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FAST NVIS MEASUREMENTS

Application Note: A13 Jan 2022

In any field where measurements lasting almost an hour are usual, an instrument that offers results in seconds or minutes may be expected to be favored. Speed and sensitivity are related however, and any reduction in measurement time would degrade results unless also accompanied by an increase in performance. Even with an increase in performance, it may be that only certain aspects of a measurement will be speeded up, and expert optimization is usually necessary to ensure accurate results are maintained.

MIL-L-85762A *(now obsolete)* specifies the minimum performance of a system to measure NVIS radiance. This is a rather old specification and improvements, relative to this performance, generally reflect the advantages of updated technology since MIL-L-85762A was published. The OL 750-NVG system combines centuries of experience with the latest optical, mechanical and electronic innovations, including DSP data acquisition. This article compares the performance of the OL 750-NVG to MIL-L-85762A, showing that fast, accurate results may be realized to a degree never before attainable. Some aspects of measurement that can be detrimental if speeded up or ignored are also covered to illustrate their importance in any optimization.

Before beginning the comparison, it is useful to review the basics of NVIS calculations red and near infrared parts of the spectrum, where the human eye has low sensitivity or none at all. Hence, a display optimized for normal viewing may change its appearance entirely when viewed.

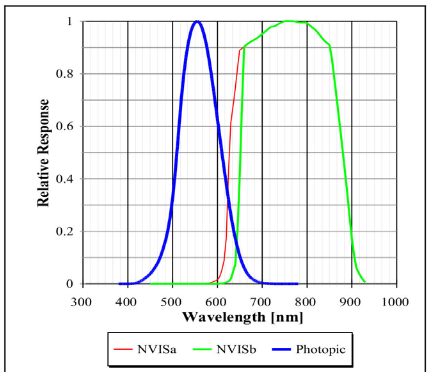

Figure 2. Relative response functions: NVISa, NVISb and photopic.

THE BASICS OF NVIS CALCULATIONS

Night vision goggles differ from the human eye in terms of sensitivity and spectral response. Figure 1 shows the relative NVISa and NVISb night vision goggle, and photopic *(standard human observer)* spectral responses. It can be seen that the NVISa and NVISb responses are highest in the night vision equipment. When graphed on a logarithmic scale however, as shown in Figure 2, the responses of NVISa and NVISb overlap significantly with the photopic response. Virtually any visible display will therefore also be seen to some extent by night vision goggles. Since all responses vary rapidly and over many decades with wavelength, extremely accurate measurements are required

Small spectral differences can produce dramatic changes in brightness as perceived by the human eye and night vision goggles. Limits placed on the relative brightness of displays under these conditions form the basis of MIL-L-85762A.

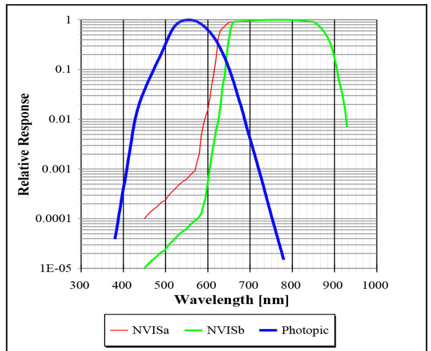

Figure 1. As Figure1, but showing a logarithmic scale.

To provide a clear comparison to individual specifications within MIL-L-85762A, the effect of an "equivalent" system on a source of known spectral distribution can be calculated. This can then be compared to the measured parameters of the OL 750-NVG. Figure 3 shows the spectral radiance of a good NVIS primary type I class A source. This was measured at 10fL using an OL 750D-NVG system, and the small amount of residual noise has been smoothed so as to provide the "known source" and clearly illustrate the various effects in this article. The spectrum is scaled as appropriate in the following arguments.

The spectral radiance, multiplied by the NVISa, NVISb and photopic relative responses, gives the effective radiances with respect to wavelength for each device *(as shown in Figure 4)*. The area under these curves, scaled appropriately, provides the NVISa radiance, NVISb radiance and luminance of the source. It can be seen that although 99.95% of the energy is at wavelengths less than 600 nm, most of the effective NVIS radiance is at wavelengths greater than 600 nm.

