor screen located at each eyepiece. GEN IIPPLUS intensifiers are high gain intensifiers and can be used in any application where GEN II intensifiers are used. GEN II night vision goggles typically do not incorporate optical filters to restrict their response in the visible range. Thus, they are classified as broad band intensifiers, intensifying both low level visible light and near IR radiation.

The GEN II AN/PVS-5 night vision goggles for use in night ground operations are shown in Figure 2a. These goggles use two GEN II or GEN IIPPLUS intensifiers incorporated into a mask assembly that fits over the user's face.

GEN III Goggles for Ground Operations

The AN/PVS-7 monocular/binocular "cyclops" goggles for U.S. Army ground operations are shown in Figure 2b. These goggles use a single GEN III intensifier combined with two eye piece lenses and are mounted off the brim of the user's helmet. The AN/PVS-7 do not incorporate a minus blue filter

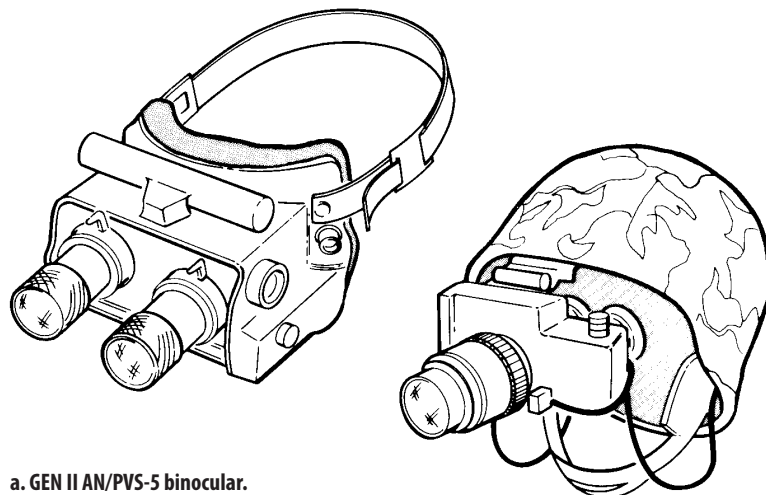
in the objective lens to restrict the response in the visible range, and so are classified as broad band intensifiers, intensifying both near IR radiation and low level visible light.

Classification of GEN III Goggles for Use in Aircraft

GEN III night vision goggles used in aircraft are classified in MIL-L-85762A as to type and class. Type refers to the optical configuration, and class refers to the type of minus blue filters used with the objective lenses.

There are currently two types of GEN III night vision goggles in use, Type 1 and Type 2 as shown in Figure 3. Type 1 goggles, termed Direct Image Systems, use an in-line optical lens viewing system to present the intensified image to the pilot's eyes. The pilot uses the GEN III goggles to see outside the cockpit and then looks down under the goggles, without using any head motion, to view cockpit instrumentation with his unaided eyes.

Type 2 goggles, termed Projected Image Systems, use an offset optical combiner lens viewing system to present the intensified image to the pilot's eyes. The pilot looks through the optical combiner lenses to see both outside the cockpit and the instrumentation inside the cockpit.



a. GEN II AN/PVS-5 binocular.

b. GEN III AN/PVS-7 helmet mounted "cyclops" monocular/binocular.

Figure 2. Night Vision Goggles for ground operations.

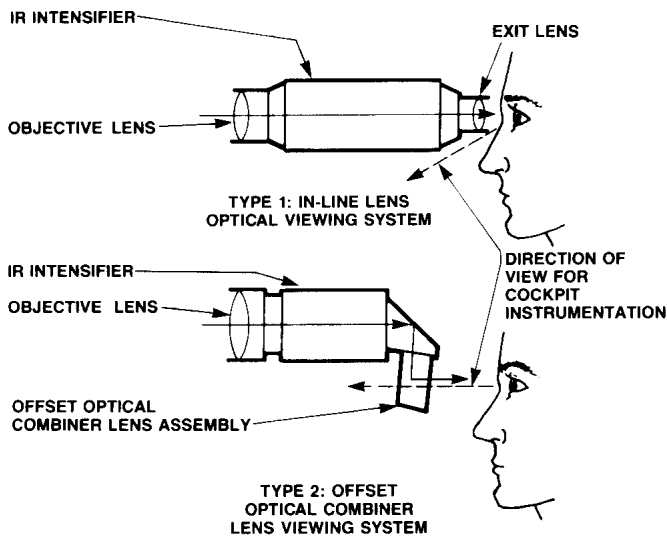


Figure 3. Types of GEN III Night Vision Goggles referred to in MIL-L-85762A.

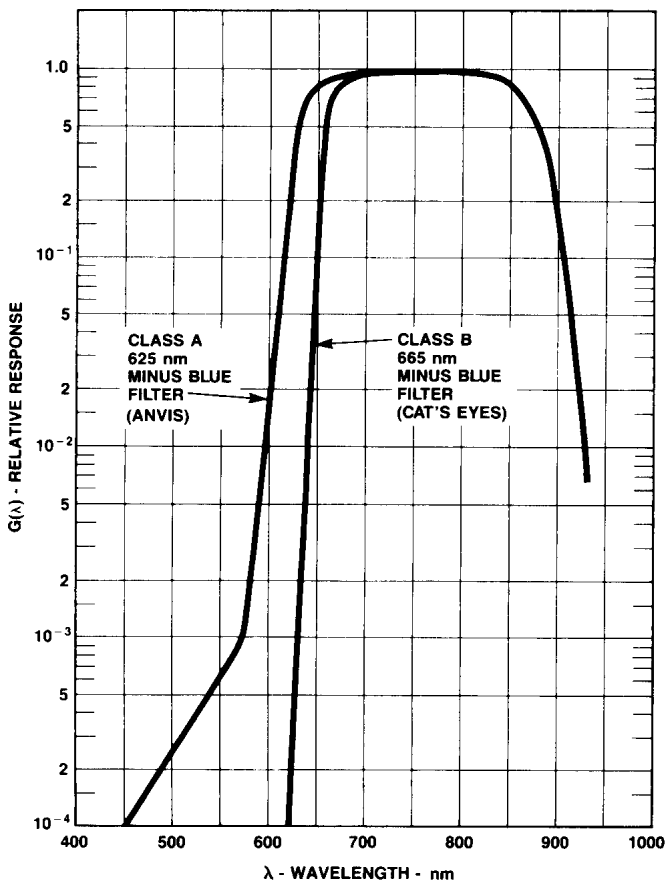


Figure 4. Spectral response of GEN III Goggles with Class A and Class B minus blue filters.

This allows the pilot to see both the intensified image and the cockpit instrumentation simultaneously.

The classes of minus blue filters are defined by the wavelengths where the relative transmission is 50%. The two classes of minus blue filters are the Class A at 625 nm and the Class B at 665 nm, as presented in Figure 4. The GEN III response characteristic with Class A 625 minus blue filters is restricted in the blue, green and yellow regions and peaks in the deep red and IR regions between 650 nm and 850 nm. With Class B minus blue filters, the response of the GEN III goggles is restricted in the blue, green, yellow and orange regions, and peaks in the deep red and IR regions between 700 nm and 850 nm.

Note: GEN IIPLUS intensifiers in combination with 625 nm minus blue filters have a response similar to that of the GEN III ANVIS goggles, but with considerably less overall gain in the IR region.

Type 1, Class A AN/AVS-6 ANVIS Goggles

The GEN III AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS), pictured in Figure 5, are direct view configuration goggles. They were developed by the U.S. Army Aviation Systems Command (AVSCOM), St. Louis, Missouri, for helicopter night operations.

The GEN III ANVIS goggles are about the size of a small pair of binoculars, weigh about 20 ounces and are mounted on the front of the pilot's flight helmet by means of a mounting and quick disconnect assembly. An automatic gain control maintains uniform phosphor brightness to compensate for varying levels of IR energy.

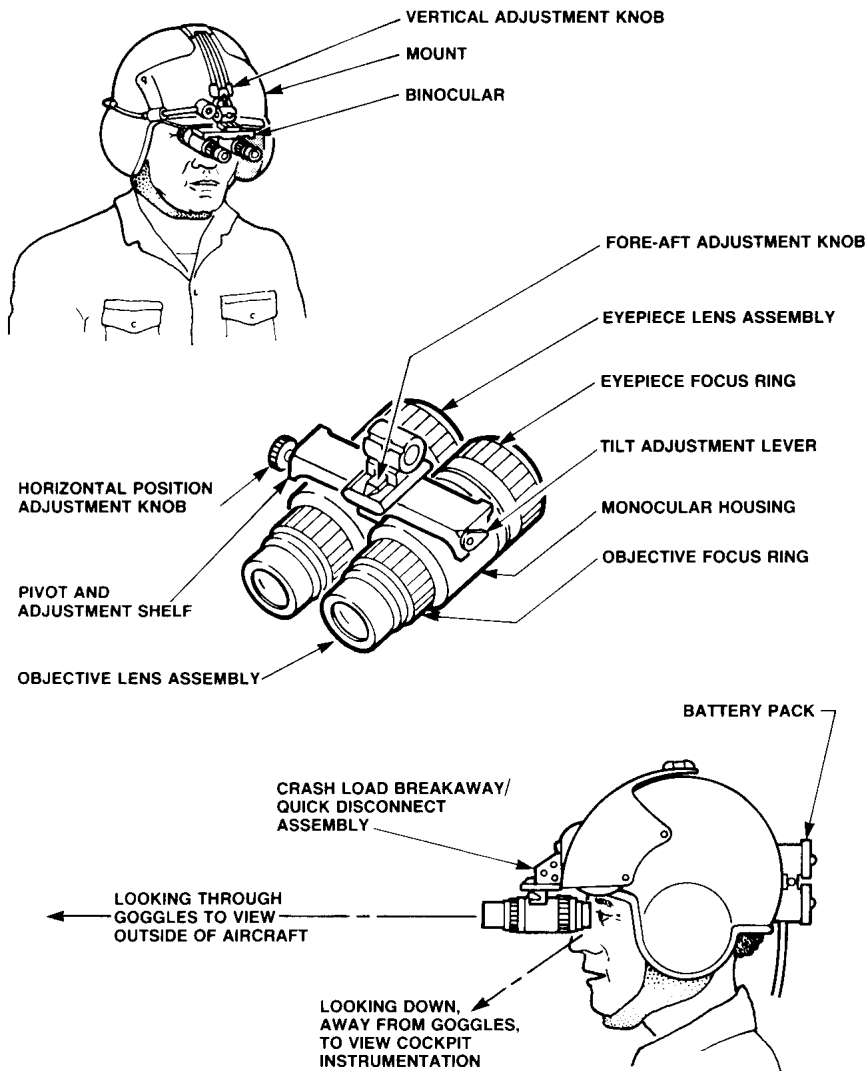


Figure 5. Details of the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) GEN III Type 1, Class A Night Vision Goggles.

