A New Generation of NVIS Spectroradiometers Combining Speed, Sensitivity and Portability

Abstract

Accurate measurement of NVIS radiance according to MIL-L-85762A is a challenging task, and often very time consuming. Usually, you need experienced and skilled people to perform the measurements. Traditional spectroradiometers are complicated to operate, not portable, and also very slow. Some measurements can take up to a couple of hours to be completed.

A new NVIS spectroradiometer has been introduced by INSTRUMENT SYSTEMS that is based on a novel monochromator design, offering very fast measurements of less than one minute at high sensitivity and accuracy for the first time. It is also easy to handle and portable.

This paper describes the features of the new NVIS spectroradiometer and discusses measurement performance in specific applications.

Outline

INSTRUMENT
SYSTEMS
OPTISCHE MESSTECHNIK

Why a NVIS spectroradiometer?

The complexity of NVIS radiance measurement is caused by two factors:

- The nature of the image intensifier´s spectral response function that is used in night vision goggles. Optical radiation in the spectral range from approximately 650 to 930 nm is amplified by some 5 orders of magnitude and converted to visible green. Thus, the display´s radiance in that spectral region must be extremely low compared to the visible spectrum.
- The NVIS radiance readings have to be ratioed to the luminance of the same sample. Thus, the luminance has to be measured precisely as well. The difference in NIR radiance and luminance is significant.

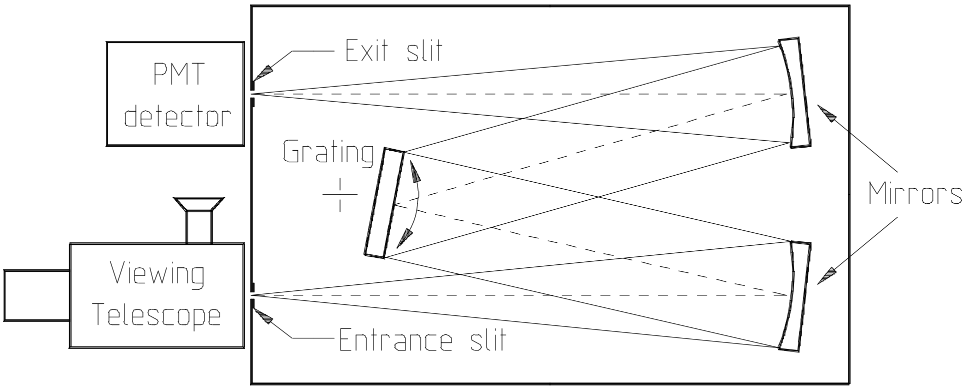
Only spectroradiometers meet the requirements for accuracy as they acquire the radiation spectrum from 380 to 930 nm. Luminance and NVIS radiance are calculated from the spectral data enabling proper ratioing and scaling. Different integration functions can easily be implemented in the software.

By design, spotmeters are not suitable for absolute measurements since filters are used to immitate the image intensifier´s as well as the eye´s response function. A filter/detector combination can only be manufactured with moderate accuracy. Temperature changes as well as aging cause additional shift in the response. An NVIS spotmeter must be calibrated for each specific sample to be measured.

Basic principle of a spectroradiometer

Precision spectroradiometers are usually based on a Czerny-Turner type monochromator with a diffraction grating that is rotated to scan the spectrum.

The radiation to be analyzed is launched into the monochromator through the entrance slit and hits the first concave mirror which collimates the radiation. Then, a diffraction grating reflects the radiation while dispersing it into its spectral components. A second concave mirror focusses the radiation on the exit slit. A detector is located behind the exit slit. Scanning of a spectrum is accomplished by rotating the grating while recording the electrical signal at the detector.



