New night vision goggle gain definition

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ABSTRACT

A new definition is proposed for the calibration of Night Vision Goggle (NVG) gains. This definition is based on the measurement of radiometric input and output quantities of the NVG. While the old definition used the "equivalent fL" which is a non SI traceable luminance unit, the new definition utilizes the radiance quantities that are traceable to the SI units through NIST standards. The new NVG gain matches the previous one as a result of the application of a correction coefficient originating from the conversion of the radiance to luminance units. The new definition was tested at the NIST Night Vision Calibration Facility and the measurement results were compared to the data obtained with a Hoffman Test Set Model ANV-126. Comparing the radiometric quantities of the Hoffman Test Set and those measured by the NIST transfer standard radiometer, indicates that the observed differences up to 15 % were due to the calibration and experimental errors of the ANV-126 Test Set. In view of different spectral characteristics of luminophores that can be utilized in the NVG design, the simulation of the NVG output for gain measurement was performed. The NVG output was simulated with a sphere-based source using different LEDs and the measured gain was compared to that obtained with the ANV-126 internal luminance meter. The NVG gain uncertainty analysis was performed for the Type A, B, and C goggles.

Keywords: night vision goggle (NVG), NVG radiometric quantities, night sky.

INTRODUCTION

In a simplified approach, the luminance gain of image intensifier based devices may be considered as a ratio of the output luminance to the input luminance[1]. This ratio, however, cannot serve as a gain definition due to significant variations in the input and output photometric quantities. Also, the related response of the human eye covers an intensity range of 5 to 8 orders of magnitude[2] (photopic, mesopic and scotopic vision intervals). Since the night vision goggles (NVG) operate mostly in the near infrared (NIR) range, this approach has an additional problem: the luminance is defined by the $V(\lambda)$ photopic function only for the visible range and the longer wavelength near-IR interval is not covered. On the other hand, both the NVG manufacturing and testing procedures need certain criteria to characterize the NVG gain. The technical solution of the problem was implemented by Hoffman Engineering and this solution is still used for NVG gain calibrations. In this calibration, the fixed-level input radiance of $2.48 \cdot 10^{-10}$ W sr^{-1} cm^{-2} was suggested to be treated as "equivalent luminance" which is a non-SI unit. The value of this "equivalent luminance" was obtained by equalizing the output of NVG when illuminated with either an IR light emitting diode (LED) peaking at ≈800 nm or with a blackbody (BB) source of 2856 K. Accordingly, the (old) NVG gain definition, which is still used in the calibration process, is:

$$\text{Gain (old)} = \text{output luminance / input luminance}, \qquad (1)$$

where the input luminance is assumed to produce the same NVG output[3] as a reference IR-LED radiance of $2.48 \cdot 10^{-10}$ W sr^{-1} cm^{-2}. Approach (1) allowed the characterization of NVG gain by the ratio of the NVG output to the input with a mix of different photometric and radiometric units. The paradox of this approach is that a photometric unit cannot be used in the IR range where the International Commission on Illumination (CIE) $V(\lambda)$ function is not defined. The uncertainty of the non-SI "equivalent luminance" has not been evaluated. In order to exclude the non-SI "equivalent luminance" from the NVG gain measurement, an irradiance ratio based method was suggested[3]. Since irradiance is distance dependent, it can be used for NVG calibrations only if the NVG input and output geometries are fixed during the calibration. However, the input and output geometries can be different at applications compared to calibrations. Conversion of the output irradiance to luminance (as seen by the human eye) would also create further problems and might increase the calibration uncertainties.

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A new NVG gain definition is suggested here based on the input and output radiance quantities:

$$\text{Gain (new)} = K1 \cdot K2 \cdot R2 / R1, \quad (2)$$

where $R1$ is an input radiance, $R2$ is an output radiance and the coefficients $K1$ and $K2$ characterize the radiance spectral features at the NVG input and output, respectively, as discussed below. The coefficients $K1$ and $K2$ are the constants for the same type of NVG. NIST has developed new transfer-standard radiance/luminance meters that can measure the radiance and luminance levels in a wide range down to values lower than required for NVG characterization[4]. The meters also can be used to transfer the NIST luminance and radiance scales to the NVG test-sets used in NVG calibration services.