Focusing and other adjustments are achieved manually by the pilot. A 2.7 V battery pack is mounted on the back of the flight helmet and acts as a balance counter weight.

The minus blue filters are incorporated as optical coatings on the objective lenses. The response of the ANVIS goggles with Class A 625 nm filters has sufficient sensitivity in the red region to permit the goggles to respond to near IR reflected off tree bark, grass

and other green vegetation. This is necessary since helicopters often operate below tree top level.

A version of the ANVIS goggles has been developed by Systems Research Laboratories, Dayton, Ohio for the U.S. Air Force that incorporates heads up (HUD) flight data into the right hand lens. The objective was to adapt the ANVIS for use with fixed wing aircraft in low level flight operations.

Type 2, Class B Cat's Eyes Goggles

The GEN III Cat's Eyes were developed in England for use in fixed wing aircraft for the Royal Air Force. The Cat's Eyes goggles are now in use by U.S. Navy pilots in fixed wing aircraft.

The GEN III Cat's Eyes are projected image goggles and are smaller and lighter than the ANVIS. The Cat's Eyes use essentially the same GEN III image intensifier tubes as the ANVIS and have automatic gain control. The Cat's Eyes are mounted high on the forehead of the pilot's helmet via a mounting and quick disconnect assembly, as shown in Figure 6. The intensified image is projected into combiner lenses. The pilot views both the intensified image and the cockpit instrumentation through the combiner lenses. The combiner lenses are spaced outward from the pilot's eyes for three dimensional viewing. Focusing and other adjustments are achieved manually by the pilot.

The minus blue filters are incorporated as separate lenses located in front of the objective lenses. The Cat's Eyes response is reduced in the red region permitting the use of orange and red-orange lighting in the cockpit for master caution and fire warning indicators. Since the primary use for Cat's Eyes is in fixed wing aircraft, which typically operate above tree top level, it is not necessary to have response sensitivity in the red region as does the ANVIS with Class A minus blue filters.

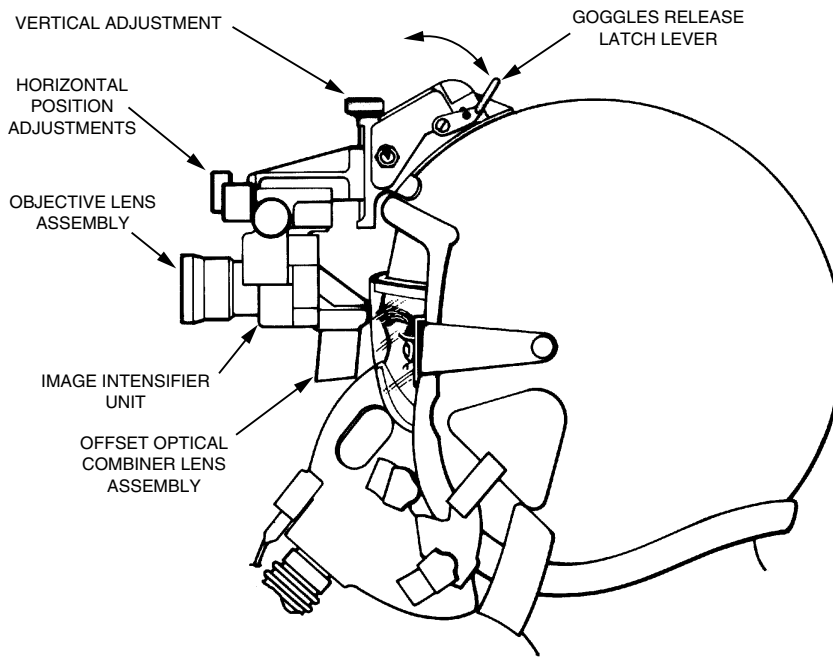


Figure 6. Details of the Cat's Eyes GEN III Type 2, Class B Night Vision Goggles.

GEN III Goggle Configurations per MIL-L-85762A

The GEN III night vision goggles may be configured in any of four possible combinations per MIL-L-85762A, as listed in Table 1. At the publication of this application note, the two configurations in use are the ANVIS Type 1, Class A and the Cat's Eyes Type 2, Class B, identified by (*).

NVG Compatibility

Definition of NVG Compatibility

An aircraft cockpit light source is NVG compatible if it does not interfere with the operation of GEN III goggles.

NVG compatibility for noncritical lighting and instrumentation is based on the appearance of tree bark as viewed through night vision goggles. Tree bark is considered to be one of

the darkest objects (very low IR reflectance) that an observer can recognize when looking through the goggles. When viewed through the goggles, noncritical cockpit lighting and instrumentation are considered to be NVG compatible by military standards when the NVIS Radiance level is equivalent to that of tree bark (see the section on "NVIS Radiance").

As viewed through GEN III goggles, the NVIS Radiance for master caution and warning lights has been established to be between 300 to 880 times the value for general cockpit lighting. This is to insure that an illuminated master caution or warning indicator will be detected by a pilot while he is concentrating on viewing outside the cockpit through the goggles. This range of NVIS Radiance provides a bright image with slight blooming but is not sufficient to interfere with goggle operation.

Objectives for NPO Compatible Cockpit Lighting

Some objectives for NVG compatible cockpit lighting can be defined:

1. Select the radiated spectra of NVG filtered general cockpit flood lighting to be outside the response characteristic of the GEN III goggles with minus blue filters.
2. Provide sufficient general illumination to locate switches and read cockpit instrumentation with unaided eyes. The illumination should be NVG filtered to achieve specified NVG compatibility, be perceptibly uniform and should be green in color. The color green should be similar to the green of the P-20 phosphor of the GEN III goggles.
3. Retain color differences within the NVG filtered light emitting displays to enhance information transfer to the pilot, specifically when pertaining to master caution and warning lights. The radiated spectra from master caution and warning displays should be NVG filtered to achieve a specified NVG compatibility.

Table 1. GEN III/Minus Blue Filter Combinations

Type of GEN III Goggle	Class of Minus Blue Filter
(*)Type 1	Class A
Type 1	Class B
Type 2	Class A
(*)Type 2	Class B

- Type 1 are Direct Image (in line lens) optical viewing goggles.
- Type 2 are Projected Image (offset combiner lens) optical viewing goggles.
- Class A is a 625 nm minus blue filter.
- Class B is a 665 nm minus blue filter.

4. The NVG filtered radiated spectra of master caution and warning lights and displays should contain wavelengths within the GEN III short wavelength response to attract the pilot's attention when looking through the goggles. The luminance level should be low enough to prevent interference with goggle operation.

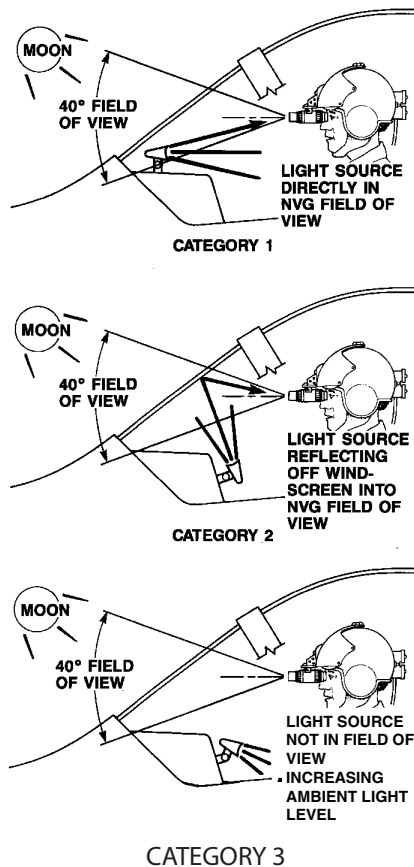


Figure 7. Categories of light sources in an aircraft cockpit.

NVG Compatibility Problems in an Aircraft Cockpit

Light sources within an aircraft cockpit may be grouped into three categories as illustrated in Figure 7. If the radiated spectra for these light sources are not NVG filtered and fall within the GEN III ANVIS or Cat's Eyes response characteristic, they can interfere with the operation of the night vision goggles.

Category 1 light sources are directly in the field of view of the goggles. NVG shut down or blooming can be caused by these light sources. NVG shut down and blooming are the conditions where all imaging is erased from the goggles' miniature phosphor screens due to an excessive amount of red and infrared wavelengths being emitted by the light source.

Category 2 light sources are those that reflect off the cockpit windscreen directly into the field of view of the goggles. The reflections from these light sources can cause either blooming or sufficient loss of viewability and contrast to hinder definitive object recognition.

Category 3 light sources are not in the field of view nor reflect directly into the field of view of the GEN III goggles. Category 3 light sources may raise the cockpit ambient light level sufficiently to cause NVG flare, caused by light scattering in the goggle's objective lenses. Contrast would be reduced, limiting viewability and object recognition.

MIL-L-85762A, Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible

Specification

The military specification that governs aircraft NVG compatible lighting and light emitting displays is MIL-L-85762A, Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible. The scope of this specification establishes performance, general configuration, test and acceptance requirements for NVIS compatible aircraft interior lighting. The purpose of this specification is to provide performance requirements and testing methodology to ensure effective and standardized aircraft interior lighting for NVIS compatibility. MIL-L-85762A also specifies requirements for Type 1 and Type 2 goggles and Class A and Class B minus blue filters.

NVIS Radiance

NVIS Radiance (NR) is a quantitative measure of NVG compatibility of a light source as viewed through GEN III goggles. It is determined by the equations and procedures listed in section 4.8.14, Spectral radiance measurements, of MIL-L-85762A. NVIS Radiance is defined by Equation 15 of section 4.8.14 as the integral from 450 nm to 930 nm of the product of 1) the GEN III NVIS response characteristic, 2) a measurement scaling factor and 3) the spectral radiance of the NVG filtered light source. A normalizing constant is used to convert the units of the integral into nondimensional NR units. The NVIS Radiance equation is presented here as it would be used to determine the NR value for an NVG filtered LED display.

$$\text{NVIS Radiance} = G(\lambda) \max \int_{450 \text{ nm}}^{930 \text{ nm}} G(\lambda) \text{SN}(\lambda) d\lambda \text{ NR}$$

Where: $G(\lambda) \max$ = NR conversion constant (1.0 mA/W).

$G(\lambda)$ = Relative response of the GEN III Class A, $G_A(\lambda)$, or Class B, $G_B(\lambda)$, night vision goggles.

