Measuring Spectral Performance of Night Vision Devices

TUTORIAL

Specialized Spectral Measurement Equipment And Techniques Dominate Night Vision Applications

Since the inception of night vision equipment in the early 1950s the development of night vision goggles has progressed through three generations of image intensifier tubes. The present generation (commonly referred to as GEN III) of goggles with gallium arsenide (GaAs) photocathodes provides many times better performance with night-sky radiance than the second generation AN/PVS-5 Aviators Night Vision Imaging System (ANVIS).

Such improved performance of the GEN III ANVIS goggles in the near infrared spectral region from 630 to 930 nanometers (Figure 1), while providing increased capability for night-time flight operations, created a compatibility problem with existing cockpit instrumentation lighting. The instrumentation illumination in certain military cockpits generates enough energy in the near infrared to affect the automatic gain control of the ANVIS goggles. In effect, this incompatibility blinds the goggles to the less-illuminated outside scene. With the pilot's vision essentially blinded, the entire aircraft crew is at risk.

To address the ANVIS goggle/cockpit lighting compatibility problem, researchers at the Naval Air Development Center (NADC) started work on a definitive specification for radiance and irradiance levels of cockpit instrumentation. The primary tool used to investigate existing cockpit instrumentation was a computer-controlled spectroradiometer that utilized a cooled photomultiplier tube with an S-1 photocathode—thereby allowing measurements over the 380-nm to 1100-nm spectral region. The resulting specification, MIL-L-85762 and the revised MIL-L-85762A, not only sets acceptable radiance and irradiance levels, but it also specifies acceptable measurement equipment and a particular calculation method. Making accurate measurements at these low spectral radiance levels is no easy task.

Measurement Equipment

MIL-L-85762A specifies a spectroradiometer for the measurement of chromaticity and spectral radiance. That spectroradiometer must have sufficient sensitivity to permit measurement of radiance levels equal to or less than those listed in Table 1. These measurements must be made at a half-power bandwidth of 10 nm and a root-mean-square signal-to-noise ratio of 10:1.

In practical application, however, spectroradiometer sensitivities 10 to 100 times higher than this are required to make measurements on actual lighted cockpit instrumentation at a repeatability level of ± 1 percent. Additional

Table 1 - Maximum Sensitivity of Spectroradiometer Required by MIL-L-85762A

Wavelength	Radiance Level
380 to 600 nm	1.0×10^{-10} W/cm^2 sr nm
600 to 900 nm	1.7×10^{-11} W/cm^2 sr nm
900 to 930 nm	1.0×10^{-10} W/cm^2 sr nm

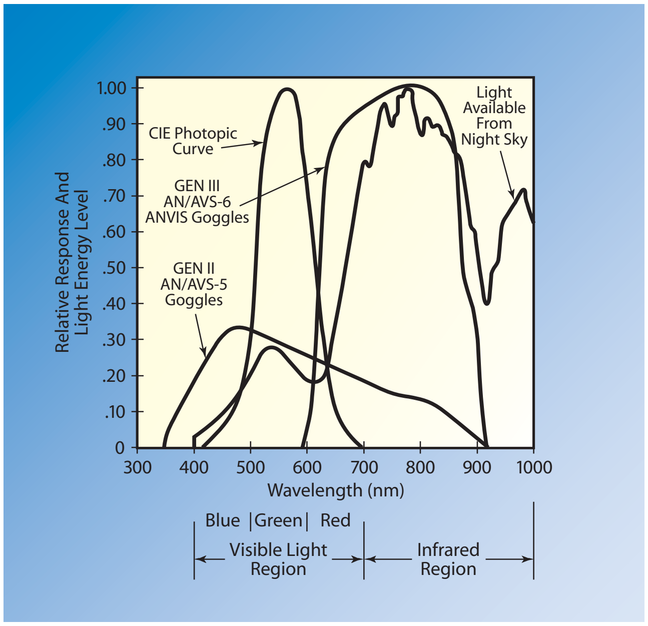


Figure 1. *Response of GEN III AN/AVS-6 ANVIS night vision goggles with respect to night sky radiation and GEN II goggles.*

requirements for the measurement system are summarized in Table 2. These system parameters represent the minimum requirements to determine whether the spectral radiance of a lighted cockpit component will interfere with automatic gain control in the GEN III goggles.

