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ACCURATE MEASUREMENT OF NVIS LIGHTING COMPONENTS

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Accurate Measurement of NVIS Lighting Components

by

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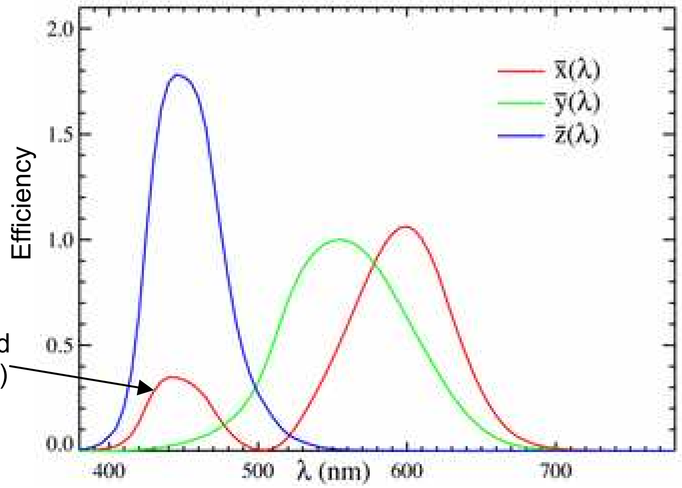
Introduction

The successful measurement of a lighting component to the requirements of MIL-L-85762A or MIL-STD-3009 requires not only an understanding of the spectral response characteristics of the human eye and the NVIS goggles but also an understanding of the measurement apparatus. How each factor can contribute to measurement error will provide the lighting engineer or laboratory technician a measurement methodology wherein the most accurate readings of the NVIS lighting component can be made.

Spectral Response Characteristics of the Human Eye

The human eye generates a biochemical response to electromagnetic energy in the 380 (violet) to 780 (deep red) nanometer region. Within this spectral response region, chromaticity and luminance is perceived through separate biochemical responses to red, green and blue light, known as the Tristimulus values X, Y and Z respectively. NVIS lighting component luminance and chromaticity measurements utilize the 1931 CIE 2 Degree Standard Observer curves, x-bar(λ), y-bar(λ) and z-bar(λ). Since the human eye does not produce a biochemical response that is uniform over all wavelengths, Figure 1 depicts the efficiency of the eye as a function of wavelength. Note the secondary spectral response of red in the blue region:



Secondary red response (x/b)

1931 CIE 2 Degree Tristimulus Response Curves

Figure 1

Most laboratory photometers and colorimeters, such as the Photo Research 1980A utilize custom filters that attempt to match the x-bar(λ), y-bar(λ) and z-bar(λ) response curves. In the case of the Photo Research 1980A, a separate x/b filter is included to allow measurement of the secondary x-bar(λ) in the blue region of the spectrum. The precision of the instrument, however, depends upon the care taken during calibration to precisely match the filter transmittance characteristics, the spectral response characteristics of the instrument detector and the 1931 CIE x-bar(λ), y-bar(λ) and z-bar(λ) spectral response functions.

While a filter photometer or colorimeter can produce adequate uncorrected precision when measuring incandescent white light sources, nearly all fail to produce acceptable precision when measuring monochromatic light sources such as LED's, CRT phosphors or light sources containing many emission peaks such as fluorescent lamps. This is because it is nearly impossible to precisely match the instrument filter and detector to the CIE Tristimulus spectral response curves at all wavelengths simultaneously. If spectral radiance standards are available, correction factors can be applied to the Tristimulus values to improve accuracy but these correction factors are usually only effective over a narrow spectral response range.