1. NVG IN A CALIBRATION SETUP

Typical conditions for NVG application and calibration modes are shown in Fig. 1. In the application mode I, the

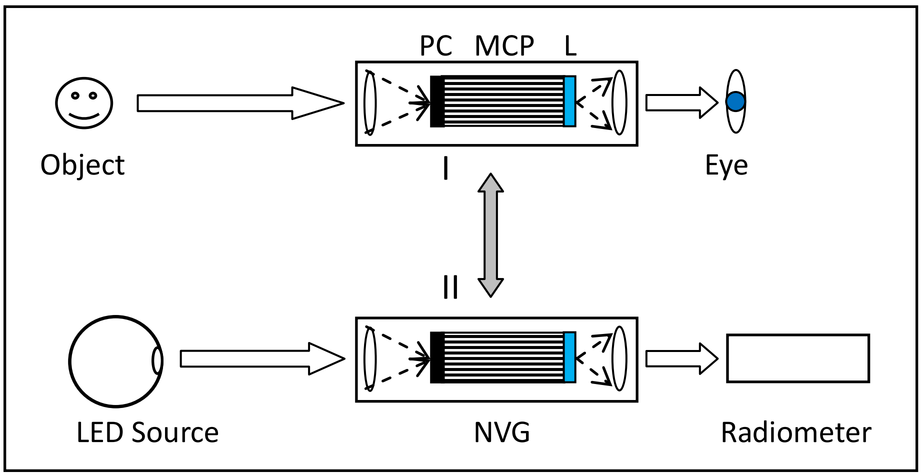

Figure 1. NVG evaluation in field application (I) and at calibration (II). PC - photocathode, MCP - microchannel plate, L – luminophore.

human eye observes the enhanced image of the object illuminated by the sky as a source. The eye estimates the NVG gain as a difference in luminance from the object and from the NVG output screen. To calibrate the NVG gain (in mode II using the new gain definition), the object is replaced by an LED irradiated sphere source of a known output radiance while the NVG output radiance is measured by the radiometer. The new NVG gain definition (Eq. 2) has to satisfy the following conditions:

- The gain must be dimensionless, therefore, the output and input quantities should be expressed in the same units (radiance).
- Gain does not depend on the amplitude of input signal in the wide linear range of the output.
- The definition has to provide the SI traceability for the test-set parameters used for NVG calibration.
- The definition has to account the responsivity curve of the human eye which would be a criterion for the NVG output.
- Certain relation to the old NVG gain definition has to be established for practical purpose since a big number of previously calibrated NVGs are still in use.

Notice that the present definition (Eq. 1) does not satisfy the above conditions.

1.1 NVG output quantities

The output of a NVG is a luminophore screen optimized for the responsivity curve of the human visual system. Usually a phosphor screen, such as P20, P43, P46 and some others, has an output dominantly in the blue-green interval of the visible spectral range. The NVG output radiance may be found from

- the spectral radiance data corrected to the responsivity curve of the eye to reflect a human perception of the

NVG gain. This option 1 is a relatively complicated and time consuming procedure,

- the measured NVG output luminance converted to radiance using the conversion factor of 1/683 W lm^{-1} (option 2).

Besides simplicity, the second method has a few advantages. It accounts for the possible variations in the spectral radiance of the phosphor screen. Also, the presently available test-sets used for NVG calibrations are equipped with a luminance meter, thus a transfer to the new gain definition may be performed by a simple test-set reprogramming without any changes in the hardware.

Both options 1 and 2 can be tested experimentally. In Fig. 2, the normalized spectral radiance of the NVG output is presented together with the CIE standardized $V(\lambda)$ function. The analysis below uses the normalized spectral radiance while the actual spectral irradiance of the screen is about 10^{-12} W cm^{-2} nm^{-1} at the peak. Assuming the same collection angle for relative comparison of radiance and luminance and using the responsivity curve of the human eye, the following output quantities can be found from integration of the normalized curves in Fig. 2:

- the radiance $R = \int_\lambda R(\lambda)\, d\lambda$ is 79.7 W sr^{-1} cm^{-2},
- the effective (photopic) radiance $R_{ph} = \int_\lambda R(\lambda)\, V(\lambda)\, d\lambda$ is 57.5 W sr^{-1} cm^{-2}
- the luminance $L = 683 \int_\lambda R(\lambda)\, V(\lambda)\, d\lambda$ (for the same data) is $3.93 \cdot 10^4$ lm sr^{-1} cm^{-2}