Calculation Method

Once the spectral radiance of the cockpit lighting component has been accurately determined, the calculation of the ANVIS radiance is performed. This process first determines the luminance of the lighting component so a scale factor value can be computed. For example, say the spectral radiance data is analyzed and the luminance turns out to be 5.432 footlamberts (18.610 cd/m^2). Then the scale factor, S, to set the luminance to 0.1 fL is S = 0.1/5.432 = 0.01841. The scale factor is then applied to the spectral radiance data, which is then convolved with the relative ANVIS response function $G(\lambda)$ and integrated over the 450 to 930 nanometer spectral region. The result of this integral is called the ANVIS radiance (AR) of the lighting component and generally must be less than 1.7 x 10^{-10} AR.

A revision of MIL-L-85762 was completed that defines lighting compatibility requirements for other types of night vision devices. MIL-L-85762A addresses this by defining a new relative response function "Class B NVIS" and redefining the old ANVIS relative response function as "Class A NVIS" (where NVIS means Night Vision Imaging System). The calculation method of ANVIS radiance for these changes remains unaltered; only the class of NVIS device, either "Class A" or "Class B", needs to be defined (NVIS radiance, Class A = NRA and Class B = NRB in MIL-L-85762A).

Figure 2 shows the difference between these two spectral response functions, where the black curve is the NVIS radiance Class A (NRA) and the colored curve is the NVIS radiance Class B (NRB). The calculation method of ANVIS radiance for these changes remains unaltered, but the luminance used to calculate the scale factor for NVIS radiance Class B (NRB) is 15 fL, instead of the 0.1 fL for ANVIS radiance (AR) and NVIS radiance Class A (NRA).

Actual Measurements

The key to making accurate and repeatable measurements at these low light levels is a spectroradiometer with a sensitivity of at least 1.7 x 10^{-11} W/cm^2-sr-nm with a 10:1

Table 2 - Spectroradiometer Measurement System Requirements In MIL-L-85762

System Parameter	Summarized Requirements
Spectroradiometer Sensitivity Calibration	Calibration must be traceable to NIST Standards at a max. 6 month interval
Wavelength Accuracy and Repeatability	Accuracy ±1.0 nm, Repeatability ±0.5 nm
Wavelength Accuracy and Repeatability Verification	Verified at one wavelength in every 150 nm interval from 350 to 950 nm using scanning or non-scanning technique
Digital Resolution of the Photocurrent	11 bit A to D plus sign or ±0.05% of each measured scale
Zero Drift	Less than 0.2% of full scale reading on most sensitive scale or range
Linearity	±1% of full scale, ±2% between scales
Linearity Verification Method	Inverse square law, aperture super-position or ND's with known transmission
Signal Conditioning	Controls to improve or change S/N ratio
Stray Light	Cannot adversely affect accuracy
Stray Light Verification	Measured spectral radiance of NIST traceable standard filtered with Schott BG23 must equal standard spectral radiance * filter transmission ±5%
Optics	Minimum spot 0.007" with 1.0 fL full scale sensitivity
Viewing System	Locate measurement spot within 5% of the diameter of the spot to be measured
Viewing System Verification	X-Y motion of black opaque rear illuminated aperture
Accuracy	Spectral radiance within ±5% of NIST traceable standard from 380 to 930 in 5 nm increments and UCS u' and v' coordinates to ±0.007
Accuracy Verification	Measure NIST traceable standard of spectral radiance other than the spectroradiometer calibration standard

signal-to-noise ratio in the 600 to 900 nm region. By developing a photomultiplier-based detector, proprietary assembly language algorithms for a microprocessor-based radiometer, and data acquisition software, we have produced a spectroradiometer that exceeds this requirement by as much as two orders of magnitude. This added sensitivity allows the use of input optics on the spectroradiometer, providing a well-defined measurement area.

The photomultiplier tube (PMT) used in this application was selected for both its spectral range and low noise characteristics. Its spectral range of 185 nm up to more than 950 nm meets the requirements imposed by MIL-L-85762A. The S/N criterion can be met by cooling the PMT to -30 °C in a water-cooled thermo-electric housing. Holding the PMT's temperature constant by carefully controlling the water bath temperature can help to ensure stable PMT operating characteristics.

Included within the cooled PMT housing are the optics necessary to couple the output of the spectroradiometer's monochromator to the PMT photocathode efficiently. The detector assembly also contains an internal reference lamp, which is controlled by the microprocessor-based radiometer. The reference lamp can be used to compensate for changes in PMT gain automatically, changes which occur when the high voltage to the PMT is set to different values to expand the system's overall dynamic range.

Single- or double-grating monochromators are the spectral selector. Both types use f/3.5 concave holographic diffraction gratings to cover the wavelength range from 300 to 1100 nm. The digital stepper motor that drives the diffraction grating(s) operates over extended periods without drift. Also part of the monochromator are several other components that keep the wavelength position of the grating accurate, control the placement of order-selection filters and operate the electric shutter.