S = A measurement scaling factor defined by Equation 14 of section 4.8.14.

$N(\lambda)$ = The spectral radiance of the NVG filtered LED display (W/sr cm² nm).

$d(\lambda)$ = 5 nm increments.

The spectral radiant intensity, $N(\lambda)$, of the NVG filtered LED display is to be measured by a spectroradiometer in a dark environment at full rated drive condition or at 15 fL, whichever is less.

The measurement scaling factor, S , is defined by Equation 14 of section 4.8.14 as the ratio of the required luminance level for NVIS Radiance (ie. 0.1 fL or 15 fL) to the luminance of the LED display necessary for a photometer or spectroradiometer to make the measurement:

$$S = \frac{L_r}{L_m} \quad (2)$$

Where:

L_r = Required luminance for NVIS Radiance

L_m = Actual measured luminance of the LED display

The purpose of this scaling factor is to ratio the luminance of the NVG filtered LED device as measured, to the required luminance for NVIS Radiance. Typically, the brightness of

an NVG filtered LED display can be set by the dimming control circuit to the required NVIS luminance. However, the luminance level required for NVIS Radiance may be insufficient to achieve valid data, and thus a higher luminance level may be necessary to make the measurement.

NVIS Radiance for Compatible Lighting

General cockpit lighting and instrumentation, set at a brightness level of 0.1 fL, are considered to be NVG compatible per MIL-L-85762A when the NVIS Radiance level is equal to or less than 1.7×10^{-10} NRA for Class A goggles and 1.6×10^{-10} NRB for Class B goggles. The NVIS radiance limit of 1.7×10^{-10} NR is close to the NVIS radiance of 1.63×10^{-10} NR measured for tree bark, as viewed through the GEN III ANVIS night vision goggles.

Tables 2a and 2b list NVIS Radiance requirements for different kinds of aircraft lighting as specified in section 3.10.9 Spectral Radiance Limits and Table IX NVIS Radiance Requirements of MIL-L-85762A.

Table 2a. NVIS Radiance Requirements for Type 1 Goggles
(Taken from Table IX of MIL-L-85762A)

Lighting Component	fL	Class A Goggles		Class B Goggles	
		Minimum NR _A	Maximum NR _A	Minimum NR _B	Maximum NR _B
Primary & Secondary	0.1	1.7×10^{-10}	1.6×10^{-10}		
Illuminated Controls	0.1	1.7×10^{-10}	1.6×10^{-10}		
Compartment, Utility, Work, Inspection	0.1	1.7×10^{-10}	1.6×10^{-10}		
Caution and Advisory	0.1	1.7×10^{-10}	1.6×10^{-10}		
Jump Lights	5.0	1.7×10^{-8}	5.0×10^{-8}	1.6×10^{-8}	4.7×10^{-8}
Warning Signals	15.0	5.0×10^{-8}	1.5×10^{-7}	4.7×10^{-8}	1.4×10^{-7}
Master Caution	15.0	5.0×10^{-8}	1.5×10^{-7}	4.7×10^{-8}	1.4×10^{-7}
Emergency Exit	15.0	5.0×10^{-8}	1.5×10^{-7}	4.7×10^{-8}	1.4×10^{-7}
Electronic, Electro-Optical Displays (Monochromatic)	0.5	1.7×10^{-10}	1.6×10^{-10}		
HUD Systems	5.0	1.7×10^{-9}	5.1×10^{-9}	1.6×10^{-9}	4.7×10^{-9}

NVIS Colors per MIL-L-85762A

The four NVIS color ranges as specified in section 3.10.8 Chromaticity of MIL-L-85762A are designated 1) NVIS GREEN A, 2) NVIS GREEN B, 3) NVIS YELLOW and 4) NVIS RED. These color ranges are shown on the 1976 UCS Chromaticity Diagram in Figure 8. The NVIS GREEN B region is yellow-green in color, defined between the dominant wavelengths of 544 nm and 562 nm. The NVIS YELLOW region includes the colors greenish-yellow, yellow and yellowish-orange, defined between the dominant wavelengths of 572 nm and 588 nm. The NVIS RED region is not red, but contains the colors orange and reddish-orange, defined between the dominant wavelengths of 598 nm and 618 nm.

Reproduced in Table 3 are the NVIS colors for NVIS compatible interior aircraft lighting as specified in Table VIII Chromaticity Requirements of MIL-L-85762A.

NOTE: NVG filtered high performance green LEDs are best suited for NVIS GREEN B light sources. However, Table VIII of MIL-L-85762A does allow “special lighting components, such as LEDs, where increased display emphasis by highly saturated (monochromatic) colors is necessary, or adequate readability cannot be achieved with GREEN A.” Thus, an NVG filtered high performance green LED light source is permissible for use in all NVIS GREEN A lighting applications. NVG filtered yellow LEDs are best for all NVIS YELLOW lighting applications.

An aircraft cockpit can be classified as either a Class A cockpit or as a Class B cockpit. A Class A cockpit does not contain NVIS RED lighting and is intended for use with either Class A ANVIS or Class B Cat’s Eyes goggles. A Class B cockpit includes NVIS RED lighting and is intended for use only with Class B Cat’s Eyes goggles.

Use of Red LEDs in NVG Compatible Cockpits

Due to the sensitivity of GEN III night vision intensifiers to red light, red light sources are not permitted in NVIS compatible aircraft cockpits.

NVG Filters

NVG Filter IR Suppression for LEDs

An idealized NVG filter is shown superimposed over an LED spectrum in Figure 9. The radiated spectrum of an LED contains a certain amount of near IR emission. Therefore, to assure NVG filtered LED lamps and displays meet the NVIS Radiance requirements of MIL-L-85762A, the NVG filter relative transmission between 650 nm and 930 nm should be less than 0.01% (10⁻⁴). This provides greater than four orders of magnitude suppression of LED IR wavelengths. The NVG filter, designed to pass LED spectrum visible wavelengths below the red region, is

Table 2b. NVIS Radiance Requirements for Type 2 Goggles
(Taken from Table IX of MIL-L-85762A)

Lighting Component	fL	Class A Goggles	Class B Goggles
		Maximum NRA	Maximum NRB
Primary & Secondary	0.1	1.7 x 10 ⁻¹⁰	1.6 x 10 ⁻¹⁰
Illuminated Controls	0.1	1.7 x 10 ⁻¹⁰	1.6 x 10 ⁻¹⁰
Compartment, Utility, Work, Inspection	0.1	1.7 x 10 ⁻¹⁰	1.6 x 10 ⁻¹⁰
Caution and Advisory	0.1	1.7 x 10 ⁻¹⁰	1.6 x 10 ⁻¹⁰
Jump Lights	5.0	5.0 x 10 ⁻⁸	4.7 x 10 ⁻⁸
Warning Signals	15.0	1.5 x 10 ⁻⁷	1.4 x 10 ⁻⁷
Master Caution	15.0	1.5 x 10 ⁻⁷	1.4 x 10 ⁻⁷
Emergency Exit	15.0	1.5 x 10 ⁻⁷	1.4 x 10 ⁻⁷
Electronic, Electro-Optical Displays (Monochromatic)	0.5	1.7 x 10 ⁻¹⁰	1.6 x 10 ⁻¹⁰
HUD Systems	5.0	1.7 x 10 ⁻⁹	1.6 x 10 ⁻⁹

Note:

NR_A = NVIS Radiance, Class A Goggles

NR_B = NVIS Radiance, Class B Goggles

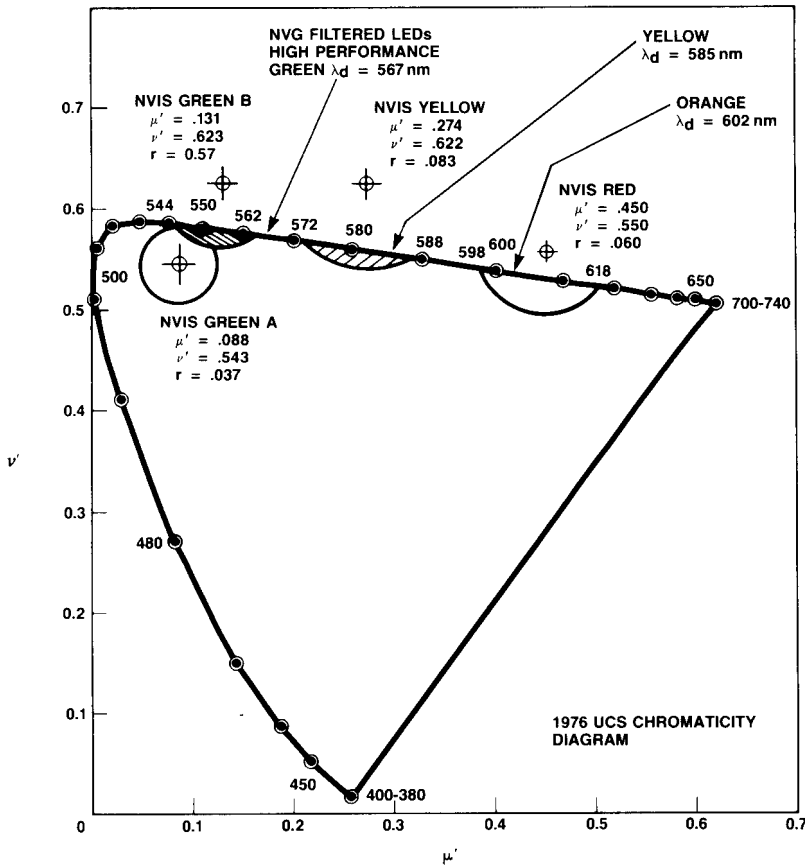


Figure 8. NVIS color ranges per MIL-L-85762A.

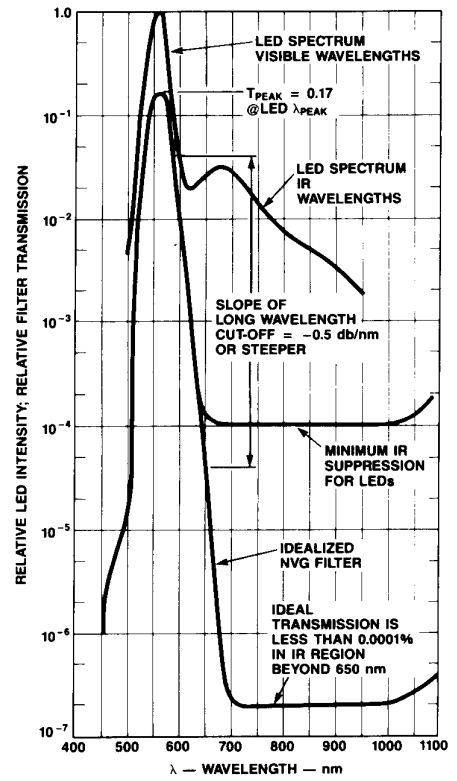


Figure 9. The relative transmission characteristic of an NVG/DV filter shown in relationship to the radiated spectrum of an LED.