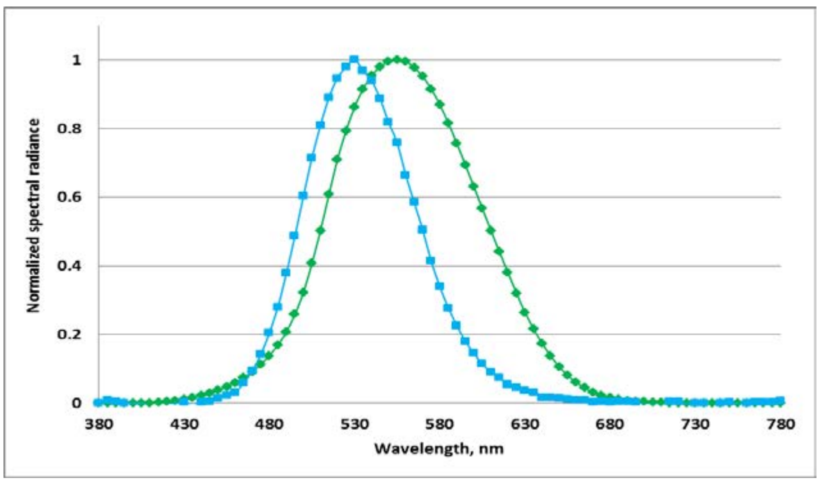

Figure 2. Normalized spectral radiance of the NVG phosphor screen (left curve) and the $V(\lambda)$ function.

Thus, in direct measurements of spectral radiance (using option 1), due to mismatch of spectral characteristics of luminophore and $V(\lambda)$ function, the $K2$ in Eq. 2 would be 57.5/79.7 = 0.72. However, once the $V(\lambda)$ function is accounted for, the photopic radiance would be 57.5 W sr^{-1} cm^{-2}.

In option 2, the luminance of $3.93 \cdot 10^4$ lm sr^{-1} cm^{-2} may be measured directly. Applying the W/lm conversion factor of 1/683, the same photopic radiance of 57.5 W sr^{-1} cm^{-2} will be obtained as from direct spectral radiance measurements in option 1. The coefficient $K2$ in option 2, therefore, will be equal to unity and may be omitted in the Eq. 2.

1.2 NVG input quantities

In the calibration setup, the radiation of the IR LED at the sphere output port is considered as an input of NVG. The spectral range of LED is located within the response interval of the NVG, usually at ~820 nm. While for a calibration test-set the LED source is much more convenient than a BB, there is a certain calibration inconsistency with the field applications where the distribution of the illuminating source is a continuous spectrum (night sky). The LED was chosen in the near-IR range to be within the photocathode responsivity curves of NVGs to be tested. At present, three types of NVGs with different spectral characteristics are standardized: Type-A, Type-B and Type-C[5]. The relative spectral responses of these NVGs are presented in Fig. 3. As seen, all NVGs have similar spectral characteristics in the upper wavelength range, likely due to the same type photocathode used. The difference at the low wavelength end is due to the long-path filters installed into the NVGs to satisfy the different cockpit lighting compatibility issues[6]. Since the spectral responses of the Type A, B, and C goggles are similar in the spectral range of the test-set LED radiation, the measured ratio of output luminance to LED radiance (old gain definition) will be a constant for different type NVGs. However, in the field application, where the object illumination (from the sky) has a continuous nature, the gain generally should be higher for the NVG with a wider spectral range (Type-A in this case). To comply with this obvious gain estimate, currently the IR LED radiance of $2.48 \cdot 10^{-10}$ W sr^{-1} cm^{-2} is used for calibration of an NVG Type-B only. In Ref. 3, the different setpoints of LED radiance for Type-A and Type-C goggles were suggested so that corresponding adjustment of NVG input will modify the measured gain.

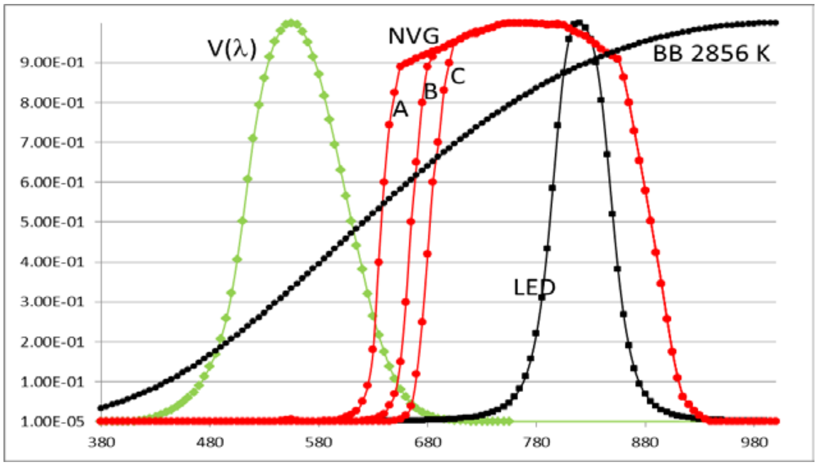

Figure 3. Normalized spectral characteristics of the NVG (A, B and C), *V*(λ) function, black-body at 2856 K and IR LED.

