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Electrooptical Evaluation Techniques of Image Intensifier Tubes – Part I

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ABSTRACT

Passive night vision devices are used for viewing the military targets at low light levels of illuminations during night. In these passive night vision devices, image intensifier tubes are used to amplify scene imagery. The performance of these tubes depends upon electrooptical parameters. The techniques of evaluating these parameters, eg, luminous gain, automatic rightness control and maximum screen luminance, photocathode sensitivity, radiant gain, equivalent background illumination, magnification and distortion, signal-to-noise ratio, veiling glare, screen brightness variation, etc. have been described.

Keywords: Passive night vision devices, night vision devices, image intensifier tubes, electrooptical devices, electrooptical tubes, photocathodes, *GaAs* photocathode, equivalent background illumination

1. INTRODUCTION

The heart of a passive night vision is an image intensifier tube. These image intensifier tubes are electrooptical devices and can be used effectively at extremely low levels of illuminations, where eye has its own limitations. The basic limitations of a human eye are its acuity, sensitivity, low quantum efficiency and level of illumination at the retina. In the day light, optical instrument forms a magnified image of the object which subtends an angle larger than 2 min of an arc, and hence, comes within the scope of human eye vision. The problem of seeing in the dark is due to insufficient light and the spectral distribution not compatible with the human eye response. Sensitivity of the human eye lies between 400 nm to 700 nm with maximum acuity at around 555 nm in green-yellow region of the spectrum. This matches with the peak of sun's radiation, and hence, eye has the best resolution during the day time . Moreover, the level of illumination during the night is extremely low, and is further degraded because of low quantum efficiency of the human eye, and so it does not stimulate visual sensation. Electrooptical tubes have been developed to enhance the capabilities of the human eye by amplification of the scene illumination, enhancing quantum efficiency, and extending their sensitivity in the near-infrared region as night illumination is more rich in the infrared region than in the visible region.

In the passive night vision systems, the target is illuminated by natural sources of low light levels, ie, moon and stars. The image intensifier tubes are used to amplify the low light level scene illumination to facilitate clear vision under the conditions of total darkness. These image intensifier tubes employ photocathode having S-25 response, which is close enough to night sky illumination. Using a good objective lens, the amount of light reaching the photocathode of an image intensifier tube, when

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scene is illuminated by overcast starlight ($Ea = 10^{-4}$ lux), will be approx. 2×10^{-6} lux, which can be calculated by the following formula:

$$Epc = \frac{Ea.r.t}{4fn^2}$$

where r is the target reflectivity, t is the OG transmission, and fn is the f number.

The image intensifier tube amplifies this extremely low light illumination to a level which can be detected by the human eye. For evaluation of various types of image intensifier tubes, MIL(US) and DEF STAN (UK) specifications[1,2] have been used. Test conditions have been specified briefly in these specifications for evaluation of various electrooptical parameters of image intensifier tubes, but details of test setups have not been specified. Besides, readymade test equipment are not available in the world market, hence, the users have to develop their own test facilities for testing various electrooptical parameters of image intensifier tubes. In the present paper, evaluation techniques for the measurement of some of the important parameters like luminous gain, automatic brightness control and maximum screen luminance, photocathode sensitivity, radiant gain, equivalent background illumination, magnification and distortion, signal-to-noise ratio, veiling glare, screen brightness variation have been described. For these measurements, low levels of illumination can be simulated in the laboratory using an integrating sphere coated inside by Kodak white reflectance paint.

2. LUMINOUS GAIN

During the night, ambient light from the moon or the stars that falls on the targets, is reflected and received by the instrument and a very faint image of the target is formed at the photocathode of the image intensifier tube. This faint image is then amplified by the image intensifier tube in a night vision device. For passive night vision devices used for driving purposes, luminous gain (lm/lm) of about 18000-25000 is essential, and for target acquisition and for surveillance instruments, luminous gain of about 35000-50000 is essential. This can be achieved using various types of image intensifier tubes like electrostatic inverter-type 25 mm second-generation image intensifier tubes, super generation image intensifier tubes, 50/40 second-generation image intensifier tubes, and 18 mm proximity focused image intensifier tubes, etc.

The luminous gain[3,4] is defined as the ratio of luminance emittance in apostilb(lm/m^2) of the phosphor screen to the input illumination in lux (lm/m^2). The luminous gain is measured on a setup shown in the Fig. 1. For this measurement, low light levels, up to 10^{-4} lux are required to be created in a dark chamber as shown in the figure. In the dark chamber, a number of baffles have been provided to minimise the stray light and it is coated inside with dull black paint. The required input illumination can be created by adjusting the iris diaphragm and the distance between the source and the integrating sphere. The colour-temperature of 12 W tungsten halogen source with integrating sphere is adjusted to 2856 K ± 50 K at the output of the integrating