Table 3. NVIS Color Requirements for Various Types of Lighting
(Taken from Table VIII of MIL-L-85762A)

Lighting Component	fL	Type 1 and Type 2 Goggles	
		Class A NVIS Color	Class B NVIS Color
Primary and Secondary	0.1	GREEN A	GREEN A
Illuminated Controls	0.1	GREEN A, GREEN B	GREEN A, GREEN B
Compartment, Utility, Work, Inspection	0.1	GREEN A	GREEN A
Caution and Advisory	0.1	GREEN A, GREEN B	GREEN A, GREEN B
Jump Lights	5.0	GREEN A, GREEN B	GREEN A, GREEN B
		YELLOW	YELLOW
Warning Signals	15.0	YELLOW	YELLOW, RED
Master Caution	15.0	YELLOW	YELLOW

placed in front of the LED display, or LED light source, as shown in Figure 10a. The NVG filter severely attenuates the red wavelengths and the infrared signature in the LED radiated spectrum to meet NVIS Radiance.

For illustration, the relative effect of an NVG filter on the high performance green LED spectrum is diagrammed in Figures 10b and 10c. These semi-log plot graphs illustrate the relative effect of an NVG filter as seen by a pilot and as detected by GEN III ANVIS night vision goggles. In Figure 10b, the NVG filtered LED spectrum as seen by the pilot with unaided eyes (without goggles), $L(NVG)$, is the integral from 450 nm to 760 nm of the product of the LED normalized radiated spectrum, $f(\lambda)$, the NVG filter relative transmission characteristic, $T(\lambda)$, and the CIE photopic curve $\bar{y}(\lambda)$:

$$L(NVG) = \int_{450 \text{ nm}}^{760 \text{ nm}} f(\lambda) T(\lambda) \bar{y}(\lambda) d\lambda \quad (3)$$

To the pilot's unaided eyes, the NVG filtered LED spectrum, $L(NVG)$, appears green in color. The pilot sets the luminance of the NVG filtered LED display or light source to 0.1 fL by adjusting a cockpit dimming control.

In Figure 10c, the NVG filtered LED radiated spectrum as detected by the GEN III ANVIS goggles, $R(NVG)$, is the integral from 450 nm to 930 nm of the product of the LED normalized radiated spectrum, $f(\lambda)$, the NVG filter relative transmission characteristic, $T(\lambda)$, and the normalized response characteristic of the GEN III goggles, $G(\lambda)$.

$$R(NVG) = \int_{450 \text{ nm}}^{930 \text{ nm}} f(\lambda) T(\lambda) G(\lambda) d\lambda \quad (4)$$

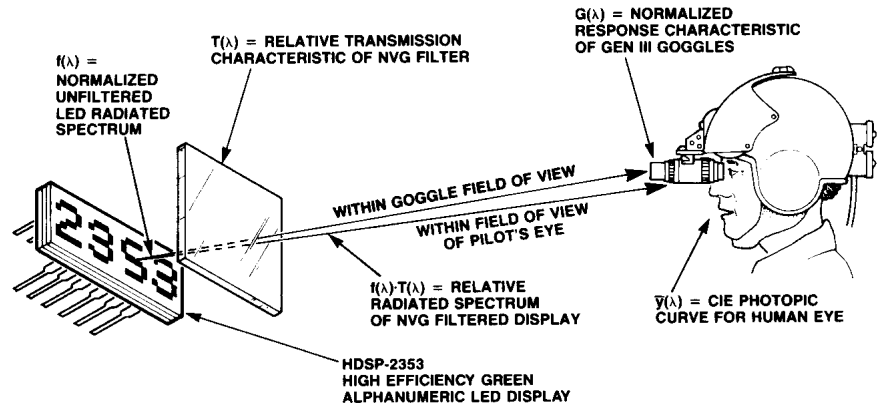


Figure 10a. Definition of parameters used to determine the effect of an NVG filter placed over the face of an LED display.

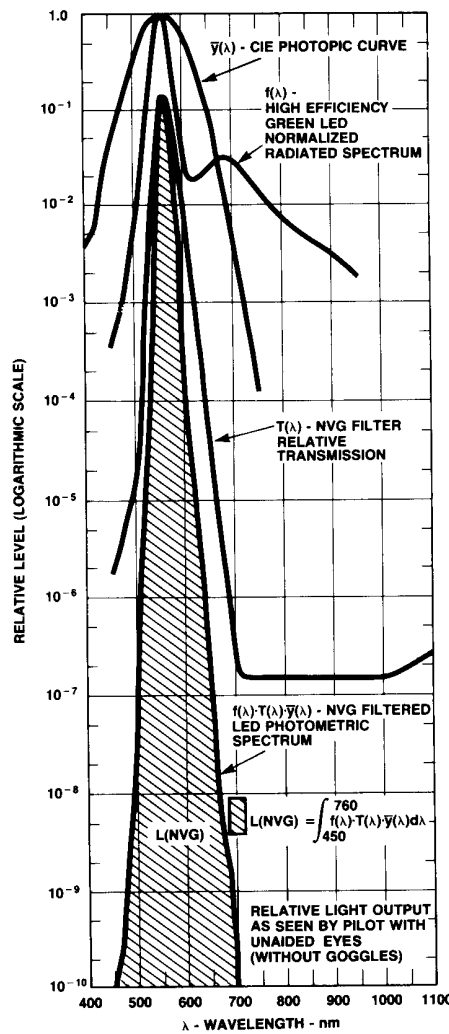


Figure 10b. Relative effect of an NVG filter placed over the face of an LED display as observed by a pilot with unaided eyes.

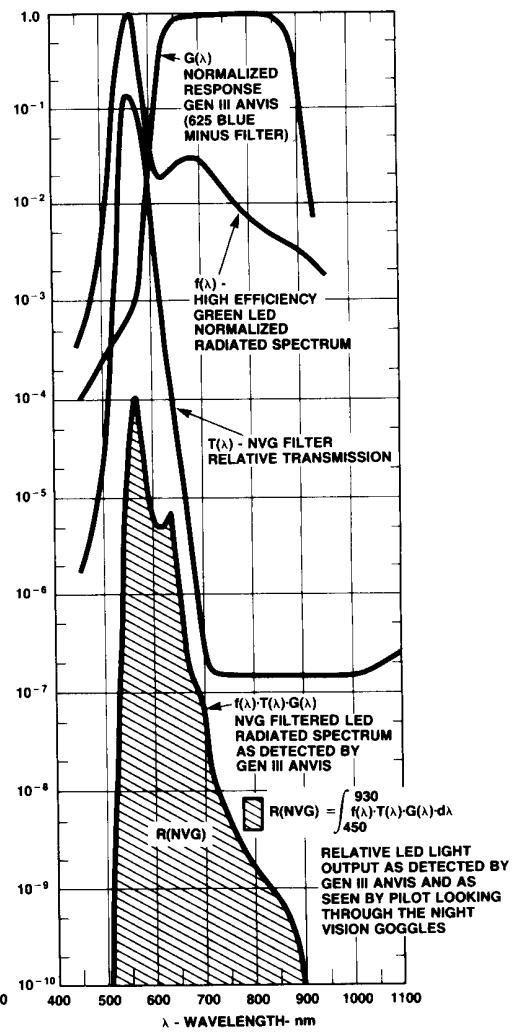


Figure 10c. Relative effect of an NVG filter placed over the face of an LED display as detected by GEN III goggles and as seen by a pilot looking through ANVIS goggles.

The total light energy contained within the R(NVG) spectrum in relationship to the L(NVG) spectrum determines the value of NVIS Radiance. To meet NVIS Radiance at 0.1 fL, the amount of energy contained within the R(NVG) spectrum must be less than 0.1% of the energy contained within the L(NVG) spectrum: $R(NVG) / L(NVG) < 0.1\%$.

Glass NVG and NVG/DV Filters

Glass NVG and glass composite NVG/DV (daylight viewing) filters provide the best suppression of IR wavelengths. They significantly reduce the IR signature of an LED spectrum, permitting NVG filtered LEDs to meet the NVIS Radiance requirements of

MIL-L-85762A. Glass composite NVG/DV filters are narrow passband filters aligned with the radiated spectra of LEDs to provide sufficient contrast enhancement for readability in bright daylight. Glass NVG filters are broad passband filters and usually attenuate the visible portion of LED radiated spectra to the extent that they typically do not provide any contrast enhancement for daylight viewing. Glass filters can withstand 85% relative humidity and temperature variations from -55° C to + 100° C.

Two vendors provide glass and glass composite filters. Their products along with the total amount of LED light transmitted by each filter, T(LED), are listed in Table 4.

Plastic NVG Filters

Plastic NVG filters, typically made of polycarbonate, provide sufficient IR suppression to permit LEDs to meet the NVIS Radiance requirements of MIL-L-85762A and the Priority 1 objective of the CECOM NVG Secure Lighting SOW. Plastic NVG filters can withstand noncondensing humidity environments and temperatures from - 40° C to + 100° C. Typically, plastic NVG filters do not provide sufficient contrast enhancement to permit viewability in daylight ambients.

Two vendors provide plastic NVG filters. Their products, made of polycarbonate, along with the total amount of LED light transmitted by each filter, T(LED), are listed in Table 5.