This adjustment is correlating with a change of NVG spectral efficiency within the broadband radiation of a 2856 K BB. Thus, in the old gain definition, the set luminance is not only a non-SI unit but its value changes with the type of the NVG. In the new NVG gain definition it is suggested to account for the NVG spectral response using the coefficient $K1$. In this case, the actual input radiance would not be critical since the measured output will change proportionally to the input. This approach comprises linear output/input NVG gain characteristics.

2. NVG GAIN MEASUREMENTS

2.1 Measurements with ANV-126 Hoffman test set

In this Section, the gain measured by an ANV-126 test set is validated and the verification of the luminance levels at the NVG input and output has been performed using a NIST calibrated new generation night vision radiometer. Due to the application of a filter combination at the front of this transfer standard radiometer (TSR), the spectral radiance responsivity is close to constant between 620 nm and 900 nm. This radiometric response correction is convenient for calibration of LEDs with different peak wavelengths and spectral bandwidths. The radiometric filter combination can be replaced with a photometric filter combination. Using the photometric filter combination, the night vision radiometer can be used as a transfer standard luminance meter[4].

The ANV-126 test set has an LED irradiated sphere source. The peak of the LED is at about 820 nm. The radiance measured by the TSR at both output ports of the test set (the left and right NVG sections) was $2.53 \cdot 10^{-10}$ W sr^{-1} cm^{-2}. This number is close to the required value of $2.48 \cdot 10^{-10}$ W sr^{-1} cm^{-2} used by the ANV-126 test set to calculate the NVG gain. The output of the NVG is measured by the internal pre-calibrated luminance meter of the test set. To verify the internal ANV-126 test set luminance meter readings, additional sphere-based sources were needed. The integrated sphere which was alternately irradiated with a few LEDs operated in the different wavelength ranges (Fig. 4), served to simulate the output of a NVG. There are two reasons to utilize the external sources. During the gain measurements the

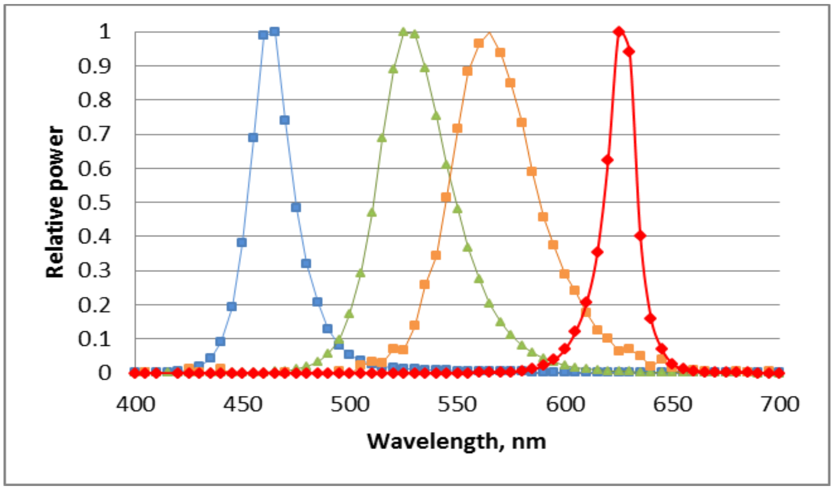

Figure 4. Normalized spectra of the LED-based sphere source.

ANV-126 does not display an actual NVG output luminance. Instead, it directly displays the NVG gain calculated according to Eq. 1. The verification of the internal luminance meter measurement was performed by comparison the gain reading from the test set (using the internal meter) and the gain obtained with a calibrated NIST luminance meter[4]. The second reason to check the ANV-126 internal meter in different wavelength bands was that different NVGs may have various spectral luminophore efficiencies.

The summary of the test results is presented in Table 1. As seen from the last column of Table 1, the NVG gain from the test set is higher than determined by the NIST night vision radiometer. Besides, the differences vary with the source spectrum. This may indicate an error in the calibration of the internal luminance meter of the ANV-126 test set. According to the manufacturer's specification, the calibration of this meter is performed using narrow-band radiation from a green LED.