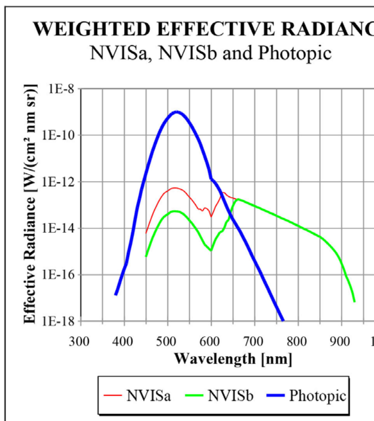

Figure 3. Effective spectral radiance of example source, as "seen" by NVISa and NVISb night vision and photopic devices.

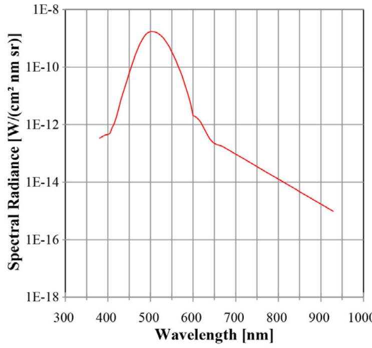

Figure 4. Spectral radiance of example source at 0.1 fL (used to illustrate effects described later).

COMPARISON OF MIL-L-85762A TO OL 750-NVG

Real instruments do not produce absolute answers. Each instrument adds noise or offsets that bias the data, decreasing the accuracy and reproducibility of results. In broad terms, the magnitude of these unwanted effects distinguishes a good system from a bad one. Complications arise since systems might be good when judged in terms of one effect and bad in another. Measurements on individual systems can isolate these various effects, which may then be compared to MIL-L-85762A to assess conformance. Conversely, the effects of known values of these parameters on a specific spectral source can be calculated, and used to assess the magnitude of errors introduced by that specific effect. For example, specific amounts of random noise may be added and the result compared with that of the unmodified spectral source. Since MIL-L-85762A expresses limits to the magnitude of effects, rather than the performance of a specific instrument, the errors of a system exactly meeting specifications can only be established through calculation. Suitable calculations, and hence comparison, can be made with respect to:

- sensitivity
- stray light
- data conversion and gain ranges
- dynamic range
- second order effects
- wavelength accuracy

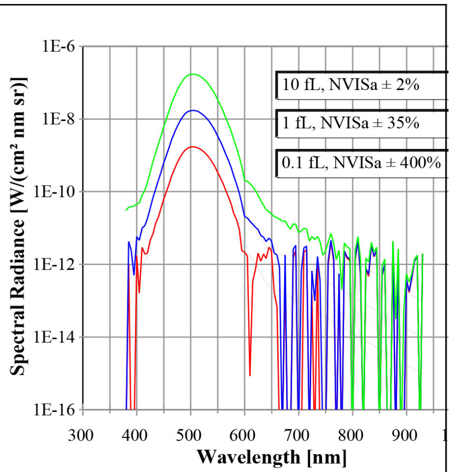

Figure 6. MIL-L-85762A stray light specifications.

The NVISa radiance of the example source used is 1.1 x 10^{-11} W/(cm^2 sr). The magnitude of each effect can be described in terms of the inherent percentage error relative to this value. If the effect influences luminance values significantly, this is also shown.

SENSITIVITY

Although most of the energy of the source is at wavelengths less than 600 nm, NVIS calculations are more influenced by the much weaker red and near infrared components. The inherent noise of the system presents a practical limit to measurements of weaker components. The noise may be multiplied by the system response to express this limit in units of radiance. MIL-L-85762A *(B30.2)* specifies the sensitivity, and hence the maximum level of acceptable noise a system can have. By adding random numbers corresponding to this noise level to the example source, the performance of a system just meeting MIL-L-85762A can be calculated. Figure 5 illustrates that a system meeting this specification may still give large errors in NVISa radiance values at luminances less than 10 fL. Since noise is essentially random, each measurement would give a different value within the error limits shown. In contrast, the OL 750 NVG *(shown in Figure 6)* gives small errors even at 0.1 fL.

Sensitivity may be perceived as an inherent property of a system, but in fact it varies with measurements conditions. In particular, it varies with both spot size and signal integration time. Older systems can therefore still meet this specification by using large spot sizes and long integration times.