Accurate measurement of luminance and chromaticity without the necessity of correction factors can only be performed using a spectroradiometer wherein the spectral radiance of the NVIS lighting component is collected wavelength by wavelength, usually in no more than 5 nanometer increments. Using this technique allows the 1931 CIE x-bar(λ), y-bar(λ) and z-bar(λ) spectral response functions to be applied utilizing the mathematical procedure shown in Figure 2:

$$X = \int_{380}^{780} I(\lambda)\,\overline{x}(\lambda)\,d\lambda \qquad Y = \int_{380}^{780} I(\lambda)\,\overline{y}(\lambda)\,d\lambda \qquad Z = \int_{380}^{780} I(\lambda)\,\overline{z}(\lambda)\,d\lambda$$

Where:

I (λ) = Spectral radiance of the photonics device
x-bar(λ), y-bar(λ), z-bar(λ) = 1931 CIE 2 Degree Standard Observer response
d(λ) = wavelength collection interval

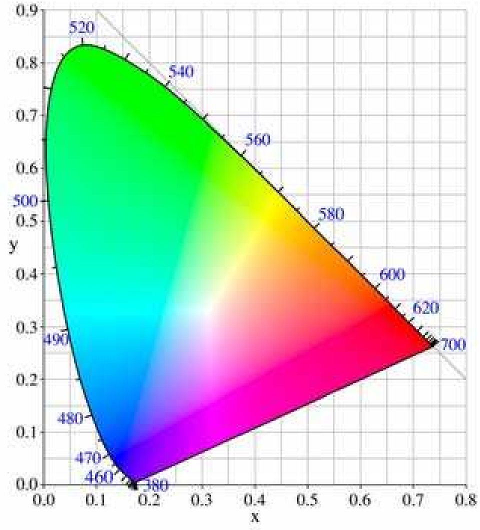
Calculation of CIE Tristimulus Values
Figure 2

Whether the CIE Tristimulus values are collected with a filter instrument or a spectroradiometer, it is still necessary to convert these values to a chromaticity coordinate system that can be compared to specification limits.

Defining Chromaticity and Luminance

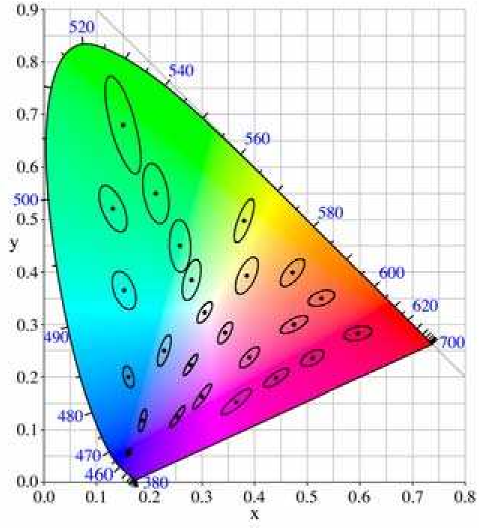
In order to make the calculated Tristimulus values meaningful in an industry standard chromaticity coordinate system, the Tristimulus values are modified to an x and y chromaticity value and then plotted on the 1931 CIE XYZ color space as shown in Figure 3. Monochromatic colors will plot along the spectral locus of the color space (the curved edge of the color space) while less saturated colors will plot somewhere out in the middle of the color space. Luminance is the Y integral calculated in the mathematical procedure in Figure 2.

$x = X/(X+Y+Z)$ or $x = \text{Red}/(\text{Red} + \text{Green} + \text{Blue})$
$y = Y/(X+Y+Z)$ or $y = \text{Green}/(\text{Red} + \text{Green} + \text{Blue})$