Table 1. Comparison of NVG gain from test set and NIST luminance data using the old NVG gain definition

Source	Peak WL, nm	Gain ANV-126	Gain NIST data	Gain ratio
1	462	2430	2177	1.1
2	527	2660	2384	1.1
3	626	2360	2063	1.14
4	565	2660	2430	1.09

The next set of the data, as presented in Table 2, shows the comparison of the NVG gain measured using the old definition (Eq. 1) and the output/input radiance ratio required for the new gain definition (the coefficient *K*1 has not been applied yet). As seen, the output/input radiance *ratio* used for gain measurements in the suggested new definition is about five times lower than the *gain* obtained from the output/input luminance *ratio* using the old definition.

Table 2. NVG Output/Input NIST data comparison when using the old and new gain definition.

Source	Peak WL, nm	Out/In luminance ratio (gain_old)	Out/In radiance ratio (for gain_new)	Out/In data ratio
1	462	2177	430	0.2
2	527	2384	471	0.2
3	626	2063	408	0.2
4	565	2430	480	0.2

The reason of the discrepancy is that the artificially defined "equivalent luminance" unit[3] used for the NVG input characterization and a luminance unit used for the NVG output quantity do not match. The calculated luminance from the 2856 K BB resulting in the same NVG output as an LED radiation of $2.482 \cdot 10^{-10}$ W sr^{-1} cm^{-2} is $3.426 \cdot 10^{-8}$ lm sr^{-1} cm^{-2}. Direct conversion of $3.426 \cdot 10^{-8}$ lm sr^{-1} cm^{-2} to its (photopic) radiance results in a value of $3.426 \cdot 10^{-8}/683 = 5.016 \cdot 10^{-11}$ W sr^{-1} cm^{-2}, i.e. 4.95 times lower than the $2.482 \cdot 10^{-10}$ W sr^{-1} cm^{-2} radiance from LED. This ratio makes it reasonable to set the coefficient *K*1 in the new definition to 4.95. Accounting that *K*2 coefficient is a unity for the photopic output measurements, the Eq. 2 (new NVG gain definition) will be

$$\text{Gain} = K \cdot \text{output radiance} / \text{input radiance}, \tag{3}$$

where the coefficient $K = K1$ is applied to equalize the numerical gain values in new and old NVG gain definitions. Notice that the ratio of 4.95 includes contribution of several different parameters: radiation spectral characteristics of a blackbody, and IR LED, spectral response of NVG Type B as well as an input radiance of $2.482 \cdot 10^{-10}$ W sr^{-1} cm^{-2} set for the NVG Type B. The summary of above numerical relations within old and new NVG definitions is presented in Table 3. This Table displays the radiometric quantities corresponding to NVG gain equal to 1000 within both old and new gain definitions.

Table 3. Example of the NVG Output/Input quantities related to NVG-B gain of 1000.

NVG Parameter	Old definition	New definition
INPUT (near-IR LED)	Radiance (2.48 10^{-10} W sr^{-1} cm^{-2}) treated as EQUIVALENT luminance of 10^{-4} non-SI unit	Radiance (2.48 10^{-10} W sr^{-1} cm^{-2})
OUTPUT	Luminance (10^{-1} non-SI unit)	Radiance (5.02 10^{-8} W sr^{-1} cm^{-2})
K	N/A	4.95
GAIN	OUTPUT : INPUT = 1000	*K* x OUTPUT : INPUT = 1000

For NVG type A and C, the coefficient *K* must be adjusted according to the change in the NVG spectral response. Instead of adjusting the output LED radiance[3] as mentioned in Section 1.2 within the new NVG gain definition, we suggest to set the coefficient *K* equal to 5.42 and 4.71 for NVGs Type A and C, respectively. In this case, the input radiance will not be critical for gain measurements when assuming a linear response for NVGs. The different values for coefficient *K* are based on the known spectral responses of the Type A and C NVGs, prorated to that of Type B. The K_i coefficients are obtained from the integrated NVG input quantities as follows

$$K_i = \int_\lambda S_i(\lambda)\, N(\lambda)\, d\lambda \,/ \int_\lambda S_B(\lambda)\, N(\lambda)\, d\lambda, \tag{4}$$

where $S_i(\lambda)$ is a normalized (standard) NVG responsivity, index *i* denotes the A- and C-type NVG, $S_B(\lambda)$ is the normalized (standard) responsivity of NVG Type B, and $N(\lambda)$ is the spectral radiance of the 2856 K blackbody. The blackbody $N(\lambda)$ spectral radiance was used to comply with a BB to LED gain balance used in old definition. In Ref. 7, a similar procedure was suggested to describe a correction factor addressing the difference between the individual NVG spectral responsivities.