The OL 750-NVG provides such enhanced sensitivity that measurements on ***all*** combinations of spot sizes down to 0.007 inches ***and*** integration times as short a one-hundredth of a second conform to or exceed MIL-L-85762A.

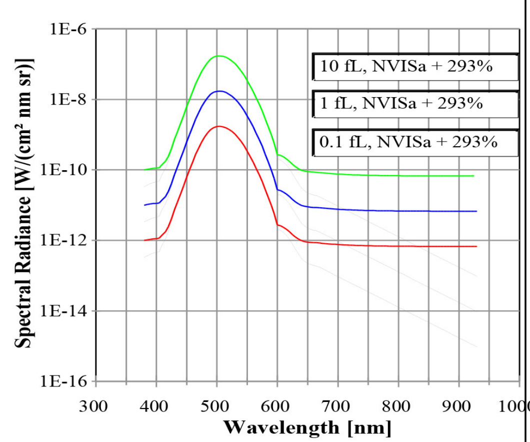

Figure 7. MIL-L-85762A stray light specifications.

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STRAY LIGHT

A monochromator is used to select specified spectral components of a source so the energy can be measured. No monochromator is perfect, so small amounts of other spectral components are also transmitted. These other spectral components are known as stray light, and are proportional to the total energy entering the monochromator. The ratio of the stray light at any wavelength to the total energy entering the monochromator is the stray light value. The lower the stray light value, the better the performance of the monochromator.

MIL-L-85762A *(B30.8.1)* specifies conditions to be met rather than a stray light value. The actual stray light value necessary to pass this test varies with the light source used but, even assuming the most favorable source, the system must still have a stray light value of less than or equal to 3×10^{-5}. If the stray light value is more than this at wavelengths between 690 nm and 930 nm, the system will never pass the test and hence cannot be used for display testing.

Multiplying the stray light value by the total energy entering the system gives the stray light level that would be observed. This stray light represents a positive offset to the data, giving a “leveling off” effect on the spectral radiance spectrum. This effect is not random, and adds a constant error to the NVIS results at each measurement.

Figure 7 shows the influence of stray light on the NVISa result of the example source using a system that just meets MIL L-85762A. Although this system would pass the specified stray light test, it still gives NVISa values nearly 4 times the actual value. Since stray light depends on the energy entering the monochromator, this error is present in all measurements regardless of brightness.

Normal single monochromators cannot provide this level of stray light performance, and double monochromators are employed instead. Highest quality single monochromators have inherent stray light values less than or equal to 3×10^{-5}, but additional proprietary techniques used in the OL 750S-NVG reduce this to less than 1×10^{-8} in the 690 nm to 930 nm region, making it ideally suited for NVIS measurements.

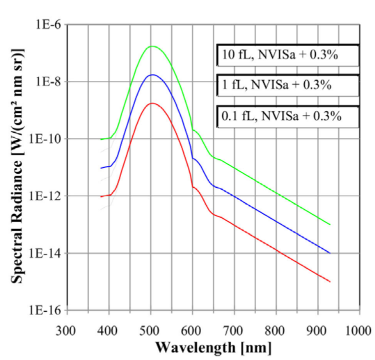

Figure 8. OL 750S-NVG performance. NOTE: The OL 750D-NVG is even better.

Double monochromators are often used for NVIS measurements, since these have much lower stray light levels than equivalent single monochromators. The OL 750-NVG provides additional special stray-light reducing optics to drastically reduce such errors. The OL 750D-NVG double monochromator version offers unparalleled performance and essentially no stray light errors. The OL 750S-NVG uses a single monochromator, yet still reduces stray light errors to negligible proportions *(as shown in Figure 8)* and in fact out-performs some double monochromator systems in this respect.

DATA CONVERSION AND GAIN RANGES

Although automatic gain changes might be assumed necessary, given the large dynamic range of some sources, nothing in MIL-L-85762A implies that fixed gain ranges are unacceptable. Indeed, if gain changes are eliminated then the time taken for scans is reduced. This is an example of sacrificing accuracy for the sake of speed however, and is not to be recommended.