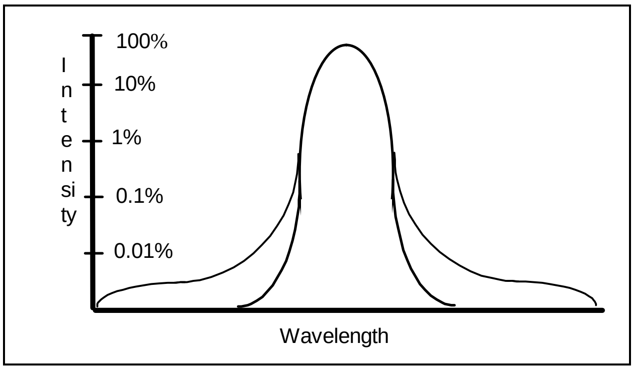
Typical spectroradiometer with grating monochromator

There are a few important parameters when evaluating the performance of a spectroradiometer:

Spectral range and response function
This is determined by the grating and detector used. Usually, the detector limits the spectral range while the grating has a significant influence in the overall response function.

Spectral resolution (bandpass)
This is determined by various parameters:

- Focal length of the monochromator, i.e. the concave mirrors; a longer focal length increases resolution. The focal length is fixed.
- Width of the entrance and exit slits; the smaller both slits are, the higher the resolution is; on the other hand small slits cause significant loss in intensitiy throughput and, thus, sensitivity. Usually, the slit width can be changed by the user to alter the desired spectral resolution. It is important that both slits are changed equally to ensure a proper bandpass function, as shown below.



The solid line represents a proper bandpass function, whereas the dashed line refers to a bandpass function where the entrance slit does not match the exit slit. As a result the spectrum is broadened at its steep slope in the infrared cut-off region causing higher NVIS radiance readings.

- Groove density of the grating; in most cases a 600 or 1200 g/mm grating is used. Sometimes, more than one grating can be installed in a monochromator to provide a choice of different spectral resolutions. More grooves means higher resolution.

Wavelength accuracy
Wavelength accuracy is limited primarily by the mechanical and optical design of the monochromator and by the precision of the grating turret rotation. The blue filter used to verify stray light accuracy according to MIL-L-85762A can change by more than 6% per 1 nm in transmission. Also the radiance of real panels even may change 15% per 1 nm in the infrared cut-off region. Thus, wavelength accuracy is critical for correct NVIS radiance measurements.

Stray light performance
Basically, the quality of the grating and the opto-mechanical layout of the monochromator determine stray light at the exit slit. Traditional symmetrical Czerny-Turner designs have moderate stray light levels, while new asymmetrical designs can reduce stray light significantly.

Sensitivity
Sensitivity is limited by the spectral resolution (i.e. the optical throughput), the design of the input optics, the grating efficiency, the detector sensitivity and the gain/noise performance of the electronics. For NVIS spectroradiometers state-of-the-art photomultiplier detectors and electronics must be used to achieve the necessary sensitivity requirements.

Traditional spectroradiometer designs and their drawbacks

Because of the sinusodial relationship of the grating´s rotation angle and the corresponding wavelength change at the detector, traditional spectroradiometers are based on a stepper motor and a sine bar driving mechanism between the stepper motor and the diffraction grating. The sine bar drive is used to convert linear steps of the stepper motor to a sinusodial rotation of the grating resulting in linear wavelength steps.

This monochromator design, however, causes several problems:

- The sine bar drive involves very high precision mechanics that is complicated to adjust and allows only slow movements of the grating
- Any mechanical backlash results in wavelength offset errors and hysteresis
- Temperature drifts and mechanical vibration cause wavelength non-linearities
- The stepper motor moves the grating to discrete wavelength positions in a stepped scanning mode, allowing data acquisition only when the grating is idle. Significant time is lost where no readings are taken.
- In the case of a double monochromator configuration both monochromators are arranged side by side. Synchronizing the two gratings of both monochromators is complicated resulting in further wavelength errors and measurement delays. It also adds mechanical fragility.