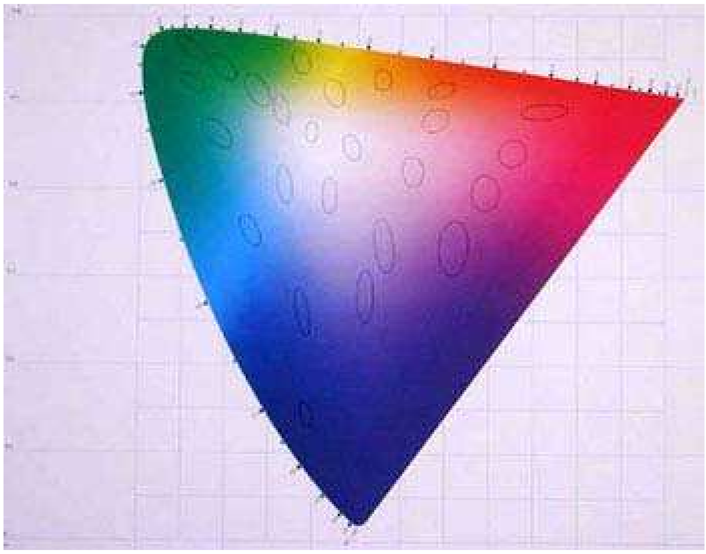
1931 CIE (2 Degree) Diagram
Figure 3

Even though the CIE 1931 XYZ color space is accepted as an industry standard, one of its weaknesses is plotting uniform appearing colors and how to specify these colors. Uniform appearing colors within the CIE 1931 XYZ color space tend to be highly elliptical as shown in the MacAdam Ellipse drawing of Figure 4. Note how the dimensions of the ellipse vary with position in the CIE color space:



MacAdam Ellipses
Figure 4

To correct this problem, the CIE LUV color space was adopted in 1976 and is shown in Figure 5. This system, also known as the Uniform Chromaticity Scale (UCS), allows uniform appearing colors to appear more circular. Although the CIE 1931 XYZ color space is still an industry standard, MIL-L-85762A and MIL-STD-3009 have adopted the UCS color space because color limits can be easily defined by specifying a radius about a given point. Transferring CIE x and y coordinates to UCS u′ and v′ coordinates is performed using the mathematical procedure shown in Figure 6.



MacAdam Ellipses on 1976 UCS Diagram
Figure 5

$$u' = \frac{4x}{-2x+12y+3} \qquad v' = \frac{9y}{-2x+12y+3}$$

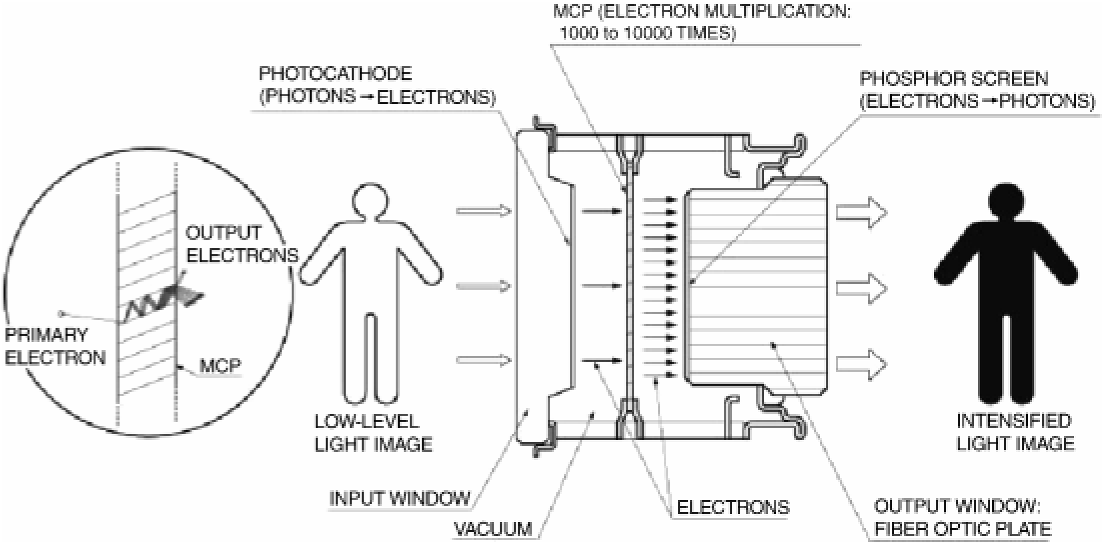
1931 CIE to 1976 UCS Coordinate Conversion
Figure 6

Spectral Response Characteristics of the NVIS Goggles

Night Vision Imaging System (NVIS) goggles are designed to be worn by aviation aircrews on tactical combat missions at night and are shown in Figure 7. The first Gen III NVIS was the AN/AVS-6, a fully stereoscopic Night Vision Goggle (NVG) comprised of filtered objective lenses, Gen III image intensifiers and ocular lenses. Gen III image intensifiers use a Gallium Arsenide (GaAs) photocathode for maximum quantum efficiency and a Micro-Channel Plate for maximum gain. The design of a typical Gen III image intensifier is shown in Figure 8.