The monochromator and the selected detector are both controlled by a microprocessor-based "intelligent" radiometer and scanning controller that acts as an interface between a host computer and the actual measurement devices. An instruction code set of about 30 ASCII (American Standard Code for Information Interchange) commands enables the system to be used for spectral and spatial measurements. The commands access firmware instructions written in assembly language. These firmware instructions, stored in erasable programmable read-only memory (EPROM), allow fast and precise interaction with the monochromator and the detector.

The ASCII commands encoded into the firmware of the radiometer allow optical measurement to be almost entirely automated. With one of these ASCII commands, the radiometer will scan from a low to a high wavelength with a specified wavelength step increment and return detector signal data at each step. Another command sets the number of digital averages taken, from 1 to 255, for each of these detector signal readings.

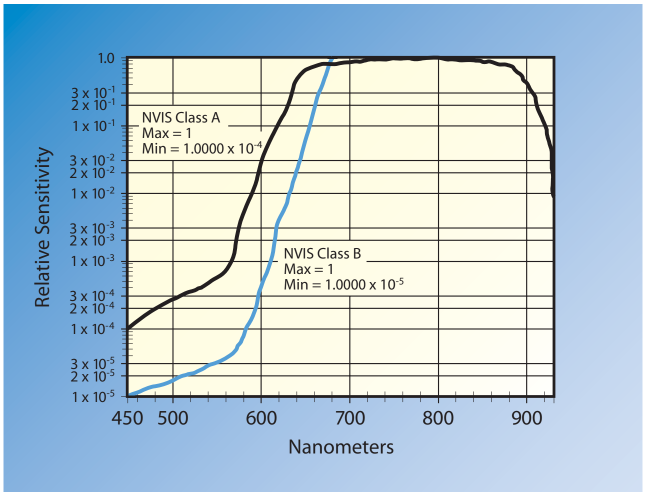


Figure 2. *Logarithmic plot of NVIS A and NVIS B relative responses.*

Some of the functions that the device performs automatically include:

- Scanning a range of wavelengths and returning the data to the host computer.
- Taking up to 255 readings at each wavelength position and returning the average value to the host computer.
- Opening and closing the shutter to the detector.
- Selecting the correct electrometer amplifier range.
- Subtracting dark current from the detector signal.
- Setting and reading the high-voltage level to PMT detectors.
- Calibrating the wavelength scale with up to nine reference wavelengths.
- Calibrating the detector amplitude scale.
- Scanning variable intervals.

- Correcting system (detector and electrometer amplifier) nonlinearity to better than 1%.
- Turning the reference lamp on or off.
- Setting or reading the real-time clock.
- Performing self-test and error-reporting functions.
- Resetting the input/output buffers and the measurement equipment.

The GS-4100 hardware consists of a photometer/radiometer printed circuit board, a central processor board, an RS-232/EPROM board, an analog-to-digital and digital-to-analog board, a motion control board, a stepper control board, and a power supply module.

A highly stable power supply, stable to ±0.06 °C over a temperature range of 0 to +50 °C and mounted on the photometer/radiometer board, drives the PMT. The electrometer amplifier boosts the signal current from the PMT in any of four channels, each differing by a factor of 10. The microprocessor in the radiometer selects the appropriate range for the photoelectrically created current from the PMT. The microprocessor also controls the high voltage applied to the PMT and automatically compensates any zero offset and suppresses the dark current. All these functions take place on the A/D-D/A board, which is matched to the radiometer board.

The motion board provides two monochromator motor speeds: fast for long moves, and slow for approaching a wavelength where a detector reading will be made. This two-speed approach eliminates overshoot and "hunting".

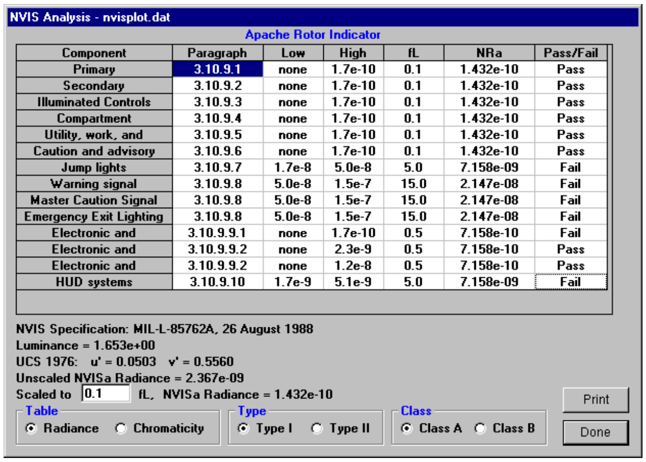
The RS-232/EPROM board contains the main program memory, the baud rate selector and the drivers for communicating with the host computer. Up to 32 kilobytes of assembly language instructions and communications rates up to 9600 baud can be selected on this board.