Table 4. Glass Filter Vendors

Vendor	Filter Part No.	Type	Color	T(LED)	LED Color	Use
WAMCO	NV-2GL-1	NVG/DV	Green	8%	Avago Green	1
	NV-2GL-5	NVG/DV	Green	11%	Avago Green	1
	NV-4YL-3	NVG/DV	Yellow-Green	11%	Avago Green	2
	NV-2C	NVG	Medium Blue	10%	Avago Green	3
	NV-3YL-4	NVG/DV	Yellowish-Orange	13%	Yellow	4
	NV-2SO-8	NVG/DV	Orange	10%	Orange	5
Kopp Glass	0403/3480	NVG/DV	Green	10%	Avago Green	1
	0404/3482	NVG	Medium Blue	22%	Avago Green	3
	0405/2424	NVG/DV	Yellowish-Orange	13%	Yellow	4
WAMCO 11555-A Coley River Circle Fountain Valley, California 92708-4272 (714) 545-5560			Kopp Glass 2108 Palmer Street Pittsburgh, PA 15218 (412) 271-0190			

USES:

- | | | |
|---|---|--|
| <p>1. Recommended for MIL-L-85762A NVIS GREEN B Class A and B Cockpits and NVG Secure Lighting applications where daylight readability is required.</p> | <p>3. Recommended for MIL-L-85762A NVIS GREEN B Class A and B cockpits and NVG Secure Lighting applications where daylight readability is not required.</p> | <p>5. Recommended for master caution and warning indicators in MIL-L-85762A NVIS RED Class B Cockpits only, where daylight readability is required. Not for use in Class A Cockpits.</p> |
| <p>2. Recommended for NVG Secure Lighting applications where daylight readability is required.</p> | <p>4. Recommended for master caution and warning indicators in MIL-L-85762A NVIS YELLOW Class A and B Cockpits and NVG Secure Lighting applications where daylight readability is required.</p> | <p>6. Recommended for master caution and warning indicators in MIL-L-85762A NVIS YELLOW Class A and B Cockpits and NVG Secure Lighting applications.</p> |

Table 5. Plastic NVG Filter Vendors

Vendor	Filter Part No.	Type	Color	T(LED)	LED Color	Use
American	R10093-120D	NVG	Green	13%	Avago Green	3
Cyanamid	R10093-120A	NVG	Yellowish-Orange	11%	Yellow	6
Gentex	Blue-Green	NVG	Green	7%	Avago Green	3
American Cyanamid Company Glendale Protective Technology Polymer Products Division P.O. Box 6885 Bridgewater, New Jersey 08807 (201) 356-2600			Gentex Corporation P.O. Box 336 Carbondale, Pennsylvania 18407 (717) 282-3550			

Avago Technologies LEDs and NVG Compatibility Per MIL-L-85762A

With proper NVG filtering, Avago Technologies high performance green and yellow LED devices are ideal for use as category 1, 2 or 3 light sources and instrumentation in aircraft cockpits. The appropriate NVG filter severely attenuates the infrared signature of the LED spectrum to achieve NVIS Radiance compatibility. High performance green LED hermetic lamps and displays are used for general cockpit instrumentation and lighting. Yellow LED hermetic lamps and displays are used as master caution and warning indicators.

LEDs and NVIS Radiance

With the use of the proper NVG/DV filter, daylight viewable high performance green LEDs will easily meet the NVIS Radiance requirement of 1.7×10^{-10} NR at 0.1 fL for general lighting and instrumentation. Also, they will be viewable in bright daylight conditions at maximum LED brightness.

With the use of the proper NVG/DV filter, daylight viewable yellow LEDs will easily meet NVIS Radiance requirement of 5×10^{-8} NR to 1.5×10^{-7} NR at a brightness of 15 fL for master caution and warning light sources. Also, they will be viewable in bright daylight conditions at maximum LED brightness.

The NVIS Radiance values presented in this application note are calculated using Equation 1.

Glass NVG/DV and NVG Filter/LED Combinations

Table 6 lists GEN III, Class A NVIS Radiance values for various brightness levels for high performance green and yellow LEDs filtered by NVG/DV and NVG filters.

As shown in Table 6, high performance green LEDs in combination with WAMCO and Kopp Glass NVG/DV and NVG filters at the brightness level of 0.1 fL meet the NVIS Radiance requirement of 1.7×10^{-10} NR for primary and secondary lighting components.

High performance green LEDs in combination with the WAMCO NV-2C filter at the brightness level of 0.5 fL are less than the NVIS Radiance limit of 1.7×10^{-10} NR for electro-optical displays.

High performance green LEDs in combination with the WAMCO NV-2C and the Kopp Glass 0403/3480 and 0404/3482 filters at the luminance level of 5 fL meet the NVIS Radiance requirement for HUD systems of 1.7×10^{-9} NR to 5.1×10^{-9} NR.

Yellow LEDs in combination with the WAMCO NV-3YL-4 and Kopp Glass 0405/2424 NVG/DV filters at a brightness of 15 fL fall within the NVIS Radiance range of 5.0×10^{-8} NR to 1.5×10^{-7} NR for master caution and warning lights.

Orange LEDs in combination with the WAMCO NV-2SO-8 NVG/DV filter at a brightness of 15 fL are below the maximum NVIS Radiance of 1.4×10^{-7} NR for master caution and warning indicators in Class B cockpits.

Table 6. Calculated GEN III, Class A NVIS Radiance Values NVG/DV and NVG Filter/LED Combinations.

Filter	NVG Filtered LED Brightness Level			
	0.1 fL	0.5 fL	5 fL	15 fL
High Performance Green LEDs				
WAMCO				
NV-2GL-1	4.6 x 10 ⁻¹¹ NR			
NV-2GL-5	1.3 x 10 ⁻¹⁰ NR			
NV-2C	3.3 x 10 ⁻¹¹ NR	1.7 x 10 ⁻¹⁰ NR	1.7 x 10 ⁻⁹ NR	
NV-4YL-3	1.7 x 10 ⁻¹⁰ NR			
Kopp Glass				
0403/3480	8.0 x 10 ⁻¹¹ NR		4.0 x 10 ⁻⁹ NR	
0404/3482	1.0 x 10 ⁻¹⁰ NR		5.0 x 10 ⁻⁹ NR	
Yellow LEDs				
WAMCO				
NV-3YL -4				9.8 x 10 ⁻⁸ NR
Kopp Glass				
0405/2424				5.7 x 10 ⁻⁸ NR
Orange LEDs				
WAMCO				
NV-2SO-8				1.8 x 10 ⁻⁸ NR (See note below)

Note: This is a Class B NVIS Radiance value for a Class B cockpit, calculated using GB(I) in Equation 1.

Table 7. Predicted GEN III, Class A NVIS Radiance Values for LEDs in Combination with Plastic NVG Filters.

Plastic NVG Filter	Plastic NVG Filtered LED Brightness Level			
	0.1 fL	0.5 fL	5 fL	15 fL
High Performance Green LEDs				
American Cyanamid				
R10093-120D	9.5 x 10 ⁻¹¹ NR			
Blue-Green				
Gentex				
Blue-Green	6.3 x 10 ⁻¹¹ NR			
Yellow LEDs				
American Cyanamid				
R10093-120A				
Yellow				5.1 x 10 ⁻⁸ NR

Plastic NVG Filter/LED Combinations

Table 7 lists predicted GEN III, Class A NVIS Radiance values for high performance green and yellow LED/plastic NVG filter combinations.

As shown in Table 7, high performance green LEDs in combination with American Cyanamid and Gentex plastic NVG filters at the brightness level of 0.1 fL meet the NVIS radiance requirement of 1.7 x 10⁻¹⁰ NR for primary and secondary lighting components.

Yellow LEDs in combination with the American Cyanamid R10093-120A filter at the brightness of 15 fL meet the NVIS Radiance requirement of 5.0 x 10⁻⁸ NR to 1.5 x 10⁻⁷ NR for master caution and warning lights.

High Performance Green LEDs and NVIS GREEN A and NVIS GREEN B

NVG filtered LED lamps and displays are saturated color light sources with their colors specified in terms of dominant wavelength, λ_d . NVIS GREEN A is a desaturated blue-green color that cannot be produced by an LED light source.

The radiated spectrum for high performance green LEDs is shown in Figure 11. The peak wavelength is 570 nm and the color is greenish-yellow, with a dominant wavelength of 574 nm. The color of NVG/DV filtered high-performance green LEDs is shifted to a yellow-green color with a dominant wavelength of 567 nm. The color does appear green to an observer. However, as shown in Figure 8, the dominant wavelength of 567 nm falls outside the upper limit of 562 nm for NVIS GREEN B compatible light sources. Therefore, a color waiver against the NVIS GREEN B requirement is usually agreed upon when NVG filtered high performance green LEDs are used in NVG compatible aircraft cockpits.

It is possible to shift the color of high-performance green LEDs into the NVIS GREEN B region with NVG filters. Blue glass and green plastic NVG filters shift the color into the NVIS GREEN B region by significantly attenuating that portion of the LED radiated spectrum above 565 nm. The trade-off is that the luminance of NVG filtered LED is reduced, limiting readability to ambient light levels of less than 1000 fc. This is a viable option when there is no requirement for daylight readability.

Yellow LEDs and NVIS YELLOW

The radiated spectrum for yellow LEDs is shown in Figure 11. The spectrum peak wavelength is at 583 nm and has the color yellowish-orange, with a dominant wavelength of 585 nm which is located within the NVIS

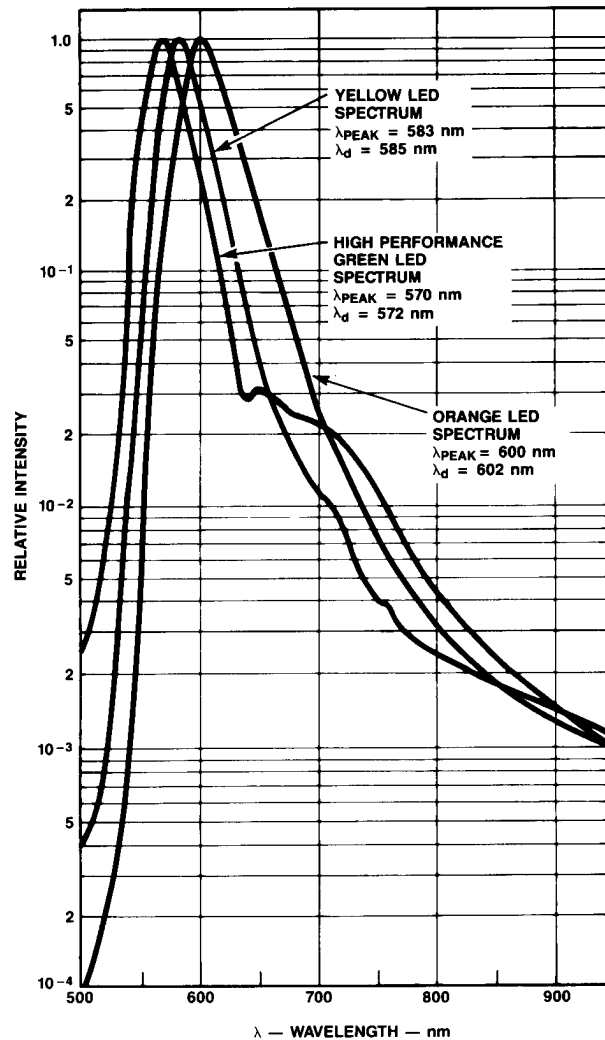


Figure 11. Radiated spectra of High Performance Green, Yellow and Orange LEDs.

