Testing LCD Displays for NVIS Compatibility

Advanced Metrology Lowers Development and Production Costs

Manufacturers of military displays and other lighted instrumentation used in conjunction with night vision imaging systems (NVIS) are required to ensure that their products conform to MIL-STD-3009. This specification, which defines the permissible amount of out-of-visible band light that an NVIS compatible display or indicator can produce, also provides guidance on performance requirements for spectroradiometric measurement equipment, including threshold sensitivity levels required for these low-light measurements. Unfortunately, the signal-to-noise ratio condition (10:1) associated with the minimum sensitivity specifications can artificially inflate measurement results of certain devices' NVIS radiance (AMLCD displays in particular). As a result, it's quite possible that tests performed with metrology systems that merely meet the current MIL-STD will actually reject good product, potentially increasing manufacturers' development or production costs because of unnecessary design changes or rejected product. This document provides some background on the requirements for NVIS compatibility testing and discusses real-world considerations that should be factored into the selection of spectroradiometers for NVIS testing. It then presents newly enhanced instrumentation that enables manufacturers to ensure compliance to the MIL-STD, without driving up costs unnecessarily, by eliminating the major causes of false "fail" readings.

NVIS Testing Challenges

NVIS components include the actual goggles worn by pilots and personnel engaged in night operations, as well as the lighting components and assemblies used in the vicinity of night vision goggles.

Modern NVIS goggles operate by collecting and amplifying low levels of light in the red and near infrared, typically in the 615 nm to 900 nm wavelength window, which is a where significant amount of the spectral output of moonlight and starlight occurs. This allows the goggle wearer to see well under ambient conditions that the human eye experiences as dark.

In actual operation, NVIS are often used in military vehicles that contain numerous displays and other lit indicators which themselves produce a substantial amount of infrared light. In the early 1980s, when these high sensitivity goggles were introduced into aircraft cockpits, the near infrared energy from the small tungsten lamps used to illuminate cockpit displays and switch panels were found to affect the performance of the goggles. This prompted the need for a definition of allowable IR radiance to ensure NVIS compatibility.

When an NVIS is used in an environment with incompatible lighting, it will compensate for what appears to be high levels of ambient IR light by automatically lowering the gain to reduce system sensitivity and avoid overload. Unfortunately, this makes the NVIS unable to detect the low light signals from outside the aircraft, thus delivering a dark scene that essentially blinds the pilot.

In order to ensure compatibility between the NVIS and other light sources that will be operational at night, a military standard (MIL-L-85762) was developed that specified the allowable amount of infrared radiation that various categories of light sources could produce to guarantee their NVIS compatibility.

A revision to MIL-L-85762 was subsequently completed that defined lighting compatibility requirements for other types of night vision devices, beyond the original AN/PVS-5 Aviators Night Vision Imaging System (ANVIS). MIL-L-85762A defined a new relative response function called "Class B NVIS," and redefined the old ANVIS relative response function as "Class A NVIS." The calculation method of NVIS radiance remains unaltered; only the class of NVIS device needs to be defined (in MIL-L-85762A, Class A = NRA and Class B = NRB).

Because of significant advances in night vision technology throughout the 1980's and 1990's, and the proliferation of new display and indicator technologies, the issues with NVIS compatibility became more pronounced. As a result, a new NVIS compatibility specification (MIL-STD-3009) was adopted in 2001. However, MIL-STD-3009 carried forward the same performance requirements for spectroradiometers that were defined in MIL-L-85762A. Today, several spectroradiometer producers offer instrumentation that meets the specified sensitivity and chromaticity requirements in this standard. Yet, all NVIS spectroradiometers are not equal.

Since its release, much experience has been gained with the application of MIL-STD-3009 to various categories of lighting components. After more than 15 years, MIL-STD-3009 is now considered by some to be seriously out of date. One section that needs to be updated is Appendix A, which enumerates the minimum sensitivity levels for NVIS spectroradiometers in various regions of the visible and near infrared spectrum. Specifically, MIL-STD-3009, paragraph A.3.2 states:

> The spectroradiometer, when assembled as a complete system, shall have sufficient sensitivity to permit measurement of radiance levels equal to or less than that listed in the tabulation below at a half-power bandwidth of 10 nm and a signal to root-mean-square noise ratio of 10:1.