While the area of greatest sensitivity of a GaAs image intensifier is in the range of 600 to 880 nanometers, they still possess enough sensitivity in the visual range of 450 to 700 nanometers to cause any visible cockpit lighting to overpower the images being viewed outside the cockpit. It is for this reason that all NVIS goggles are equipped with a vacuum deposited long-pass interference filter that can be seen as the bluish reflection in Figure 7. This filter prevents compatible cockpit lighting from interfering with the NVIS goggles. To view the cockpit instruments, the pilot looks down underneath the NVIS goggles.

AN/AVS-6 NVIS Goggles
Figure 7



Gen III Image Intensifier Design
Figure 8

The different Classes of NVIS are specified by letter designations in MIL-L-85762A and MIL-STD-3009 and differ only in the spectral characteristics of the long pass filter. The Class A NVIS has a cutoff wavelength of 625 nanometers which gives it the widest spectral response and therefore the greatest sensitivity. The Class A NVIS was designed to be used in helicopters flying Nap of the Earth (NOE) missions and the added sensitivity is necessary to avoid terrain features. Unfortunately, the wide spectral response prohibits the use of any full color Multifunction Displays (MFD) or NVIS Red warning indicators in these aircraft.

The Class B NVIS has a cutoff wavelength of 635 nanometers and the proposed Class C NVIS has a cutoff wavelength of 670 nanometers. Both were specifically designed to sacrifice some sensitivity in order to allow full color MFDs and NVIS Red warning indicators. The Class B and Class C NVIS are used only in fast jet aircraft operating at higher speeds and altitude than helicopters, where the loss of sensitivity is more acceptable. The proposed Class C NVIS also has a small secondary spectral response at 540 nanometers to allow Head Up Display (HUD) viewing through the NVIS.

A comparison of the spectral response characteristics of the human eye and the various Classes of the NVIS goggles is shown in Figure 9. Note that the peak response of the human eye occurs around 555 nanometers in the yellow-green portion of the visual spectrum whereas the peak response of the NVIS goggles occurs around 760 nanometers in the deep red portion of the visual spectrum. Also note that there is significant NVIS spectral response beyond the visual response spectrum out to 930 nanometers.

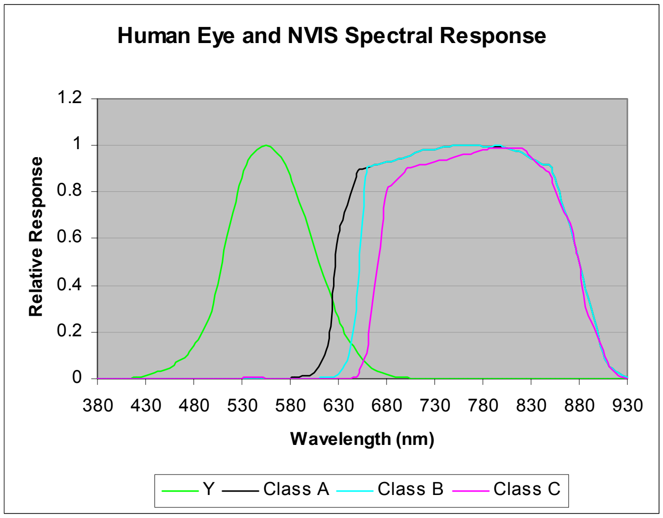
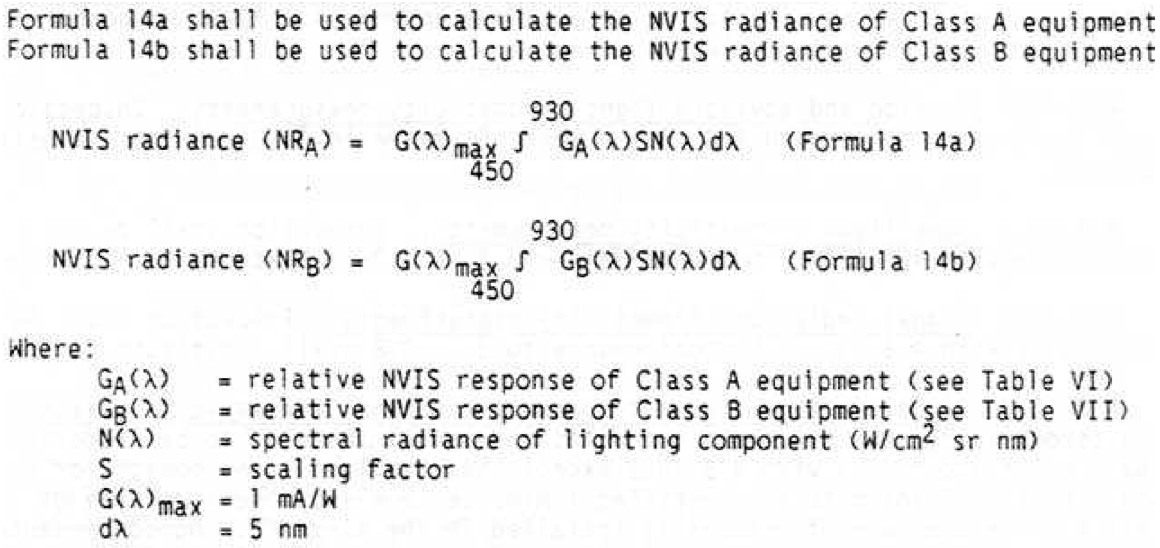