If the viewing telescope is directly attached in front of the entrance slit further concerns arise:

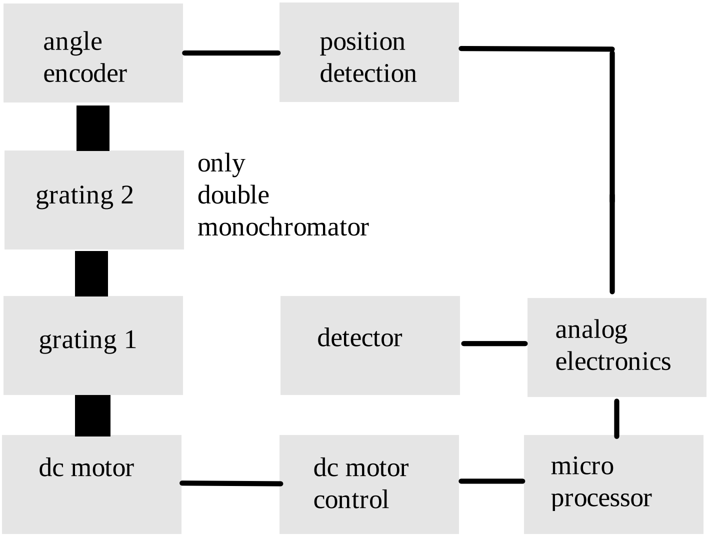
- Significant polarization dependence occurs because the light is imaged onto the grating directly.
- Uncomfortable operation and handling due to the large setup. It is not compatible with positioners that accommodate industry standard spotmeters.
- Changing the entrance slit of the monochromator affects the measurement spot accuracy because the measurement spot is imaged onto the entrance slit. On the other hand, changing the spot size may change the effective bandpass and cause wavelength offsets.

A new generation of NVIS spectroradiometers

INSTRUMENT SYSTEMS developed a complete new spectroradiometer concept dubbed SPECTRO 320 that is based on a novel monochromator design and a unique attachment of the telescopic probe via optical fiber. The result is a substantial improvement over traditional spectroradiometers.

<u>The novel monochromator design</u>

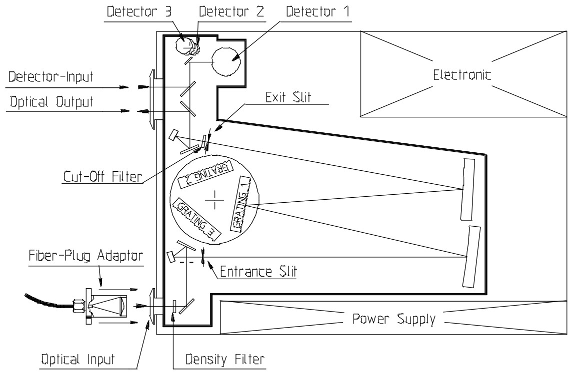
A direct grating drive uses a dc motor to rotate the diffraction grating smoothly at a constant speed during data acquisition. The complex sine bar drive is eliminated because sineinterpolation of the data is accomplished by software. This allows very fast scan speeds of a couple of seconds for a complete spectrum. A high precision angle encoder is attached to the grating turret synchronizing data acquisition



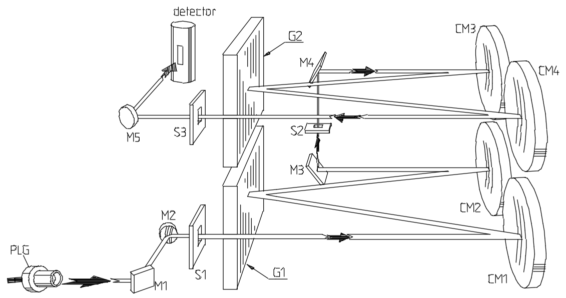
during rotation. As there is no mechanical backlash between the grating and the angle encoder, excellent wavelength accuracy and stability is guaranteed. High sensitivity is achieved by the efficient optical design, a cooled photomultiplier, and by taking data readings without interruption during the scan.

The monochromator assembly is shock mounted and housed along with complete control and measuring electronics and the cooled photomultiplier detector in a robust 19“ enclosure. Portability, easy handling, long term stability and accuracy are key benefits of the SPECTRO 320.