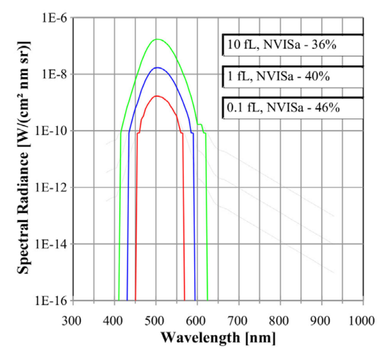

Figure 9. Fixed gain system to MIL-L-85762A specifications.

Although gain changes within a scan are not mandatory, MIL-L-85762A *(B30.4)* does specify the digital conversion accuracy of any measurement scale as ± 2048 counts of resolution. If a fixed gain measurement with this conversion accuracy is made, any value less than 1 count is automatically zero *(since negative light does not exist)*. Thus, as illustrated in Figure 9, light that should contribute significantly to NVIS results is not counted, and the overall value of NVISa is consistently low.

The OL 750-NVG employs automatic gain ranging and digital signal processing *(DSP)* technology to provide complete signal coverage and an immense number of counts of resolution, eliminating this problem entirely and giving exact results.

Autoranging is obviously much better than fixed ranges for all NVIS applications, but it can only be implemented if the monochromator is stationary at the time of signal acquisition. This is because the system needs to take a reading to see if the range needs changing. If so, the gain is changed and the signal allowed to settle before another reading is taken. This is repeated until the gain is optimal for that particular signal. If the monochromator scans at a constant speed, the wavelength of the reading is passed before any decision can be made. Under such circumstances, it must return to the original spectral component before optimal gain ranging can occur. Constant speed scans are therefore inherently incompatible with autoranging and should be avoided in NVIS measurements.

DYNAMIC RANGE

Dynamic range is defined for set conditions as the largest signal that can be measured divided by the smallest signal that can be measured, as shown in Equation 1.

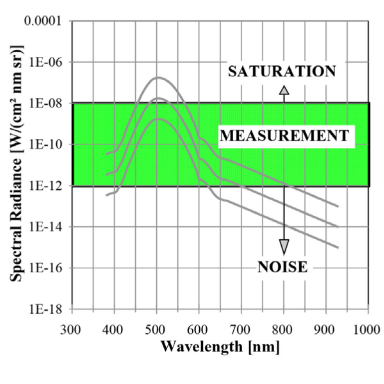

Figure 10. Effect of a 4 decade dynamic range, showing measurements have upper (saturation) and lower (dominated by noise) limits.

Measurements within the noise limits of the system are unreliable, so the minimum signal is generally at least as big as the noise level *(1:1 signal-to-noise)*.

$$\text{Dynamic Range} = \frac{\text{Largest Measurable Signal}}{\text{Smallest Measurable Signal}}$$

Equation 1. Definition of Dynamic Range under set conditions.

Operation under fixed gain limits the dynamic range, but this may be limited even in autoranging systems. Photomultipliers, especially those used in NVIS systems, have an inherently small dynamic range since they are relatively noisy and linear response is limited to very low light levels. Figure 10 shows the effect of a limited, 4 decade, dynamic range on measurements of the example source. Since four decades is not enough to represent any of the spectra, results would be affected regardless of intensity of the source. Also, to achieve the full four decade performance, the source would need to be matched to the measurement capabilities of the system: too bright and saturation *(or non-linearity)* results; too dim and the noise floor is encountered before four decades are reached.

If a source is too bright for the limited dynamic range, a neutral density filter may be added to attenuate the intensities and prevent saturation. However, this moves both the upper and the lower limit so the dynamic range is not increased. In fact, the attenuation makes the system less sensitive so it may no longer meet the sensitivity specifications of MIL-L-85762A under such circumstances.

To achieve an increase in the dynamic range of an instrument, without altering the set conditions, the neutral density filter must be inserted before the spectral radiance becomes too high and removed when no longer needed. In this way, the highest radiances measurable may be increased almost indefinitely *(dependent only on the density of the filters available)* without losing the sensitivity at the lowest levels.