YELLOW region, as shown in Figure 8. This makes NVG/DV filtered yellow LEDs the ideal light source for master caution and warning indicators.

Orange LEDs and NVIS RED

The radiated spectrum for orange LEDs is shown in Figure 11. The spectrum peak wavelength is at 600 nm and has the color reddish-orange, with a dominant wavelength of 602 nm which is located within the NVIS RED region, as shown in Figure 8.

Dominant Wavelength, λ_d , (Color and 1976 UCS Coordinates for NVG Filtered LEDs)

The u' and v' chromaticity coordinates for LED devices used in combination with NVG/DV and NVG filters plot on the dominant wavelength perimeter of the 1976 UCS Diagram.

The dominant wavelength (color) and 1976 chromaticity coordinates for NVG filtered LEDs are listed in Table 8 for glass NVG and NVG/DV filters and in Table 9 for plastic NVG filters. Tables 8 and 9 also show the amount of color shift that a particular NVG filter provides.

As shown in Tables 8 and 9, the dominant wavelength and 1976 UCS u' and v' chromaticity coordinates for high performance green LEDs used in combination with the WAMCO NV-2GL-1 NVG/DV, the Kopp Glass

0403/3480 and the American Cyanamid R10093-120D filters fall just outside the upper wavelength limit for the NVIS GREEN B region. The observed color does appear green to the eye. A deviation to the NVIS GREEN B requirement is usually written into procurement documents when NVG filtered high performance green LEDs are used in NVG compatible aircraft cockpits.

Although the color of the high performance green LED/NV-4YL-3 NVG/DV filter combination falls at the lower

wavelength limit for NVIS YELLOW, it looks more green than yellow, inducing confusion as to whether it is or is not a caution indication. For this reason, this combination is not recommended for use as master caution and warning indicators.

The dominant wavelengths and 1976 UCS u' and v' chromaticity coordinates for high performance green LEDs used in combination with the WAMCO NV-2C, the Kopp Glass 0404/3482, and the Gentex Blue-Green NVG filters plot within the NVIS GREEN B color region.

Table 8. Dominant Wavelength and 1976 Chromaticity Coordinates for LEDs used in Combination with Glass NVG and NVG/DV Filters

Vendor	Glass NVG Filter	LED Color	$\Delta \lambda d$	Filtered λd	1976 UCS Coordinates
WAMCO	NV-2GL-1	High Performance Green	-7 nm	567 nm	$u' = .1865$ $v' = .5719$
	NV-2GL-5	High Performance Green	-6 nm	568 nm	$u' = .1918$ $v' = .5709$
	NV-2C	High Performance Green	-17 nm	557 nm	$u' = .1401$ $v' = .5784$
	NV-4YL-3	High Performance Green	-1 nm	573 nm	$u' = .2194$ $v' = .5669$
	NV-3YL-4	Yellow	0 nm	585 nm	$u' = .2959$ $v' = .5554$
	NV-2SO-8	Orange	0 nm	602 nm	$u' = .4173$ $v' = .5372$
Kopp Glass	0403/3480	High Performance Green	-6 nm	568 nm	$u' = .1918$ $v' = .5709$
	0404/3482	High Performance Green	-12 nm	562 nm	$u' = .1622$ $v' = .5753$
	0405/2424	Yellow	-2 nm	583 nm	$u' = .2822$ $v' = .5575$

Table 9. Dominant Wavelength and 1976 Chromaticity Coordinates for LEDs used in Combination with Plastic NFG Filters

Vendor	Plastic NVG Filter	LED Color	$\Delta \lambda d$	Filtered λd	1976 UCS Coordinates
American Cyanamid	R10093-120D	High Performance Green	-9 nm	565 nm	$u' = .1766$ $v' = .5732$
	R10093-120A	Yellow	0 nm	585 nm	$u' = .2960$ $v' = .5554$
Gentex	Blue-Green	High Performance Green	-20 nm	554 nm	$u' = .1286$ $v' = .5792$

For yellow LEDs used in combination with the WAMCO NV-3YL-4, the Kopp Glass 0405/2424 and the American Cyanamid R10093-120A filters the dominant wavelengths and 1976 UCS u' and v' chromaticity coordinates plot within the NVIS YELLOW region.

For orange LEDs used in combination with the WAMCO NV-2SO-8, the dominant wavelength and 1976 UCS u' and v' chromaticity coordinates plot within the NVIS RED region.

U.S. Army NVG Secure Lighting Program

NVG Secure Lighting Concept

NVG Secure Lighting is concerned with the detectability of a light source by threat GEN II night vision goggles at some distance. The shorter this detection distance is, the better is the NVG Secure Lighting. For example, if the light source does not emit infrared energy the probability of detection is reduced. Detectability is now a function of the amount of visible light that is emitted. Also, if the distance that a light source may be detected by night vision goggles is reduced by dimming to a very low brightness level, then the security from NVG detection has been increased by the factor of the distance reduction. Similarly, if the off-axis angle of detection has been reduced from a wide to a narrow angle, the security from NVG detection has been increased by the factor of the off-axis angle reduction.

Secure Lighting Requirements and Statement of Work (SOW)

The U.S. Army Communications-Electronics Command (CECOM) at Fort Monmouth, New Jersey has initiated an NVG Secure Lighting Program. Other U.S. Army commands have similar programs. The U.S. Army CECOM has issued a Secure Lighting Statement of Work, SOW, which details the lighting modification guidelines that may be incorporated to make various light sources NVG secure.

The objective of the Secure Lighting Program (paraphrased) is "to render all combat nomenclatured items designated for use at Corps level and below less detectable to threat image intensifier night observation as far as is practical." The goal is "to reduce, as much as possible, the signature of all light sources to detection by image intensifier night vision devices while still retaining sufficient luminance to be useable." All combat items used in the field after year 1988 shall be modified or built to meet the requirements of the Secure Lighting Program.

The Secure Lighting SOW is concerned with both vulnerability to detection by and compatibility with GEN II night vision goggles. Modified light sources must not degrade the performance of wide band GEN II goggles which may be used in close proximity to modified equipment. Verification of performance is typically performed visually by using a wide band GEN II image intensifier that does not incorporate a minus blue filter.

NVG secure light sources must provide the best possible daylight viewability while providing sufficient readability at night at a brightness level of 0.05 fL.

Threat NVG detection vulnerability is to be reduced by incorporating three priority objectives for light source modifications, presented here paraphrased from the CECOM NVG Secure Lighting SOW:

1. Priority 1, Wavelength restriction: Eliminate energy not used by the human eye or otherwise required by an observer. The total energy emission above 700 nm shall be no more than 0.5% of the total energy emission between 350 nm and 930 nm. The wavelength cutoff to 0.5% shall be between 600 nm and 700 nm, and as close to 600 nm as possible.
2. Priority 2, Luminance reduction: Dimming or stopping down all light sources to 0.05 fL or less (NVG filtered brightness). The light sources still must be capable of being operated at full brightness for daytime use.
3. Priority 3, Viewing angle restriction: Make the viewing angle as small as possible, consistent with the mission profile for the equipment. Note, a viewing angle of $\pm 10^\circ$ is desirable whenever possible.

These three Priorities are objectives, not specifications. The objectives of the CECOM NVG Secure Lighting SOW are not intended to be in concert with the specifications MIL-L-85762A. It is intended that these priorities be met as close as possible on a best effort basis, depending upon the piece of equipment involved and its intended use and mission. The SOW format, listing priority objectives instead of precise specifications, was used by CECOM to allow for conversion of the large number and wide variety of pieces of equipment within the U.S. Army arsenal to NVG Secure Lighting.

The NVG Secure Lighting SOW does not utilize NVIS Radiance as a measure of performance, but limits the amount of detectable red and infrared emitted light as a percentage of total emitted light, as stated in the Priority 1 objective.

The goal of the SOW is to replace all red and white light sources with NVG secure green and yellow light sources. All red LEDs are to be replaced with green or yellow LEDs. The acceptable hues of green and yellow are not defined, as the SOW does not specify green and yellow chromaticity coordinates. The reason is that precise color definitions are not needed to achieve NVG Secure Lighting. The LEDs shall

be green in systems that require indicators of a single color. Yellow LEDs shall be used for caution, warning and other critical indicators.

Military grade daylight viewable high performance green and yellow LEDs used with glass NVG/DV filters meet both the Priority 1 and Priority 2 NVG Secure Lighting objectives and provide for readability in daylight.

Military grade high performance green and yellow LEDs used with glass and plastic NVG filters listed in this application note meet both the Priority 1 and Priority 2 NVG Secure Lighting objectives, exclusive of daylight readability.

Percent IR Emission for LED/NVG Filter Combinations

The goal of the Priority 1 objective is to limit the amount of IR radiated flux, $IR\phi_e$, from an NVG secure light source to 0.5% of the total radiated flux, ϕ_e , produced by the light source. The intent is to have the 0.5% IR level occur as close to 600 nm as possible. The 0.5 % level must be achieved for wavelengths greater than 700 nm.

Tables 10 and 11 present calculated values for the percent IR emission that is produced by the various LED/NVG and LED/NVG/DV filter combinations listed in this application note. This percentage is determined from the following relationship.

$$\%IR(\lambda_{CUT-OFF} \text{ nm to } 930 \text{ nm}) = \frac{IR\phi_e(\lambda_{CUT-OFF} \text{ nm to } 930 \text{ nm})}{\text{Total } \phi_e(350 \text{ nm to } 930 \text{ nm})}$$

Where: $\lambda_{CUT-OFF}$ = The wavelength where the amount of IR emitted radiometric flux falls below the 0.5% of the total radiated flux.

Table 10. Percent IR Radiometric Flux Emitted for LEDs used in Combination with Glass NVG and NVG/DV Filters

Vendor	Glass NVG Filter	LED Color	% IR ($\lambda_{CUT-OFF}$ nm to 930 nm) Maximum = 0.5% IR (700 nm to 930 nm)
WAMCO	NV-2GL-1	High Performance Green	0.30% IR (605 nm to 930 nm)
	NV-2GL-5	High Performance Green	0.34% IR (610 nm to 930 nm)
	NV-4YL-3	High Performance Green	0.21% IR (620 nm to 930 nm)
	NV-2C	High Performance Green	0.05% IR (600 nm to 930 nm)
	NV-3YL-4	Yellow	0.26% IR (625 nm to 930 nm)
Kopp Glass	0403/3480	High Performance Green	0.30% IR (605 nm to 930 nm)
	0404/3482	High Performance Green	0.05% IR (600 nm to 930 nm)
	0405/2424	Yellow	0.31% IR (630 nm to 930 nm)

Table 11. Percent IR Radiated Flux Emitted for LEDs used in Combination with Plastic NVG Filters

Vendor	Plastic NVG Filter	LED Color	%IR ($\lambda_{CUT-OFF}$ nm to 930 nm) Maximum = 0.5% IR (700 nm to 930 nm)
American Cyanamid	R10093-120D	High Performance Green	0.20% IR (610 nm to 930 nm)
Gentex	Blue-Green	High Performance Green	0.33% IR (635 nm to 930 nm)
American Cyanamid	R10093-120A	Yellow	0.33% IR (630 nm to 930 nm)

IR Secure Lighting

IR Secure Lighting is essentially a subset of NVG Secure Lighting derived from the Priority 1 objective. For IR Secure Lighting the only criterion is the amount of permissible IR emission from a light source, no greater than 0.5% from 700 nm to 930 nm of the overall emission from 350 nm to 930 nm. There are no requirements as to specific colors, luminance level, viewing angle or daylight readability.