Furthermore, a new asymmetrical Czerny-Turner configuration has been developed resulting in significantly lower stray light than conventional single monochromator spectroradiometers. The asymmetrical design shifts wavelength dependent stray light to a shorter wavelength region. Thus, stray light is reduced to a minimum especially in the critical NVG spectral range from 600 to 930 nm.



SPECTRO 320 Single Monochromator



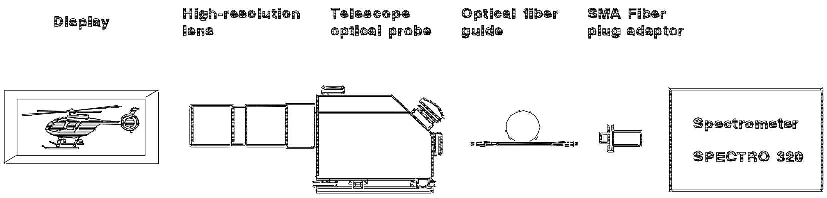
SPECTRO 320 D Double Monochromator

INSTRUMENT SYSTEMS also manufactures a spectroradiometer based on an innovative double monochromator configuration. A compact system has been designed by stacking both single monochromators. Because the two gratings are mounted on the same turret the same advantages of high measurement speed and wavelength accuracy as the single monochromator version are achieved. This design is also mechanically robust with only one moving part. The SPECTRO 320 D double monochromator is currently used in metrology and solar UV-B measurement applications that require extremely low stray light (as low as 10E-8).

The SPECTRO 320 D is also readily available to address possible future applications for NVIS radiance measurements. However, sensitivity is approximately 10 times less compared to the single monochromator version and the cost of the system is higher.

<u>The fiber attachment of the telescopic probe</u>

INSTRUMENT SYSTEMS has designed a unique telescope probe that is attached by an optical fiber to the spectroradiometer. The optical fiber reduces polarization dependence significantly and allows a high degree of flexibility for performing measurements. The optical fiber can be as long as 20 meters without significant sensitivity losses. Now it is convenient to perform accurate NVIS radiance measurements in a real aircraft cockpit by placing the telescope probe inside the cockpit while leaving the spectroradiometer outside.

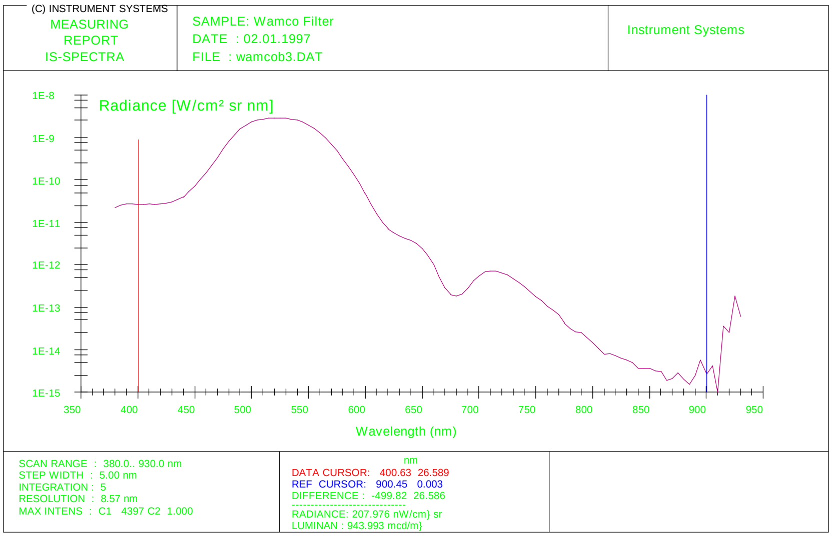


The TOP 100 telescopic probe is attached by an optical fiber

DTS320-201 Technical Specifications

INSTRUMENT SYSTEMS is marketing a complete spectroradiometer system dubbed DTS320-201 for NVIS radiance measurements that meets and exceeds MIL-L-85762A specifications. It is based on the SPECTRO 320 single monochromator, the TOP 100 telescopic probe with fiber attachment, and a comprehensive Windows software program for instrument control and data analysis. The system is superior to traditional NVIS spectroradiometers in several ways:

	DTS320-201	Traditional spectroradiometers
Measurement time	1 minute (independent of data point interval)	30 to 60 minutes at 5 nm data point interval (a smaller data point interval results in even longer measurement times)
Spot sizes	0.15 to 1.8 mm standard	0.175 to 1.5 mm
Sensitivity [W/cm^2 sr nm] (MIL-Spec requires 1.7 10E-11)	10E-13 at 1.8 mm spot 10E-11 at 0.15 mm spot	10E-10 to 10E-12 at large spots only
Polarization dependence	< 5% using a fiber bundle	significant
Stray light	10E-5 single monochromator (10E-8 double monochromator)	10E-4 single monochromator 10E-8 double monochromator
Spectral resolution (bandpass)	0.5 to 10 nm software controlled; calibration remains	1 to 10 nm by manually changeable slits; new calibration is necessary; spectrally broadened bandpass function if only one slit is changed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REPORT
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SAMPLE: Wamco Filter
DATE : 02.01.1997
FILE : wamcob3.DAT

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SCAN RANGE : 380.0.. 930.0 nm
STEP WIDTH : 5.00 nm
INTEGRATION : 5
RESOLUTION : 8.57 nm
MAX INTENS : C1 4397 C2 1.000

nm
DATA CURSOR: 400.63 26.589
REF CURSOR: 900.45 0.003
DIFFERENCE : -499.82 26.586

RADIANCE: 207.976 nW/cm} sr
LUMINAN : 943.993 mcd/m}

DTS320-201 Measurement example

This spectrum shows a measurement of a Wamco test filter at 1 fL luminance recorded by the DTS320-201 using the direct fiber input. It demonstrates a dynamic range of 6 orders and a noise floor of 10E-14 W/cm^{2}sr nm. Measurement time was 2 minutes.

Is a double monochromator necessary for low NVIS radiance readings?

Traditional single monochromator designs offer a stray light level of 10E-4 which often is not sufficient for accurate NVIS measurements. Thus, a double monochromator can improve stray light performance significantly.

The advanced asymmetrical Czerny-Turner design of the single monochromator from INSTRUMENT SYSTEMS has a stray light level of 10E-5 which exactly meets the requirements for precise NVIS radiance measurements of todays existing panels. Correlation tests with double monochromator based NVIS spectroradiometers have shown that a stray light level of less than 10E-5 does not further improve performance. The measured NVIS radiance at very low levels is often limited by the actual radiance of the panel in the spectral region of 620 to 650 nm. Since a double monochromator has approximately 10 times less light throughput and, hence, worse sensitivity, the SPECTRO 320 single monochromator based spectroradiometer offers the best overall performance today.

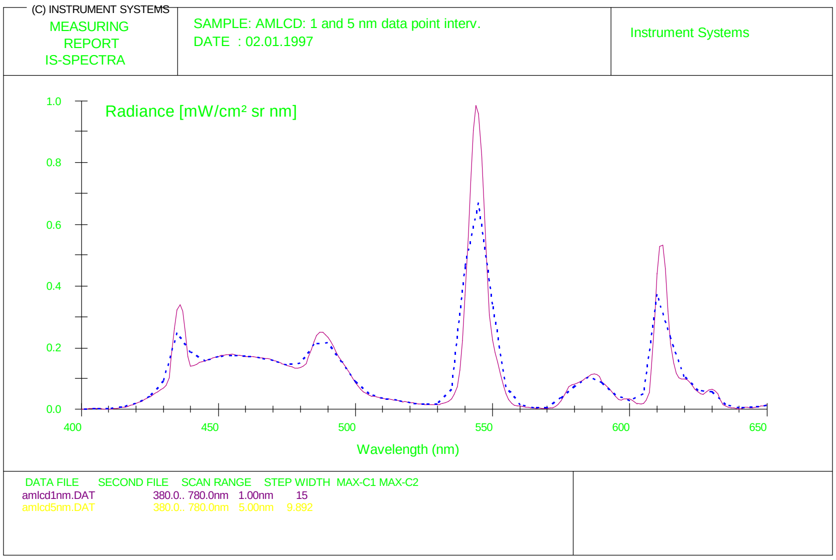
Correct measurement conditions for AMLCDs