If the optimum filter for measurements at the peak radiance is ND3 *(neutral density 3 = 0.1% transmission)*, the signal is suddenly attenuated by three decades whenever this filter is selected. Although the ND3 filter extends the dynamic range of a 4 decade system to 7 decades, the photomultiplier signal *(and hence signal-to-noise)* over the fifth decade is the same as that of the second. This condition means that the system may be operating at optimum performance at high or low radiance, but will give poor results in between. To ensure optimum performance at all levels of spectral radiance, several filters of increasing density should be used.

Neutral density filters vary in their attenuation both with wavelength and angle of incidence. To be effective in producing accurate results, they must therefore be spectrally characterized in the monochromator.

The OL 750-NVG system employs an independent neutral density filter wheel with fully characterized incremental filters to give 10 decades of dynamic range as standard. Intelligent software selects the optimum filter to give the best signal-to-noise at all wavelengths and intensities, so the user may make measurements without prior knowledge of the source brightness. This means that ***light sources of 10,000 fL or more can be determined as easily as 0.1 fL sources without changing the conditions of measurement.*** Even higher dynamic ranges can be easily accommodated with additional neutral density filters.

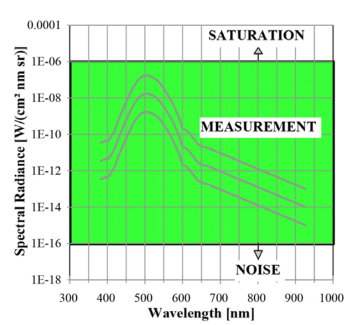

Figure 11. OL 750-NVG performance gives 10 decades of dynamic range.

Figure 11 shows how the OL 750-NVG would cope with the measurements of the example source. Essentially, all values lie within the dynamic range and are measured without saturation or degenerating into noise.

This inherent 10 decade dynamic range not only impacts measurements, but also provides more ***accurate calibrations***. Without neutral density filters, calibrations have to be made at low intensities. This introduces errors in setting that intensity and is affected strongly by other light sources *(computer monitors, LEDs, room lights etc.)* that may be present. Calibration at higher light levels eliminates these problems in high dynamic range systems such as the OL 750-NVG.

This extended dynamic range requires both gain and filter wheel changes to be made during a scan. Eliminating these changes would certainly speed up scans, but would also severely and adversely affect the quality of results.

SECOND-ORDER BLOCKING FILTERS.

Whenever a monochromator selects a wavelength, say 900 nm as an example, the spectral components at half that wavelength are also transmitted. This means that a mixture of 450 nm and 900 nm components will reach the detector. For normal NVIS sources, the energy at 450 nm is much greater than at 900 nm. The measurement system will also normally respond more to 450 nm than to 900 nm, and the combined effects mean that the true 900 nm signal is swamped by the undesired second order of 450 nm.

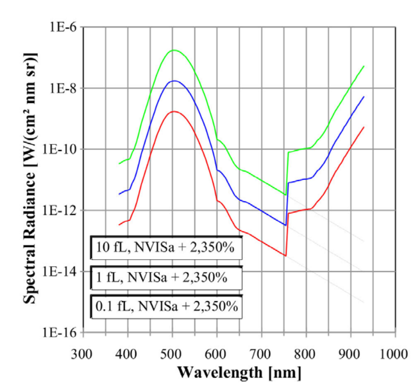

Figure 12. A system without blocking filters, showing that second orders severely affect NVISa results.

Removing these second orders is done by inserting blocking filters into the optical system at set wavelengths. These filters absorb light at shorter wavelengths while transmitting the light at longer wavelengths. For example, a 600 nm blocking filter would absorb the 450 nm component while allowing the 900 nm component to be measured correctly.

Figure 12 shows the type of spectrum that may be encountered if blocking filters are not employed during a scan. The actual intensity of the second order, relative to the first order, depends on the grating blaze but an optimistic value of equal intensities is assumed for illustration purposes. Also, wavelengths less than 380 nm would be expected to contribute, giving less accurate results than those presented.

Even so, the NVISa value calculated would be 24.5 times those of the real value, making all displays fail.

The OL 750-NVG changes blocking filters automatically and efficiently, giving reproducible optimized results in the shortest possible time.

In contrast, a system employing good quality blocking filters appropriately would be expected to give negligible errors due to second-order effects, as shown in Figure 13.