Figure 9

The differences in the spectral response of the human eye and the NVIS are significant. Because most of the NVIS spectral response lies beyond the wavelengths that can be perceived by the human eye, it is simply impossible to visually examine an NVIS lighting component and judge NVIS performance.

Defining NVIS Radiance for an NVIS Lighting Component

In order to accurately quantify the response of the NVIS to an NVIS lighting component, both MIL-L-85762A and MIL-STD-3009 require that a spectroradiometer be used to collect the spectral radiance measurements of an NVIS lighting component. The spectral radiance curve of the lighting component is then multiplied by the spectral response curve of the applicable NVIS Class and integrated as shown in Figure 10. Note that the equation also contains scaling factor S that is used to scale the measured luminance of the NVIS lighting component to the prescribed luminance in the specification.



Formula 14a shall be used to calculate the NVIS radiance of Class A equipment
Formula 14b shall be used to calculate the NVIS radiance of Class B equipment

$$\text{NVIS radiance } (NR_A) = G(\lambda)_{max} \int_{450}^{930} G_A(\lambda)SN(\lambda)d\lambda \quad \text{(Formula 14a)}$$

$$\text{NVIS radiance } (NR_B) = G(\lambda)_{max} \int_{450}^{930} G_B(\lambda)SN(\lambda)d\lambda \quad \text{(Formula 14b)}$$

Where:

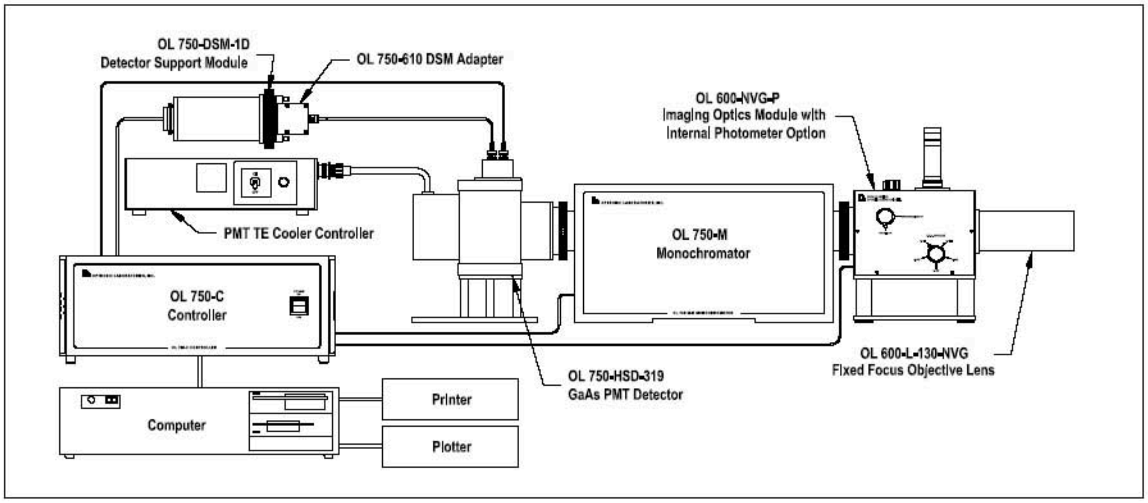
$G_A(\lambda)$ = relative NVIS response of Class A equipment (see Table VI)
$G_B(\lambda)$ = relative NVIS response of Class B equipment (see Table VII)
$N(\lambda)$ = spectral radiance of lighting component (W/cm^2 sr nm)
S = scaling factor
$G(\lambda)_{max}$ = 1 mA/W
$d\lambda$ = 5 nm