An IBM PC or compatible computer runs the DOS or new Windows™ based software package that utilizes the firmware commands in the device. This software is menu-driven and allows automatic test sequencing. All system measurement parameters such as high voltage, number of averages, wavelength range and interval, and scan direction can all be selected in advance and stored in test sequence disk files. The program can then execute the test sequence with a single keystroke and run totally unattended for hours or days, acquiring, storing and automatically analyzing the spectral radiance data. Once the test sequence is set, measurements can be taken by semiskilled operators with a minimum of training, providing a great advantage in production-line applications of these low-light-level measurements.

The Windows™ 95/98/NT version of the software also provides a direct link to Microsoft EXCEL™ spreadsheet. A powerfull macro function allows selection of the data to be linked from the spectral radiance values to the luminance or chromaticity coordinates. The NVIS analysis section of this software package also facilitates the pass/fail criteria of the measurement results with a cockpit lighting application catagory. Figure 3 shows an example of an analysis display of this software function.

Typical results are shown in Figure 4. This spectral radiance measurement was made with an effective spot diameter of 3.18 millimeters on a 1.3 fL filtered tungsten source. The spectral radiance values between 600 and 700 nm drops from 1 x 10^{-10} to less than 5 x 10^{-12} W/cm^2-sr-nm. Figure 4 illustrates the effect of applying the NVIS Class "A" weighting function (the black curve of Figure 2) to the spectral radiance data of Figure 5. The previously dominant visible portion of the spectrum is reduced to about one quarter of the total NVIS Class "A" radiance value of 1.7 x 10^{-10} W/cm^2-sr-nm. The important region turns out to be that between 600 and 700 nm. The low point of 5 x 10^{-12} W/cm^2-sr-nm at 685 nm can clearly be seen in the middle of the plot.

Figures 6 and 7 show the results of a measurement with the same effective spot diameter on an electroluminescent panel with improper filtration. Once again, the radiance in the 600 to 700 nm span ranges from 1 x 10^{-10} to almost 5 x 10^{-12} W/cm^2-sr-nm. This time, however, the luminance is only 0.66 fL, so that when the NVIS Class "A" weighting function is applied, there is a larger proportionate amount of radiant energy in the near infrared versus the visible region. So, when the spectral radiance is scaled to give a luminance of 0.1 fL, the AR calculation gives an unacceptably high NVIS Class "A" value of 3.2 x 10^{-10} AR.



NVIS Analysis - nvisplot.dat

Apache Rotor Indicator

Component	Paragraph	Low	High	fL	NRa	Pass/Fail
Primary	3.10.9.1	none	1.7e-10	0.1	1.432e-10	Pass
Secondary	3.10.9.2	none	1.7e-10	0.1	1.432e-10	Pass
Illuminated Controls	3.10.9.3	none	1.7e-10	0.1	1.432e-10	Pass
Compartment	3.10.9.4	none	1.7e-10	0.1	1.432e-10	Pass
Utility, work, and	3.10.9.5	none	1.7e-10	0.1	1.432e-10	Pass
Caution and advisory	3.10.9.6	none	1.7e-10	0.1	1.432e-10	Pass
Jump lights	3.10.9.7	1.7e-8	5.0e-8	5.0	7.158e-09	Fail
Warning signal	3.10.9.8	5.0e-8	1.5e-7	15.0	2.147e-08	Fail
Master Caution Signal	3.10.9.8	5.0e-8	1.5e-7	15.0	2.147e-08	Fail
Emergency Exit Lighting	3.10.9.8	5.0e-8	1.5e-7	15.0	2.147e-08	Fail
Electronic and	3.10.9.9.1	none	1.7e-10	0.5	7.158e-10	Fail
Electronic and	3.10.9.9.2	none	2.3e-9	0.5	7.158e-10	Pass
Electronic and	3.10.9.9.2	none	1.2e-8	0.5	7.158e-10	Pass
HUD systems	3.10.9.10	1.7e-9	5.1e-9	5.0	7.158e-09	Fail

NVIS Specification: MIL-L-85762A, 26 August 1988
Luminance = 1.653e+00
UCS 1976: u' = 0.0503 v' = 0.5560
Unscaled NVISa Radiance = 2.367e-09
Scaled to 0.1 fL, NVISa Radiance = 1.432e-10
Table: ● Radiance ○ Chromaticity
Type: ● Type I ○ Type II
Class: ● Class A ○ Class B