Dimming LED Displays for NVIS Compatibility

As discussed in the section on NVIS Compatible Lighting Requirements, NVIS radiance is specified at low brightness levels for NVG filtered LED devices. An LED lamp or display may be dimmed by either pulse width modulation, PWM, for strobed drive conditions or by reducing the LED drive current for DC drive conditions. For strobed operation at a fixed refresh rate, the time average light output (the brightness as perceived by the eye) is directly proportional to the LED on-time. For DC operation, the light output is approximately proportional to the forward DC drive current.

Strobed Alphanumeric LED Displays

For a strobed alphanumeric LED display, such as the HCMS-201X/-235X four character alphanumeric display families, PWM of the blanking input is the most effective method of dimming the display. PWM of the blanking input reduces the LED on-time duty factor without affecting the column strobe refresh rate. The light output and color balance between display pixel elements are maintained. A four character alphanumeric display can be dimmed on the order of 2000 to 1, from the maximum LED on-time duty factor of 20% (for maximum brightness) to 0.01%, as

illustrated for the HDSP-2353 display in Figure 12. Filtered brightness levels at or below the NVIS specification of 0.1 fL (0.34 cd/m²) are achievable. There is no noticeable color shift with PWM dimming.

The HDSP-2133 intelligent alphanumeric display has an on-board IC that strobes the display. The device logic and LED supply grounds are on separate pins. Dimming to NVG lighting levels is achieved by use of an external circuit to PWM the LED supply ground between system ground and system voltage, V_{DD} .

Single Digit Dot Matrix LED Displays

The HDSP-096X/-088X series single digit dot matrix LED displays have an on board integrated circuit with inputs that can be utilized for dimming. The HDSP-0962/-0882 hexadecimal LED displays can be dimmed by PWM of the blanking input. The apparent

brightness of the display is directly proportional to the PWM duty factor of the blanking input. As an example, a 2000 to 1 dimming can be achieved with a 5 μ s display-on pulse out of a 10 ms period for a 100 Hz pulse rate, reducing the typical NVG filtered brightness for an HDSP-0962 high performance green display from 92 fL (315 cd/m²) to 0.05 fL (0.17 cd/m²).

The HDSP-0960/-0880 numeric single digit dot matrix LED displays do not have a blanking input. However, dimming can be achieved by alternately loading valid data for an illuminated character and a BCD code 15, which is not decoded by the IC and thus will blank the display. The amount of dimming is in direct proportion to time that valid data illuminates the display in relationship to the time the BCD code 15 blanks the display. This is normally done with the enable input held at logic low.

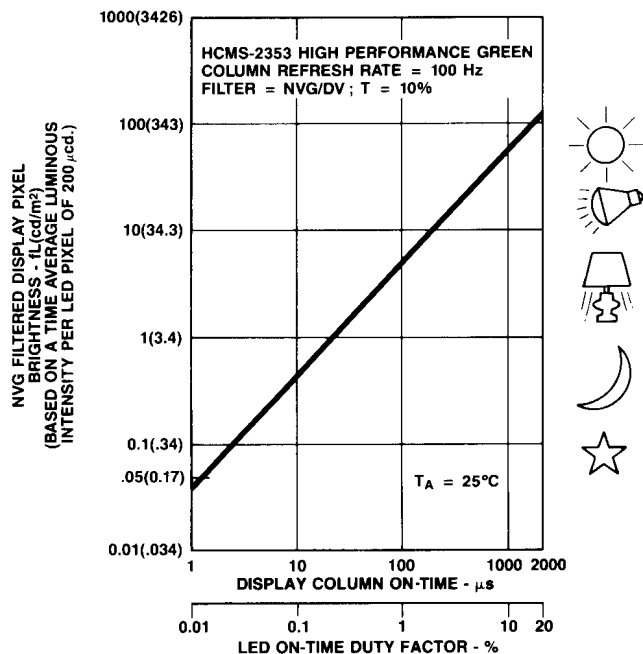


Figure 12. Possible dimming range of the daylight viewable HCMS-2353 high performance Green LED display by pulse width modulation, PWM.

For example, a circuit that presents valid data for an illuminated character for only 5 ms which is then followed by BCD code 15 to blank the display at a 100 Hz (10,000 ms period) rate, dims the display by a factor of 2000 to 1.

LED Hermetic Lamps

For individual LED hermetic lamps that are pulse driven, PWM may be used to reduce the time average light output by reducing the LED on-time duty factor. The LED peak drive current and pulse rate remain constant. For example, the time average brightness of the 87019G01 high performance green IR secure LED panel mount lamp driven at 90 mA peak, 1/3 duty factor and a pulse rate of 100 Hz, can be dimmed from an NVG filtered brightness of 110 fL (376 cd/m²) to 0.05 fL (0.17 cd/m²) by reducing the LED on-time from 3.33 ms to 1 ms, a reduction of 3120 to 1.

For DC driven LED hermetic lamps, reduction of the DC forward drive current reduces the light output, as shown for the 87019G01 high performance green IR secure LED panel mount lamp in Figure 13. For an array of matched LED devices, effective dimming can be achieved with a 10 to 1 reduction in the DC drive current, such as from 35 mA to 3.5 mA. Light output and color balance between

like devices track well over this range. However, it may not be possible to maintain light output and color balance for drive current changes greater than 10 to 1. Individual LED devices that are not part of a matched array or located within close proximity to each other may be dimmed by reducing the drive current to as low as 0.35 mA.

Luminous Contrast and Readability of NVG/DV Filtered Sunlight Viewable LED Displays

Passband night vision goggle/daylight viewable, NVG/DV, filters provide luminous contrast enhancement for acceptable readability of sunlight viewable LED displays in daylight conditions. The NVG/DV filters are of composite glass construction, but do not contain a circular polarizer. The inclusion of a circular polarizer makes it difficult to control the IR suppression characteristics of the filter. NVG/DV filters may be obtained with a front surface antireflection, AR, coating to reduce the level of front surface specular reflections from 5% to 0.25%.

A graph of luminous contrast, C₁, on-pixel to background, for sunlight viewable and daylight viewable LED display NVG/DV filter combinations

in daylight ambients is presented in Figure 14. The data shows that a luminous contrast of 2:1 or better is achievable in 10000 fc sunlight with the HCMS-235X series sunlight viewable LED displays. A 2:1 luminous contrast is achievable in an 8000 fc daylight ambient with the HDSP-2133 daylight viewable LED displays. The measurement technique used to obtain the data is described in Application Note 1029, Luminous Contrast and Sunlight Readability of the HDSP-238X Series LED Displays for Military Applications.

SAE ARP4169 Night Vision Goggle (NVG) Filters in Section 7.4.2.3, Measuring the Contrast Performance of an NVG/DV Filter, defines a figure of merit for the luminous contrast performance of an NVG/DV filter. This figure of merit is the ratio of the filter single pass transmission of the LED emitted visible light, %T(Y), to the double pass transmission of the CIE Illuminant B light source, %T²(CIE B). CIE B simulates the spectra of direct sunlight. When the ratio %T(Y)/%T²(CIE B) is at a value of 17.0 or greater, the NVG/DV filter provides good luminous contrast for daylight readability of the LED light source. Table 12 lists the figure of merit for luminous contrast for glass NVG/DV filters.

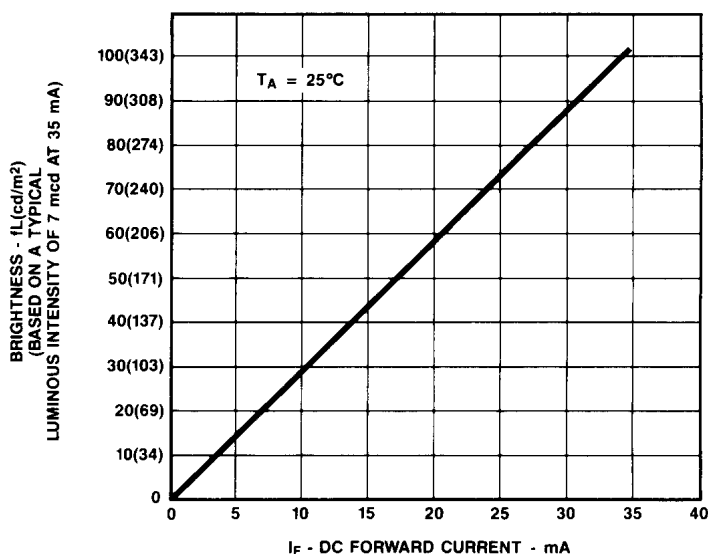


Figure 13. Effect of dimming the 87019G01 IR secure high performance green panel mount lamp by reducing the DC forward current.

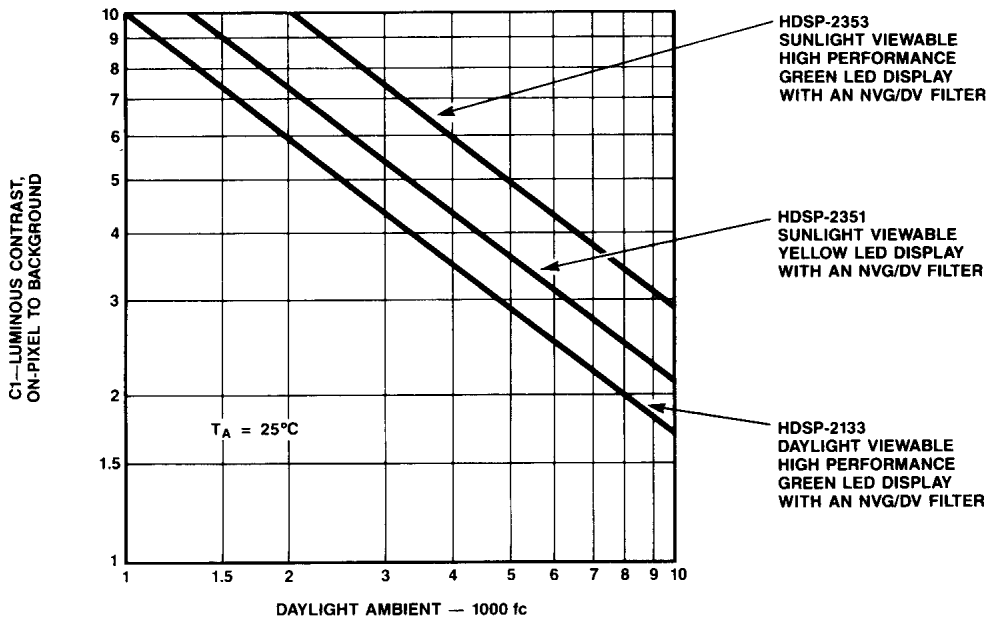


Figure 14. Representative luminous contrast, LED on-pixel to background, for sunlight viewable and daylight viewable LED displays in combination with NVG/DV filters in daylight ambients.