Notice that in the Hoffman NVG calibration setup only the output quantity (luminance) is measured and then converted to NVG gain. The input ($2.48 \cdot 10^{-10}$ W sr^{-1} cm^{-2}) is set at calibration. Thus, an alternative option to prorate the measured gain for different type of NVGs may be the adjustment of input as suggested in Ref. 3 and using the same *K* coefficient (4.95). In this case, the input radiance should be set to $2.68 \cdot 10^{-10}$ W sr^{-1} cm^{-2} and $2.33 \cdot 10^{-10}$ W sr^{-1} cm^{-2} for NVG Type A and C, respectively, to obtain the same NVG gain as with utilization of different *K* coefficients and a fixed radiance of $2.48 \cdot 10^{-10}$ W sr^{-1} cm^{-2}.

2.2 NVG gain measurements at the NIST night vision calibration facility

Input and output quantities of a 4th generation NVG (Model ANT PS-15) were measured with a TSR to evaluate the new NVG gain definition. The NVG measured the radiance of several sphere sources irradiated by four different LEDs. The two red LEDs had 630 nm and 690 nm peaks and the near-IR LEDs peaked at 810 nm and 820 nm. In these spectral ranges the TSRs had nearly constant responsivity. While exact spectral response of the NVG ANT PS-15 was not known, the assumption was an effective spectral match of the NVG response and the above LED spectral distributions for the gain measurements. A GaAs photocathode used in the NVG ANT PS-15 is known to cover even a wider spectral range than the wavelength coverage of the four LEDs. The NVG input radiance was measured directly with the TSR while the output NVG (photopic) radiance was found from luminance measurements with the TSR as described in Section 2.1. For better statistics, the left (L) and right (R) sections of the NVG were evaluated independently. The summary of the results is shown in Table 4. Because of the unknown spectral responsivity of the tested NVG (ANT PS-15), its gain in Table 4 is shown as a product of the found output/input radiance ratio multiplied by the coefficient *K* according to Eq. 3. The coefficient *K* depends on the spectral shape of both the NVG response and the LED output. If these two parameters are known, the coefficient *K* may be found by comparison of the tested NVG to NVG type B as indicated in Eq. 4. Notice that all *K* coefficients in Table 4 may be different as they relate to different LED wavelength range. Ideally, the variation of the output/input radiance ratio has to be compensated by the coefficients *K* to obtain the same NVG gain.

Table 4. NVG input and output radiometric quantities measured with four different LED sources.

NVG section	LED Peak, nm	In radiance, W sr^{-1} cm^{-2}	Out radiance*, W sr^{-1} cm^{-2}	Out/In ratio	Gain (new)
L	630	2.00E-10	1.66E-7	832	832x*K*
R	630	2.13E-10	1.76E-7	828	828x*K*
L	690	1.86E-10	1.62E-7	875	875x*K*
R	690	1.86E-10	1.66E-7	893	893x*K*
L	810	3.85E-11	3.37E-8	876	876x*K*
R	810	3.85E-11	3.34E-8	869	869x*K*
L	820	2.00E-10	1.65E-7	827	827x*K*
R	820	2.00E-10	1.62E-7	812	812x*K*

*from luminance measurements: photopic radiance (W sr^{-1} cm^{-2}) = luminance (lm sr^{-1} cm^{-2})/683

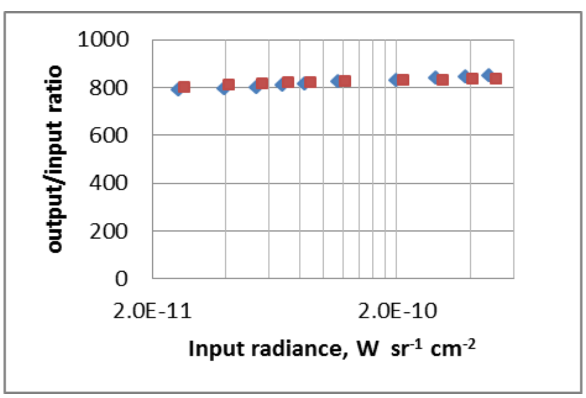

Figure 5. NVG output to input radiance ratio versus the input radiance.

Another factor that can affect the measured gain is a possible nonlinearity of the NVG gain characteristic. Nonlinearity may appear not only due to a charge saturation effect in the NVG image intensifier but also due to the automatic gain control (AGC). The AGC usually reduces the NVG gain at a higher input radiation to prevent the NVG from damage.