Wavelength	Radiance Level
380 to 600 nm	$1.0 \cdot 10^{-10}$ W/cm² sr nm
600 to 900 nm	$1.7 \cdot 10^{-11}$ W/cm² sr nm
900 to 930 nm	$1.0 \cdot 10^{-10}$ W/cm² sr nm

The specified 10:1 signal-to-noise ratio was intended to ensure that the system noise would have a negligible effect on the measurement results. However, recognizing that these sensitivities are difficult to achieve, and that the specified signal-to-noise ratios are potentially inadequate for an accurate measurement, MIL-STD-3009 is actually written to allow for certain test conditions to be altered in order to further increase the signal-to-noise ratio.

For example, in Appendix B, sample measurements and calculations are described for advisory signal lights. In paragraph B.3 (NVIS Radiance Calculations) the following guidance was provided:

> As specified in TABLE III of this standard, the required luminance level for NVIS radiance, L_r, for advisory signals is 0.343 cd/m² (0.1 footlamberts (fL)). If it can be shown that the luminance and radiance of the lighting device scale together, the measurement can be taken with the lighting component at the rated drive condition or with sufficient drive to produce 51.5 cd/m² (15 fL), whichever is less (as specified in section 5.7.12 of the standard). This will increase the signal-to-noise ratio in the measurement of spectral radiance **but must be carefully restricted for devices like LCD's, where radiance does not change in proportion to luminance.** *(our emphasis)*

Clearly, the specification's authors recognized that a higher signal-to-noise ratio would produce a better measurement result. They believed it was reasonable to improve signal-to-noise by allowing the device under test (DUT) to be driven to a higher output level, as long as it could be demonstrated that the device's luminance and radiance scale together. But, they also recognized that certain lighting components (LCD displays, in particular) do not behave in such a way that allows the measurement to be taken at artificially high luminance levels. So, for these lighting components, the luminance of the DUT must be set to the specified level (0.5 fL). And, in these instances, the measurement system must deliver the required signal-to-noise ratio when working at correspondingly low levels of NIR energy. Thus, for LCD display measurements, the spectroradiometer must be even more sensitive than for other lighting categories.

Spectroradiometers that meet the currently specified threshold sensitivities thus become problematic when measuring LCD displays that produce NVIS radiance levels that are close to the specified limits. Specifically, a 10:1 signal-to-noise ratio implies that measured results can be as much as 10% higher than the radiance levels actually produced by the display. For manufacturers of LCD display products who want to optimize their product design, and avoid unnecessary over-engineering of the product, a higher signal-to-noise ratio spectroradiometer would be advantageous. The higher signal-to-noise ratio allows a more precise measurement of NVIS radiance, which in turn allows the designer to reduce his design margin and operate closer to the specified limits. For example, there will certainly be performance variations within a production run, but even within the range of variance, those units that produce higher radiance levels could still meet the specification. The challenge is getting and accurate and reliable NVIS radiance measurement to avoid false failures of those units caused by the test system, not by the operating characteristics of the specific unit.

Meeting a Higher Standard

Most suppliers of NVIS metrology equipment have been content to design their instruments to meet the minimum requirements of the MIL-SPEC. After all, it IS the specification. But, Gamma Scientific, with over 50 years of experience in high precision spectroradiometry, long ago realized the shortcomings of the MIL-SPEC, and the negative cost impact it would have on manufacturers seeking to achieve NVIS compatibility.

In response to the need for a more accurate means of gauging NVIS compatibility, Gamma Scientific developed its GS-1290-NVIS series of NVIS Spectroradiometers. While the MIL-SPEC and competitive systems targeted a 10:1 signal-to-noise (SNR) measurement ratio, these new instruments from Gamma Scientific are designed and built to deliver SNR of 100:1 or greater. This increase in the performance level in the metrology system enables manufacturers to ensure that that their products are fully compliant with the MIL-SPEC, without the downside of unnecessarily failing good product.

Gamma Scientific GS-1290-NVIS series products utilize the RadOMAcam, a telescope with a lens system which collects light from the DUT and focuses it into a fiber optic cable. A series of selectable apertures allow the sampling field of view to be varied from 3.2 mm down to as little as 72 um. The smaller fields of view enable the instrument to measure extremely small spot sizes on the DUT. This might be used, for example, to measure just a single character, or even an individual stroke on a character, on a display.

The RadOMAcam also contains an internal LED which projects a spot onto the DUT to indicate the precise measurement area, and the exact position of this spot can be viewed on a monitor to facilitate precise alignment during testing. While some competitive products have a similar feature, these block out the actual spot location on the display, making alignment more difficult. Finally, the fiber optic cable feeds the collected light into a spectroradiometer, which uses a grating and temperature controlled CCD array detector to measure the spectral composition of the light with high precision.