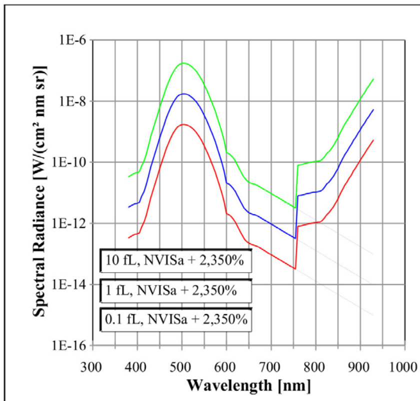

Figure 12. A system without blocking filters, showing that second orders severely affect NVISa results.

Changing the blocking filter takes time. The current filter must be removed and another inserted at a specific, reproducible wavelength during each scan. During this process, the light through the monochromator *(and hence the signal from the detector)* goes to zero. Following the insertion of the new filter, the amplifiers etc. must be allowed to recover before continuing the scan. The wavelength of the monochromator must therefore be constant during this process.

Since the adverse effects of ignoring blocking filters are so extreme, good quality instruments will always employ such techniques. However, constant scan speed instruments cannot remain stationary and are inherently unsuited to this method.

WAVELENGTH ACCURACY

The photopic, NVISa and NVISb response functions feature rapid changes over small wavelength regions. Also, typical NVIS devices have spectral radiance values that change rapidly - often decreasing where NVISa or NVISb responses are increasing. This situation makes the photopic, NVISa and NVISb results very sensitive to small changes in wavelength.

To obtain correct results, the monochromator must transmit say, 500 nm, every time the wavelength of 500 nm is selected. If, instead, it transmitted light at 501 nm, the measured spectral radiance values would be shifted relative to their true wavelengths. MIL-L-85762A specifies the acceptable maximum values of wavelength error as ± 1 nm. The effects of this wavelength shift are shown in Figure 14.

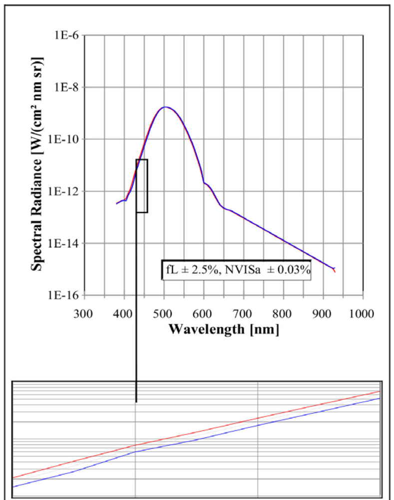

Figure 14. System with ±1nm wavelength shift error as specified if MIL-L-85762A

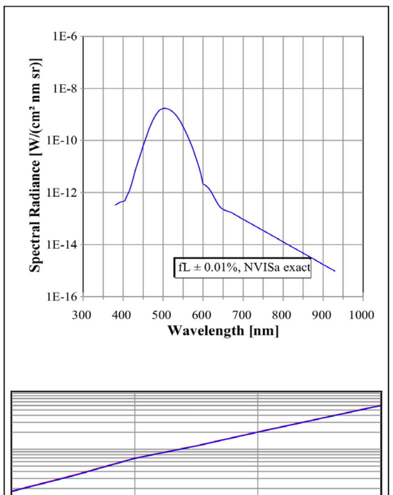

Figure 15. OL 750-NVG wavelength performance.

In Figure 14, the luminance is affected significantly whereas the NVISa hardly changes. This is dependent on the example spectrum chosen. Since the peak spectral radiance is less than 555 nm *(the maximum of the photopic response function)* shifts to higher wavelength increase its effective luminance. However, this shift also increases its NVISa, and the two effects almost cancel in this example. If another example were chosen with a peak spectral radiance higher than 555 nm, large changes in NVISa would be anticipated.

The only way to achieve good luminance and NVISa results regardless of the source is to use an instrument with an inherent accuracy much higher than specified in MIL-L-85762A. Figure 15 shows the typical, and virtually negligible, errors introduced with the OL 750-NVG system.