Experimental results that demonstrate the linearity of the NVG gain characteristic are presented in Fig. 5. It was found that in the range of the input radiance between 10^{-11} W sr^{-1} cm^{-2} and 10^{-9} W sr^{-1} cm^{-2} where the gain measurements were performed, the NVG output may be considered as a linear function of its input signal within the uncertainty of the experiment.

3. NVG IN THE FIELD APPLICATIONS

Unlike in the calibration procedure, where the NVG gain is measured using IR radiation but is referenced to blackbody radiation, in field NVG applications the NVG input is a broad band radiation from the no-moon night sky. The 2856 K BB is a standard radiation source, however, its spectral distribution is different than the distribution of the no-moon night sky. While the spectral shape of the BB radiation is very well established, the radiation of a night sky may vary in both the radiance level and the spectral radiance depending on the particular conditions - observation place, time, fog, and rain. Besides, the actual radiation at the NVG input depends also on the optical properties of the monitored object, i.e. absorption, reflection, and scattering. Thus because of the difference in the spectral distribution of the BB and night sky radiation, certain uncertainties in the NVG gain may be expected although unlikely may be evaluated by human vision. The related uncertainty estimation may be provided by comparing the contribution of a particular spectrum to the NVG input. To take all of these conditions into consideration would be impractical. However, in a simplified approach, ignoring the above conditions, Eq. 4 may be applied for estimation of the gain correction factors[7]. The comparison of the spectral shapes of no-moon night sky radiation is presented in Fig. 6. The night sky spectral radiance is presented as an average of about 200 experimentally recorded spectra[8]. A similar spectral distribution of the night-sky spectral irradiance was taken from Ref. 9. The normalization of both spectra was performed so that a minimum mismatch in the spectral range of a NVG type B efficiency (570 nm to 930 nm) would be observed. Using the experimental distributions presented in Fig.6, it is possible to estimate the gain correction factors for the NVG output caused by a difference in the spectral distribution of BB and no-moon night sky radiance. Applying the same integrating procedure as in case of a BB radiation (paragraph 1.2) and using the night sky spectral distributions shown in Fig. 6, the source correction factors prorated to those of BB were obtained (Table 5). Because no standard for

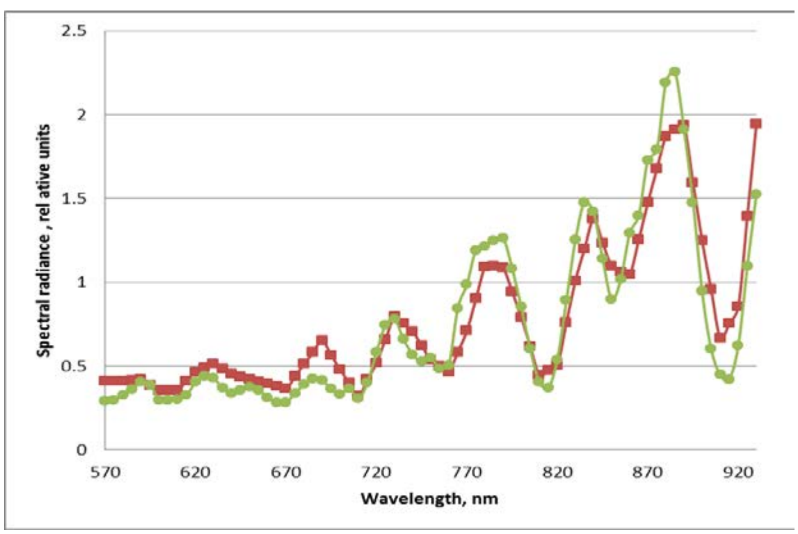

Figure 6. Normalized spectra of the no-moon night sky spectral radiance (round markers) and spectral irradiance.

NVG gain under night sky illumination exist, the gain of the NVG type B and also the 2856 K blackbody spectrum were chosen as reference. Accordingly, Table 5 was compiled assuming no errors for NVG type B due to either BB or night sky spectral radiance, i.e. the coefficient K remains the same. As seen from Table 5, the error due to the specific shape of the night sky radiation spectrum is under a few percent. This may be a small value compared to the effect of the above simplified approach to actual spectrum emitted by the monitored object. However, this estimate still provides the idea on how the illumination spectrum may affect the gain defined in the calibration procedure. Notice that the difference in the NVG gain of few percent is relatively small for absolute evaluation by human vision without a proper reference.

Table 5. Correction factors and estimated errors for NVG gain definition in field applications.