Class A and Class B NVIS Radiance Calculation
Figure 10

The result of the equation is the NVIS Radiance (NR) of the NVIS lighting component and is compared to the appropriate specification limit listed in Table IX of MIL-L-85762A or Table III of MIL-STD-3009.

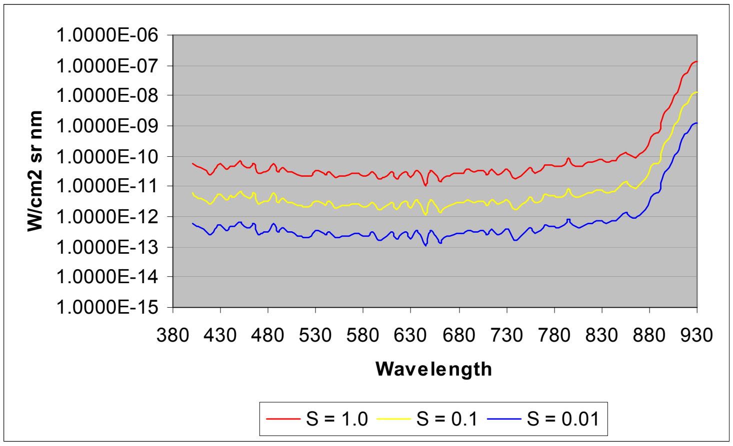
Collection of Spectral Radiance Data

A typical spectroradiometer system designed specifically for NVIS measurement is shown in Figure 11. The basic system consists of an input objective lens, measurement apertures, a high efficiency Czerny-Turner monochromator, a cooled GaAs photomultiplier and a microprocessor-based controller. Such a system is compliant with the requirements of Appendix B of MIL-L-85762A and Appendix A of MIL-STD-3009.



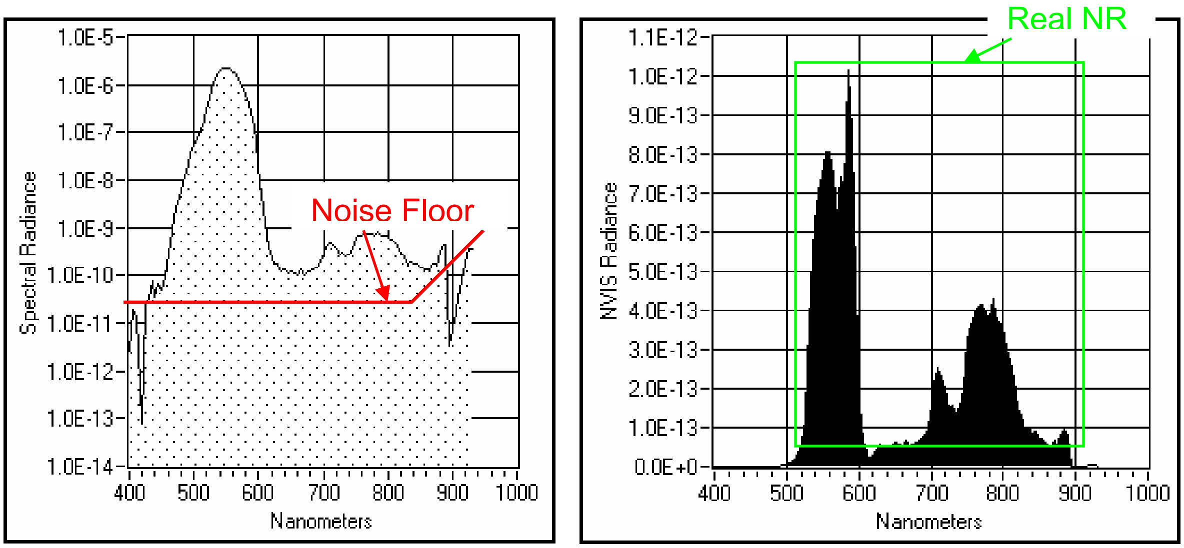
Compliant NVIS Spectroradiometer
Figure 11