The Gamma Scientific products embody a number of important technical advances that enable these GS-1290-NVIS instruments to deliver the substantially higher levels of performance cited earlier, yet still remain competitive in terms of cost and measurement speed. These include improvements over competitive products in the areas of instrument noise floor, stray light removal, spectral accuracy and dynamic range. It's worth exploring how each of these was addressed.

GS-1290-NVIS Spectroradiometer and RadOMAcam

Building a Better Instrument

It’s critical that an NVIS measurement system be even more sensitive than the device’s it’s going to measure in order for it to report accurate radiance levels. One necessary step in achieving this goal is to lower the instrument noise floor.

A major noise source in CCD spectroradiometers is the detector array itself. Its noise level is dependent on both the ambient temperature and the amount of cooling applied to the sensor. GS-1290-NVIS spectroradiometers employ a dual-stage, thermoelectric cooling system that stabilizes the CCD at a lower ambient temperature than competing systems based on single-stage cooling designs. Specifically, in Gamma Scientific products, the CCD is cooled and stabilized to -15°C, whereas competitive products are typically only cooled down to -5° or -10°. Because of the non-linear dependence of CCD noise on operating temperature, this apparently small temperature difference makes about an order of magnitude difference in the noise floor.

Another important source of “noise” is stray light. There are actually several potential sources of stray light in the optical system of a spectroradiometer. Of course, both our optical design and manufacturing methods are optimized to eliminate or minimize stray light, but these measures alone are not sufficient to reduce it to the levels needed for accurate NVIS measurements.

Stray light affects the spectroradiometer’s spectral purity – that is, the ability to precisely and accurately measure wavelength. Spectral purity is necessary because the weighting functions defined in the MIL standard are necessarily wavelength dependent, and these weighting values change rapidly from the visible to near IR regions. Stray light in the spectroradiometer can manifest itself as reported energy at the wrong wavelengths, and often at wavelengths that are not part of the input spectrum. In an NVIS measurement application, where extremely low levels of IR radiation are measured in the presence of relatively high levels of visible light, assigning a measured value to the wrong wavelength can have a major impact on results accuracy. Stray light from the visible spectrum that is captured by pixels mapped to the NIR range can degrade the measured NVIS radiance in a similar fashion to thermal noise components.

To take stray light suppression to the next level, we offer an optional stray light characterization and correction method developed by the National Institute for Standards and Technology (NIST). This technique was previously implemented by Gamma Scientific in earlier spectroradiometer products, but further proprietary improvements were made for the GS-1290-NVIS series products in order to extend the stray light suppression level down to $<10^{-4}$ (at 633 nm).

The other major area in which Gamma Scientific has significantly advanced CCD spectroradiometer performance is dynamic range extension. This is important in NVIS measurements because there is typically a very large range in radiance between the visible region and NIR region in measured lighting components.

Normally, a CCD-based spectroradiometer analyzes the spectral power distribution using s single measurement. The measurement integration time is set so that the peak wavelength is just below the saturation point for the detector. However, this approach means that low level signals may be near the measurement noise floor. To address this, Gamma Scientific developed a new software algorithm for extending the effective dynamic range of the system which dramatically improves measurement noise characteristics, especially for measurements of the IR region when high levels of visible light are present.