Input data	source correction Factor			Error, %		
NVG type	A	B	C	A	B	C
Sky spectral irradiance	5.25	4.95	4.72	-3.2	0	0.3
Sky spectral radiance	5.2	4.95	4.8	-4.1	0	1.9
BB 2856 K spectral radiance	5.42	4.95	4.71	0	0	0

4. UNCERTAINTY ANALYSES

The uncertainty components of the NVG gain calibration are discussed here. The basic components of the uncertainty may be due to the difference in the LED spectral characteristics, the variation in the spectral responses of the same type of NVGs and the measurement errors of both the input and output radiometric quantities.

Although the spectral peaks of the LEDs are located within the NVG response function close to its maximum, both the LED peak position and its FWHM spectral width still will affect the measured gain even if the output radiance is measured correctly. Usually, the calibration test sets are equipped with an LED that peaks at ~820 nm. The LED-related uncertainty components for the B-type NVGs were calculated from the variation of the integral quantity $\int_\lambda S_B(\lambda) L(\lambda)\, d\lambda$, where $S_B(\lambda)$ (normalized NVG type B spectral response) is a constant while the $L(\lambda)$ (LED parameter) is varied. At this assumption, a 10-nm shift is in the LED peak position and a10 %-variation is in the FWHM of the 820-nm LED (used in the Hoffman test set). These estimates provide the uncertainty components which are caused by practically possible variations of the LED parameters. These two uncertainty components are shown in the first two rows of Table 6. The spectral response of the same type of NVG is affected by several factors contributing to the NVG

Table 6. Uncertainty budget for type B NVG gain measurements, %.

#	Component	Standard uncertainty $(k = 1)$	Expanded uncertainty $(k = 2)$
1	LED peak position	1.2	
2	LED FWHM	0.1	
3	NVG spectral response	2.5	
4	Input radiance	1.5	
5	Output radiance	0.7	
	Combined uncertainty	3.0	6.0

input spectral characteristics. The actual variation of these characteristics is defined in the factory issued list of technical performances. Because of a limited spectral range of the LED radiation, the unknown variation in the NVG spectral response may not be detected during calibration. Thus, the related uncertainty component presented in the 3rd row of Table 6 is based on the 30 nm-spread of the spectral coverage for a NVG[5] and 2856 K BB radiation. The remaining uncertainty components are related to measurements of input and output NVG quantities. These numbers are known from the performance of the radiometers and photometers used in the calibration. In Table 6, the related uncertainty component is based on the performance of the NIST transfer standard NV meter[4].

The field-related corrections for NVG gain, considered in Paragraph 3, do not contribute to the uncertainty of the NVG gain calibration process but can be additionally estimated for the evaluation in the field applications.

CONCLUSIONS

A new definition for night vision goggle gain calibration using SI traceable radiometric units is suggested and evaluated. Unlike in the old definition, the gain now is dimensionless, and it does not depend on the amplitude of the input signal within the linear model. Also, the new definition takes the responsivity of the human eye into consideration. The definition is based on the output radiance to input radiance ratio that will be used for the NVG gain calibration. While the straight ratio of the output to input radiometric quantities in the new definition is about 5 times lower than the gain in the old definition, the implemented gain correction coefficient in the new definition makes both gain values about the same. This correction coefficient is needed exclusively because of the artificial unit, called "equivalent luminance" introduced in the old definition.

The development and evaluation of the new definition includes direct measurements of the input and output radiometric quantities for a 4th generation NVG (ANT PS-15). This NVG has a filmless GaAs photocathode and a green phosphor screen. In order to take the spectral characteristics of different luminophores used in the different NVG designs into consideration, the simulation of the NVG output for the gain measurement was performed with different sphere-based LED sources. In this configuration, also the comparison of the gain data from the Hoffman ANV-126-A test set and the data from NIST transfer standard radiometers was performed. The simulated output was measured by the NIST radiometer in both radiance and luminance measurement modes. Different spectral characteristics of the goggle output were studied to characterize the band weighted radiance (photopic radiance or luminance) needed for gain measurements within the new definition. The obtained data including the spectral mismatch of the NVG output screen radiation and the CIE photopic function (Y-bar) indicate the equivalence of photopic radiance found with either the spectral radiance meter or the luminance meter.

The analysis of about 200 spectra of the field night sky (no-moon) radiance spectra[8] was performed. It was shown that related (measured) spectral radiance is a main factor in the difference between calibrated with the LED source NVG gain and the night-sky produced (but not calibrated) NVG gain. The uncertainty analysis provided accounts for the different spectral response of the NVGs of types A, B and C.

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Disclaimer: c*ertain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by NIST, nor does imply that the equipment are necessarily the best available for the purpose.*

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