In order to be accurate with respect to wavelength, it is best if the wavelength is kept constant during measurements. If the wavelength is moving, the reaction time of the electronic components *(amplifiers in particular)* will produce an apparent wavelength shift. For slowly changing signals this may be negligible, but for fast changing spectral radiances the signal will “lag” behind - producing a shift. This is the basis for some users of constant speed scan systems to calibrate wavelength at different scan speeds. However, this notion is erroneous, since the lag depends on the rate of change of radiance with wavelength and calibration is done using discrete “line” sources such as mercury lamps. NVIS sources are generally not “line” sources, so the shifts found during calibration cannot represent the shifts encountered during measurements. In fact, the shifts during measurements will be variable, reflecting the steepness of the spectral radiance with wavelength.

The OL 750-NVG system normally operates in “burst mode,” that is a wavelength is selected, the system waits for a user-selectable settling time before acquisition, the signal is integrated and, if optimum conditions are met, the next wavelength is selected. Since the monochromator stops at each wavelength of measurement, filter and gain changes can be implemented without adverse effects and the system operates at optimum at all times.

SCAN SPEED

Many of the effects described above affect the scan speed, in that eliminating them to achieve faster results produces severe errors. Noise, and hence sensitivity, is affected by integration time and is a variable that gives different results at different scan speeds.

For any random component of a signal, such as noise, the standard deviation *(a measure of the spread of values)* decreases with the square root of the integration time. In order to decrease the noise, and hence increase the sensitivity, by a factor of ten the integration time must be increased by a factor of one hundred.

Figure 16 shows the affect of changing scan time on results with the OL 750-NVG system. Increasing the scan time from 1 minute to 5 minutes actually increases the data acquisition time by about 16 times. This gives a reduction of a factor of 4 in the noise and achieves a more accurate result. To achieve a similar improvement relative to a 5 minute scan however, requires a 60 minute scan to be performed.

The user may thus optimize the measurement parameters according to the speed and accuracy of the desired result.

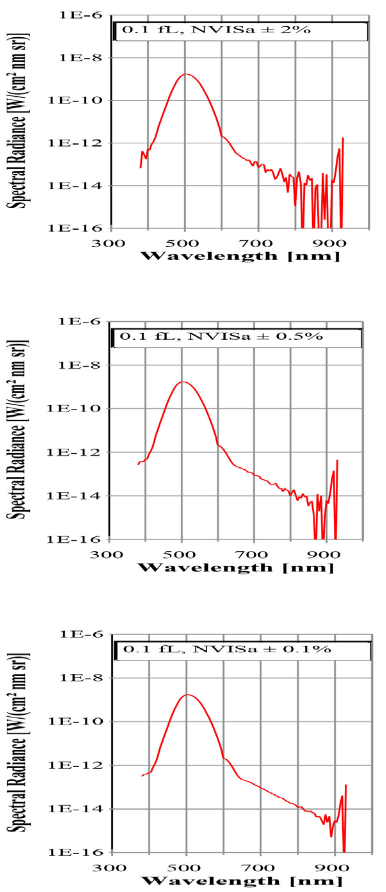

Figure 16. Measurement with the OL 750-NVG system in 1 minute (top), 5 minutes (middle) and 60 minutes (bottom) scan time.

CONCLUSION

Measurements of luminance, NVISa and NVISb must be made using real instruments. These instruments have several sources of error that yield results different from the true values of the source. The error effects illustrated are combined for any actual measurement, but their individual contributions to the overall error can be estimated using calculations and known values for that component of error.

Comparing the specifications in MIL-L-85762A to those of the instrument can give immediate tangible classification in terms of good or bad performance, together with the impact of that parameter on actual results. Users can decide between instruments on the basis of this performance, and feel confident of the quality of results and limits to the system.

Most of the parameters affecting performance cannot be ignored in measurements. Although these limit the speed of the fastest scan obtainable, they are a necessary part of any measurement. Fast scanning is therefore only acceptable if the results are equivalent to slow scanned measurements, and simply moving the grating faster does not achieve this.

In older systems, most of the time spent during scans is in data acquisition to integrate the signal for a sufficient interval to reduce noise to acceptable levels. Increases in sensitivity of the system by a factor of ten will decrease the data acquisition time by a factor of one hundred for the same result quality. Thus the OL 750-NVG, with enhanced sensitivity, achieves scan times of a minute or less.

The OL 750-NVG also offers increased performance relative to other systems, so results may be obtained with greater accuracy as well as faster.

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