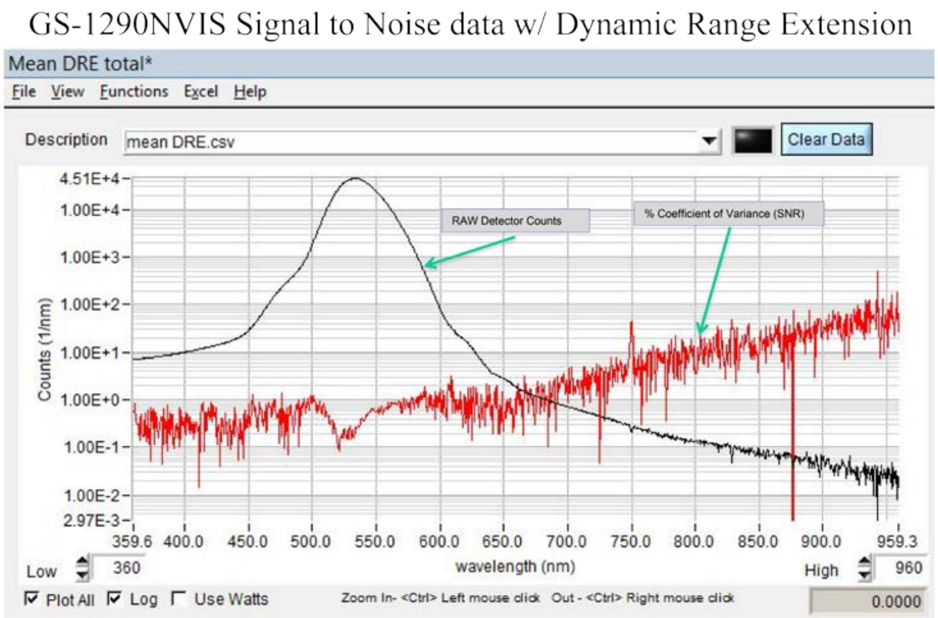

Figure 1. The measurement of an LED backlight AMLCD display is shown in the black line plot of raw detector signal, A to D counts, with 4,000,000 to 1 usable dynamic range. This is accomplished using the enhanced data acquisition technique. The red plot is the signal to noise ratio (SNR) in percent for multiple, raw A to D scans.

The result of all these efforts is that the Gamma Scientific GS-1290-NVIS achieves a dynamic range of over seven orders of magnitude, and a noise floor below 10^{-16} W/cm²/sr/nm. In contrast, the best competitive products are limited to a dynamic range of six orders of magnitude, and a noise floor of 10^{-14} W/cm²/sr/nm (two orders of magnitude worse). This higher noise floor makes it impossible for these competitive units to reliably distinguish good DUTs from bad.

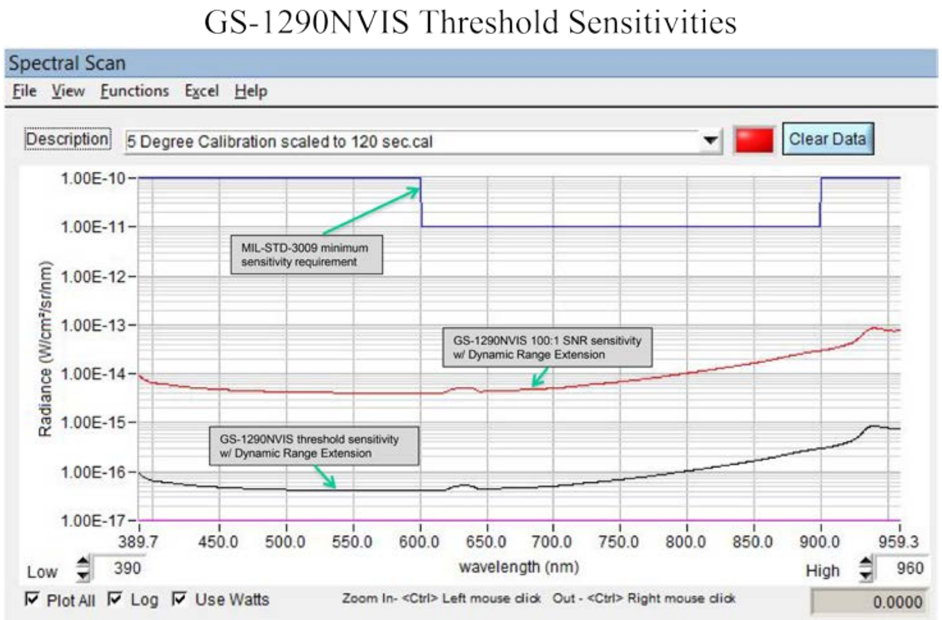

Figure 2. Using the raw A to D signal to noise determination from Figure 1, threshold sensitivity at 100:1 signal to noise sensitivity levels are determined and plotted in red. The performance is 1000 times more sensitive than the MIL-STD-3009 required thresholds over most of the 380 to 930 nm spectral range at this 100:1 SN ratio sensitivity level. ***This means faster measurements and smaller spot size measurements can be made compared to other NVIS spectroradiometer systems.***