Even though a spectroradiometer system may be fully compliant with the military specification, care still must be taken during setup to achieve accurate and meaningful results. The thermal noise level of the photomultiplier is constant and establishes the minimum discernable signal level of the entire system. Figure 12 illustrates the measured noise floor of a double grating spectroradiometer and how scaling factor S can mathematically lower the noise floor during NR calculations. The engineer or technician must therefore be aware of how the selection of aperture, high voltage and luminance of the NVIS lighting component can affect the contribution of noise to measurements.



Instrument Noise Floor and Scaling Factor S
Figure 12

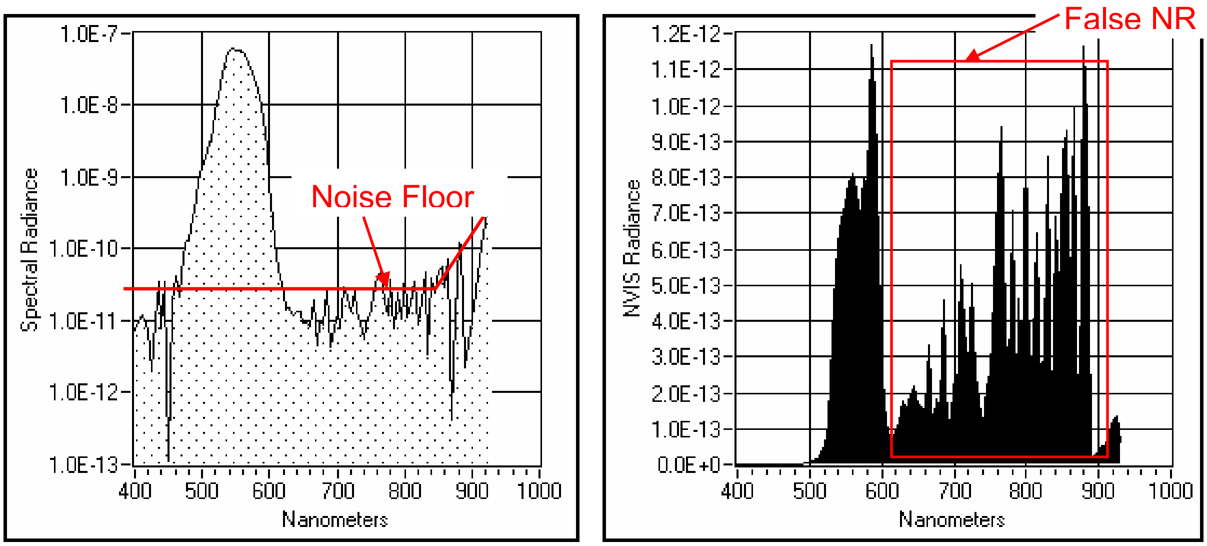
An example of how the luminance setting of the NVIS lighting component can affect accuracy is shown in Figures 13 and 14. Figure 13 shows the spectral radiance and NVIS plots of an NVIS Green B switch measured with a 3 degree field illuminated at 15 footlamberts in accordance with MIL-L-85762A and MIL-STD-3009. Note that the peak spectral radiance of the switch is at least 4 orders of magnitude above the background noise. The measured Class A NR of this NVIS lighting component using this setup is NR$_A$= 0.96x10^{-10}.