Recently, aircraft manufacturers have begun to heavily integrate AMLCDs in new designs as well as in existing aircraft upgrades. AMLCDs, however, require measurement conditions that are in some ways different to what MIL-L-85762A appendix B specifies:

	MIL-L-85762A App. B	AMLCD Requirement
Bandpass	10 nm	2 to 5 nm
Data point interval	5 nm	0.5 to 2 nm

The emission spectrum of AMLCDs is significantly different to conventional filtered incandescent or LED panel light sources. Such a spectrum is smooth, whereas an AMLCD shows characteristic peaks in the spectrum that are caused by the fluorescent backlight.

The hardcopy shows the measurement of an AMLCD at 5 nm and at 1 nm data point interval. The peaks of the spectrum (dashed line) recorded at 5 nm are clipped because 5 nm is too coarse for sampling it. At 1 nm the peaks are sampled correctly.



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MEASURING
REPORT
IS-SPECTRA

SAMPLE: AMLCD: 1 and 5 nm data point interv.
DATE : 02.01.1997

Instrument Systems

DATA FILE	SECOND FILE	SCAN RANGE	STEP WIDTH	MAX-C1 MAX-C2
amlcd1nm.DAT		380.0.. 780.0nm	1.00nm	15
amlcd5nm.DAT		380.0.. 780.0nm	5.00nm	9.892

Spectrum of an AMLCD recorded at 1 and 5 nm resp.

In addition to a smaller data point interval, the bandpass must be less or equal to 5 nm for accurate measurement of luminance and chromaticity. The spectral width of fluorescence peaks is 10 nm typically. A 10 nm bandpass according to the MIL-Spec would broaden the measured spectral width of the peak to about 15 nm. As a consequence, the calculated luminance and chromaticity are compromised. Correct luminance values are important as they are used for scaling the NVIS radiance results.

Another important factor to be considered is the AC operation of flat panel displays. The electronics and the data acquisition software must match these specific conditions to avoid ripple on the measured spectrum, or much longer integration and measuring times.

Conclusion: Recommendations for a modern NVIS spectroradiometer

As NVG technology and applications are expanding, a modern spectroradiometer for NVIS radiance measurement should meet certain requirements that are outlined in the following table:

Parameter	**Specifications**	**Remarks**
Sensitivity	• measurements at 0.1 fL must be possible at larger spot sizes • 1 fL standard for small spot size	most panels are operated as low as 0.1 fL in an aircraft, thus, it is an advantage when the spectroradiometer can perform measurements at this luminance level; 1 fL is good for standard applications
Measurement Time	not more than a couple of minutes	production control makes testing of nearly every panel necessary; measurement time is critical for overall productivity; measurement time should not be longer at smaller data point intervals
Stray Light	10E-5	this is good for all existing applications; new NVG generations might require lower stray light in specific applications
Bandpass	selectable from 1 to 10 nm	AMLCDs make a smaller bandpass necessary; all slits of the monochromator should be changed equally without making a recalibration necessary
Polarization Dependence	< 5%	important for testing of LCD flat panel displays
Telescope	viewing telescope shall have standard camera mounts	most labs have a meter mover or similar positioning stages that currently accommodate luminance meters
Setup	portability and user friendly operation	testing of panels in an aircraft requires portability and robustness of the system; easy handling is required in manufacturing and QC environments

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