Figure 3. *Example of MIL-L-85762A analysis of cockpit display measurement data.*

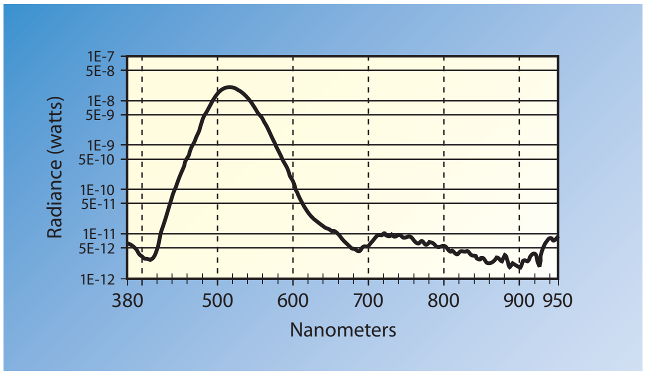


Figure 4. *Single spectral radiance measurement of lighting component meeting compatibility requirements of MIL-L-85762. Note that the radiance units are in microwatts.*

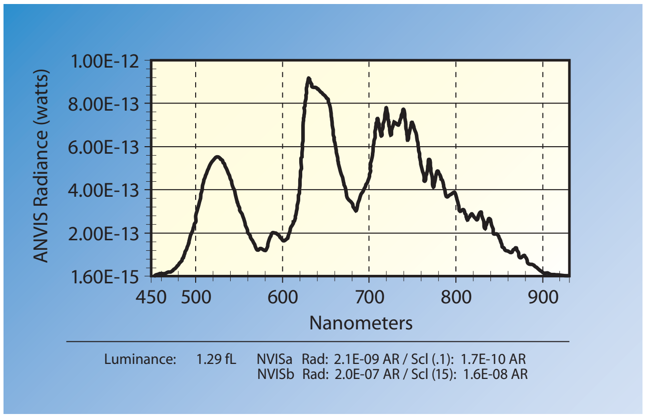


Figure 5. *Spectral radiance data from Figure 3, multiplied by the ANVIS relative response curve (the black curve in Figure 2). The data under the plot shows the luminance for the measurement data. Also, the NVIS A and NVIS B radiances are given for scaled and unscaled luminance values.*

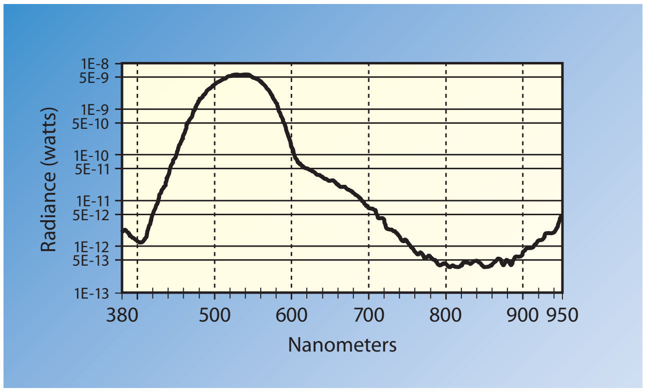


Figure 6. *Similar data as in Figure 3, but from an improperly filtered electroluminescent display.*

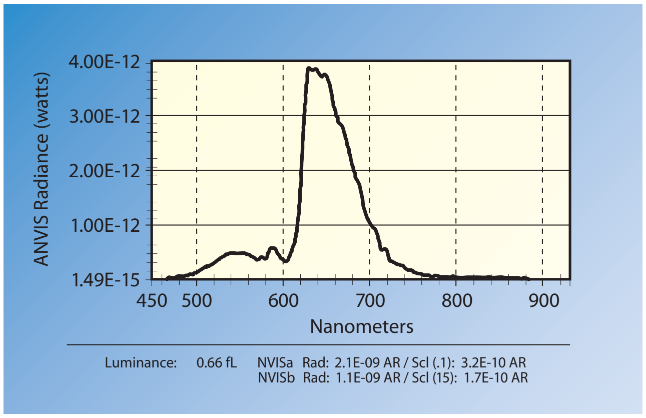


Figure 7. *Spectral radiance data from Figure 5, multiplied by the ANVIS relative response curve. The data under the plot shows the luminance and NVIS A and NVIS B radiances for the scaled and unscaled luminance values. Note that the peak radiance in the 600 to 700 nm region is four times that in Figure 4.*