NVIS Green B Switch Measured at 3 Degrees, 15 Footlamberts, NR$_A$= 0.96x10^{-10}

Figure 13

In Figure 14, the NVIS Green B switch is again measured with a 3 degree aperture but the luminance has been reduced to 1.0 footlamberts. Note how the peak spectral radiance of the switch has degraded and that the system noise contribution has raised the apparent NR to NR$_A$= 1.59x10^{-10}. While this value is still within specification limits, system noise contribution has increased the NR falsely by 65%. In addition, real NR in the range of 650 to 850 nanometers is no longer visible and cannot be accurately quantified.



NVIS Green B Switch Measured at 3 Degrees, 1.0 Footlambert, NR$_A$= 1.59x10^{-10}

Figure 14

Another source of error is the design of the monochromator. Since all monochromators respond to multiple orders, a cutoff filter is required so that energy at 300 nanometers is not also measured at 600 nanometers. Most NVIS measurement systems use a single grating monochromator with stray light performance of around 1 x 10^{-4}. This limitation means that the NVIS Radiance on highly monochromatic NVIS lighting components may be measured higher than the actual NR. If the insertion wavelength of the second order cutoff filter is carefully selected, not only will second order responses of the monochromator be suppressed but the stray light performance can be improved in the NVIS Radiance measurement region from 630 nm to 930 nm. Figure 15 shows an NVIS Green B switch measured with and without a 630 nm second order filter and shows how stray light can be improved with a properly selected filter.

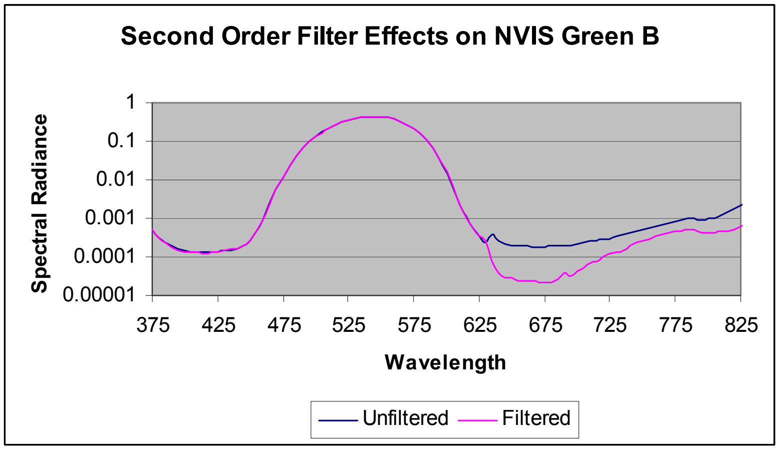


Figure 15

An NVIS measurement system with a double grating monochromator has a stray light performance of around 1 x 10^{-8} and would theoretically solve the stray light problem. Unfortunately, the inherent lower efficiency of the second monochromator would mean the instrument would likely no longer meet the sensitivity requirements of MIL-L-85762A and MIL-STD-3009. A double grating monochromator is the best approach for design and evaluation of NVIS filter transmittance because it can accurately measure the ultimate attenuation of the filter. A single grating monochromator is the best approach for production and qualification testing because it provides the greatest sensitivity.

Figure 16 shows the reduction in instrument sensitivity that can be expected using different apertures and different monochromators. The chart is normalized to the most sensitive configuration, a single grating monochromator using the widest commercially available aperture. Since the light entering an aperture is equivalent to the area of the aperture, each successive reduction in aperture diameter by a factor of three represents approximately one order of magnitude reduction in sensitivity.

Aperture	Single Grating	Double Grating
3 Degrees	1.00000	0.20000
1 Degrees	0.10000	0.02000
20 Minute	0.01000	0.00200
6 Minute	0.00100	0.00020
2 Minute	0.00010	0.00002

Normalized Instrument Sensitivity

Figure 16

Conclusions

It is important that personnel assigned the task of designing or evaluating NVIS lighting components be properly trained. An understanding of the spectral response characteristics of the eye, the spectral response characteristics of the various NVIS Classes and knowledge of the inherent limitations of measurement equipment is vital to achieving accurate measurements. It is also important that personnel charged with writing measurement procedures understand how the selection of measurement criteria can inadvertently cause inaccurate measurements.