Table 12. The $\%T(Y) / \%T_2(\text{CIE B})$ Figure of Merit For Luminous Contrast Performance for Glass NVG/DV Filters

Filter Vendor	NVG/DV Filter	T(LED)	LED Color	$\%T(Y) / \%T_2(\text{CIE B})$
WAMCO	NV-2GL-1	8%	High Performance Green	22.5
	NV-2GL-5	11%	High Performance Green	16.7
	NV-4YL-3	11%	High Performance Green	16.7
	NV-3YL-4	13%	Yellow	17.7
	NV-2SO-8	10%	Orange	15.3
Kopp Glass	0403/3480	10%	High Performance Green	17.2
	0405/2424	13%	Yellow	16.8

Note: T(LED) is the percent of LED emitted light transmitted by the filter.

Appendix A

Bibliography

Avago Technologies
Application Note 1029, Luminous Contrast and Sunlight
Readability of the HDSP-238X Series
LED Alphanumeric Displays for
Military Applications

SAE Aerospace Recommended Practices document:

ARP 4169, Night Vision Goggle (NVG) Filters

To obtain a copy of ARP 4169, write to the following address:

SAE
400 Commonwealth Drive
Warrendale, PA 15096-0001
Telephone: (412) 776-5760

Appendix B

RELATIVE RESPONSE OF GEN III ANVIS WITH 625 BLUE MINUS FILTER (CLASS A, TYPE 1 NIGHT VISION GOGGLES)

Wavelength (nm)	Relative Response	Wavelength (nm)	Relative Response
450	1.0000 x10 ⁻⁴	690	9.3790 x10 ⁻¹
455	1.1250 x10 ⁻⁴	695	9.4480 x10 ⁻¹
460	1.2500 x10 ⁻⁴	700	9.5170 x10 ⁻¹
465	1.3750 x10 ⁻⁴	705	9.5680 x10 ⁻¹
470	1.500 x10 ⁻⁴	710	9.6550 x10 ⁻¹
475	1.6172 x10 ⁻⁴	715	9.7304 x10 ⁻¹
480	1.7500 x10 ⁻⁴	720	9.7930 x10 ⁻¹
485	1.9375 x10 ⁻⁴	725	9.8020 x10 ⁻¹
490	2.1250 x10 ⁻⁴	730	9.8280 x10 ⁻¹
495	2.2266 x10 ⁻⁴	735	9.8838 x10 ⁻¹
500	2.3750 x10 ⁻⁴	740	9.9310 x10 ⁻¹
505	2.7656 x10 ⁻⁴	745	9.9719 x10 ⁻¹
510	3.1250 x10 ⁻⁴	750	1.0000
515	3.4297 x10 ⁻⁴	755	1.0000
520	3.7500 x10 ⁻⁴	760	1.0000
525	4.1875 x10 ⁻⁴	765	1.0000
530	4.6250 x10 ⁻⁴	770	1.0000
535	5.0703 x10 ⁻⁴	775	9.9814 x10 ⁻¹
540	5.5000 x10 ⁻⁴	780	9.9660 x10 ⁻¹
545	5.8359 x10 ⁻⁴	785	9.9543 x10 ⁻¹
550	6.2500 x10 ⁻⁴	790	9.9450 x10 ⁻¹
555	7.0000 x10 ⁻⁴	795	9.9380 x10 ⁻¹
560	7.7500 x10 ⁻⁴	800	9.9310 x10 ⁻¹
565	8.5000 x10 ⁻⁴	805	9.8620 x10 ⁻¹
570	9.2500 x10 ⁻⁴	810	9.7930 x10 ⁻¹
575	1.4525 x10 ⁻³	815	9.7283 x10 ⁻¹
580	1.9800 x10 ⁻³	820	9.6550 x10 ⁻¹
585	4.7175 x10 ⁻³	825	9.5515 x10 ⁻¹
590	7.8000 x10 ⁻³	830	9.4480 x10 ⁻¹
595	1.1400 x10 ⁻²	835	9.3402 x10 ⁻¹
600	1.5000 x10 ⁻²	840	9.2410 x10 ⁻¹
605	2.6263 x10 ⁻²	845	9.1720 x10 ⁻¹
610	5.2000 x10 ⁻²	850	9.1030 x10 ⁻¹
615	8.8388 x10 ⁻²	855	8.6334 x10 ⁻¹
620	1.7500 x10 ⁻¹	860	8.0000 x10 ⁻¹
625	4.3288 x10 ⁻¹	865	7.2848 x10 ⁻¹
630	6.1380 x10 ⁻¹	870	6.5520 x10 ⁻¹
635	6.7756 x10 ⁻¹	875	5.8016 x10 ⁻¹
640	7.4480 x10 ⁻¹	880	5.0340 x10 ⁻¹
645	8.2458 x10 ⁻¹	885	4.2523 x10 ⁻¹
650	8.8970 x10 ⁻¹	890	3.4480 x10 ⁻¹
655	8.9654 x10 ⁻¹	895	2.5704 x10 ⁻¹
660	9.0340 x10 ⁻¹	900	1.7500 x10 ⁻¹
665	9.1051 x10 ⁻¹	905	1.1009 x10 ⁻¹
670	9.1720 x10 ⁻¹	910	6.2100 x10 ⁻²
675	9.2241 x10 ⁻¹	915	4.3125 x10 ⁻²
680	9.2760 x10 ⁻¹	920	2.7600 x10 ⁻²
685	9.3254 x10 ⁻¹	925	1.5525 x10 ⁻²
		930	6.9000 x10 ⁻³

Appendix C

RELATIVE RESPONSE OF GEN III CAT'S EYES WITH665 BLUE MINUS FILTER (CLASS B, TYPE 2 NIGHT VISION GOGGLES)

Wavelength (nm)	Relative Response	Wavelength (nm)	Relative Response
450	1.00 x10 ⁻⁷	690	9.19 x10 ⁻¹
455	1.12 x10 ⁻⁷	695	9.35 x10 ⁻¹
460	1.25 x10 ⁻⁷	700	9.51 x10 ⁻¹
465	1.37 x10 ⁻⁷	705	9.58 x10 ⁻¹
470	1.50 x10 ⁻⁷	710	9.65 x10 ⁻¹
475	1.62 x10 ⁻⁷	715	9.73 x10 ⁻¹
480	1.75 x10 ⁻⁷	720	9.79 x10 ⁻¹
485	1.95 x10 ⁻⁷	725	9.80 x10 ⁻¹
490	2.12 x10 ⁻⁷	730	9.82 x10 ⁻¹
495	2.30 x10 ⁻⁷	735	9.88 x10 ⁻¹
500	2.50 x10 ⁻⁷	740	9.93 x10 ⁻¹
505	2.80 x10 ⁻⁷	745	9.99 x10 ⁻¹
510	3.10 x10 ⁻⁷	750	1.00
515	3.37 x10 ⁻⁷	755	1.00
520	3.65 x10 ⁻⁷	760	1.00
525	4.00 x10 ⁻⁷	765	1.00
530	4.37 x10 ⁻⁷	770	1.00
535	4.77 x 10 ⁻⁷	775	9.98 x10 ⁻¹
540	5.25 x10 ⁻⁷	780	9.96 x10 ⁻¹
545	5.65 x10 ⁻⁷	785	9.95 x10 ⁻¹
550	6.25 x10 ⁻⁷	790	9.94 x10 ⁻¹
555	6.80 x10 ⁻⁷	795	9.93 x10 ⁻¹
560	7.50 x10 ⁻⁷	800	9.93 x10 ⁻¹
565	8.10 x10 ⁻⁷	805	9.86 x10 ⁻¹
570	8.90 x10 ⁻⁷	810	9.79 x10 ⁻¹
575	9.90 x10 ⁻⁷	815	9.72 x10 ⁻¹
580	1.07 x10 ⁻⁶	820	9.65 x10 ⁻¹
585	1.18 x10 ⁻⁶	825	9.55 x10 ⁻¹
590	1.30 x10 ⁻⁶	830	9.44 x10 ⁻¹
595	1.40 x10 ⁻⁶	835	9.34 x10 ⁻¹
600	1.50 x10 ⁻⁶	840	9.24 x10 ⁻¹
605	3.50 x10 ⁻⁶	845	9.17 x10 ⁻¹
610	8.00 x10 ⁻⁶	850	9.10 x10 ⁻¹
615	2.10 x10 ⁻⁵	855	8.63 x10 ⁻¹
620	6.45 x10 ⁻⁵	860	8.00 x10 ⁻¹
625	1.94 x10 ⁻⁴	865	7.28 x10 ⁻¹
630	7.97 x10 ⁻⁴	870	6.55 x10 ⁻¹
635	2.37 x10 ⁻³	875	5.80 x10 ⁻¹
640	8.93 x10 ⁻³	880	5.03 x10 ⁻¹
645	2.63 x10 ⁻²	885	4.25 x10 ⁻¹
650	1.06 x10 ⁻¹	890	3.44 x10 ⁻¹
655	2.86 x10 ⁻¹	895	2.57 x10 ⁻¹
660	5.05 x10 ⁻¹	900	1.75 x10 ⁻¹
665	6.82 x10 ⁻¹	905	1.10 x10 ⁻¹
670	7.79 x10 ⁻¹	910	6.21 x10 ⁻²
675	8.39 x10 ⁻¹	915	4.31 x10 ⁻²
680	8.90 x10 ⁻¹	920	2.76 x10 ⁻²
685	9.04 x10 ⁻¹	925	1.55 x10 ⁻²
		930	6.90 x10 ⁻²

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