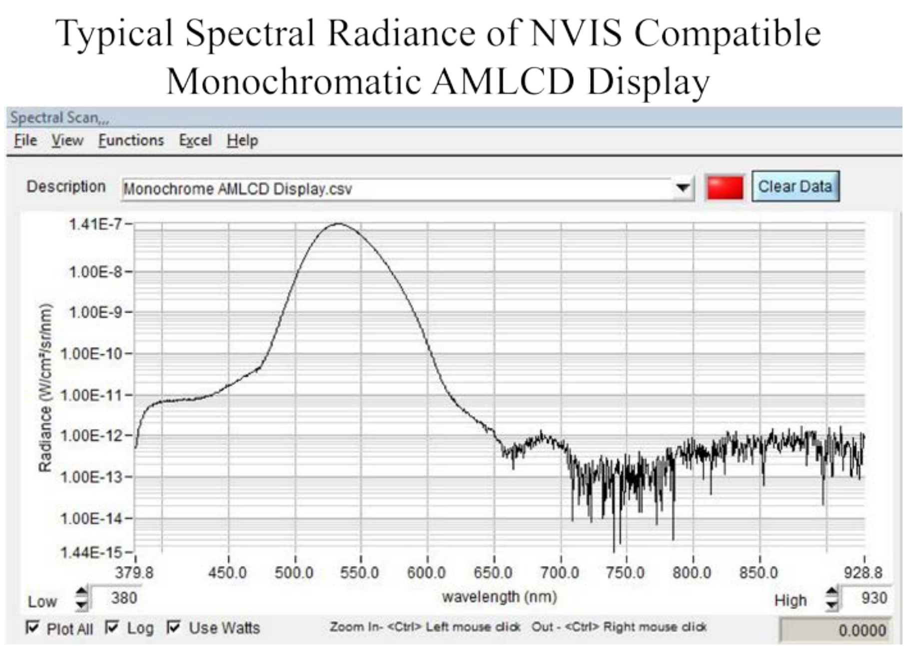

Figure 3. Multiplying the raw A to D counts and the threshold sensitivity functions together, and then applying the spectral purity improvement function, provides the absolute spectral radiance in Watt/cm²/sr/nm. This can be scaled by the NVIS weighting functions to validate pass/fail criteria.

Conclusion

Many suppliers of spectroradiometers for NVIS compatibility testing claim that their product is compliant with the current MIL-SPEC. But for certain types of lighting components, such as LCDs, accurately measuring NVIS radiance levels is a challenge. For manufacturers of those lighting components, investment in a spectroradiometer system that exceeds the minimum performance requirements in MIL-STD-3009 can actually save money by allowing them to more accurately measure true NVIS radiance levels and demonstrate compliance of their products without costly rework or design changes.

Gamma Scientific solves these problems with their GS-1290 series of NVIS Spectroradiometers. These instruments far surpass the requirements of the MIL-SPEC, while still remaining cost competitive with other systems that don't. The result enables manufacturers to ensure NVIS compatibility without driving up their own development and production costs needlessly.

Typical Spectral Radiance of NVIS Compatible
Monochromatic AMLCD Display

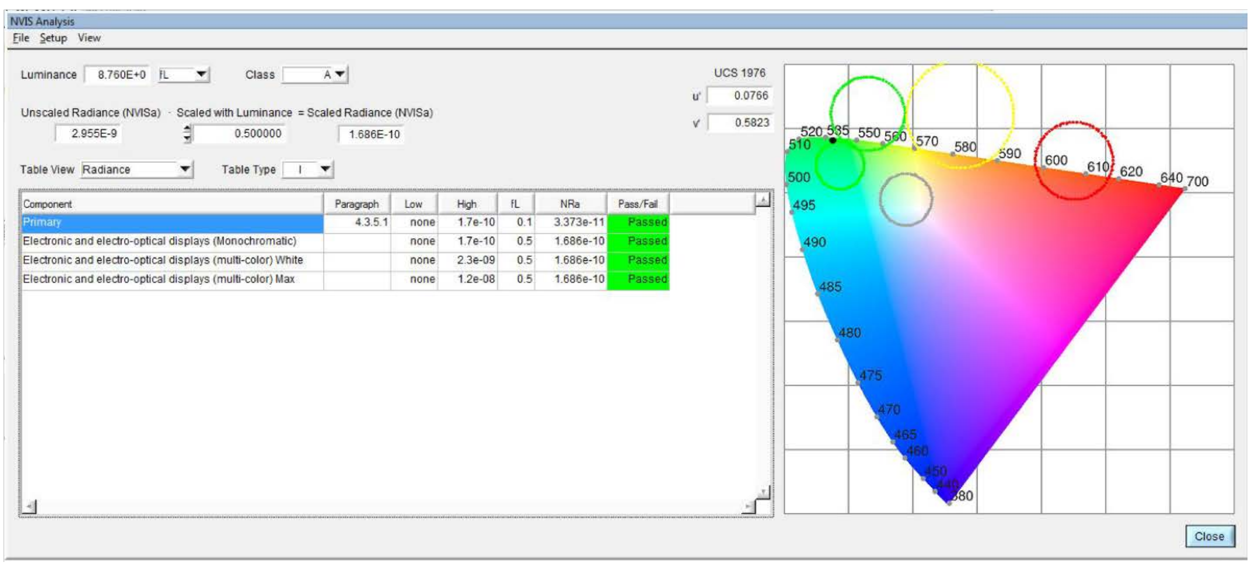

Figure 4. The final NVIS class A analysis results are shown here for the electronic and electro-optical display cockpit component categories.