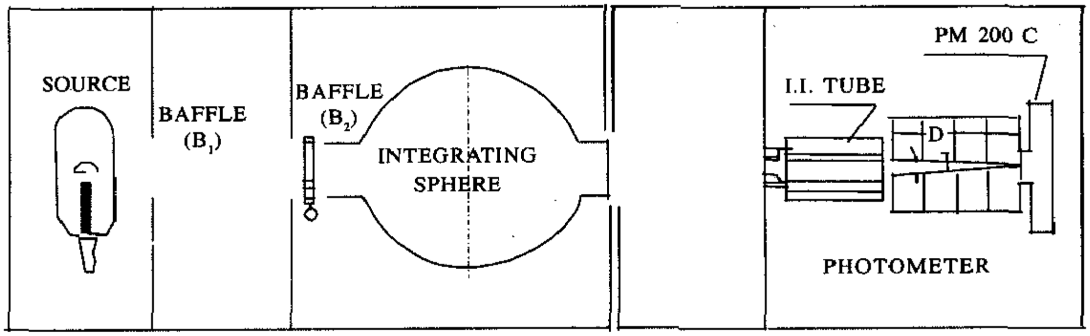

Figure 1. Measurement of luminous gain (1.1. tube)

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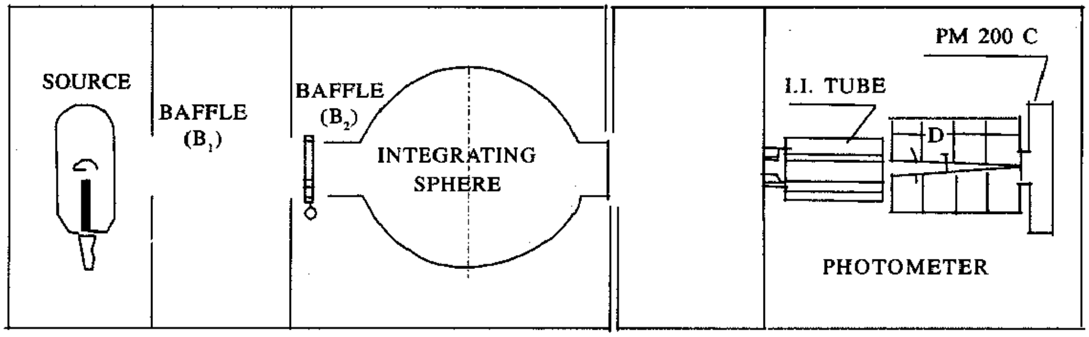

Figure 1. Measurement of luminous gain (1.1. tube)

sphere and measured by a Pritchard photometer 1980-A.

The image intensifier tube is placed on an appropriate mount as shown in the figure and the photocathode of the image intensifier tube is exposed to 10^{-4} lux illumination level, which is measured by a calibrated IL-700 research photometer using PM 200C or equivalent photomultiplier tube fitted with a photopic filter. The amplified light, ie, screen luminance is measured using Pritchard photometer 1980-A or a luminance barrel with 2° or less acceptance angle. Knowing the input illumination in lux and the screen luminance in apostilb, the luminous gain, G can be calculated as follows:

$$G = \frac{\text{Screen luminance}}{\text{Input illumination}} = \frac{L}{E_i}$$

3. MAXIMUM SCREEN LUMINANCE & AUTOMATIC BRIGHTNESS CONTROL

Using the same experimental setup (Fig. 1), maximum screen luminance and automatic brightness control characteristics (Fig. 2) can also be determined. The input illumination is varied from 10^{-3} lux to 10^{2} lux and the corresponding screen luminance is measured. By plotting the screen luminance in foot lambert (ft.L) against input illumination in lux (lx), maximum screen luminance and automatic brightness control characteristics can be obtained. The input current can also be measured at different illumination levels, which gives an idea of battery drainage as it depends upon current drawn by the image intensifier tube during the operation.

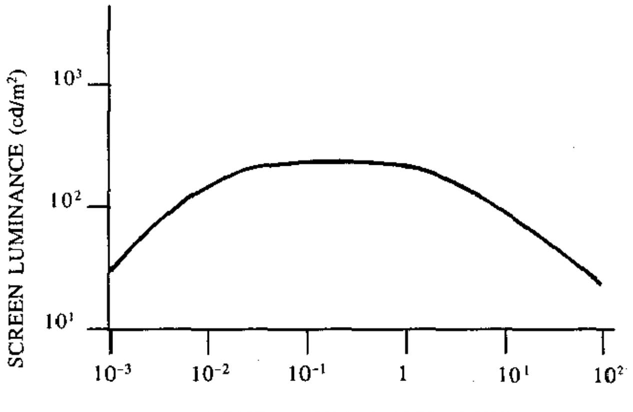

Figure 2. Automatic brightness control characteristics

4. PHOTOCATHODE SENSITIVITY

The performance of an image intensifier tube mainly depends upon photocathode luminous and radiant sensitivities[4,5], phosphor efficiency, and applied voltage. The phosphor efficiency and applied voltage cannot be increased beyond a certain limit. Hence, only photocathode efficiency can be improved upon to enhance the performance of an image intensifier tube. By improving the radiant sensitivity, more information can be extracted from the night scene. As can be seen from the Fig. 3, starlight is more rich in the near-infrared region and also reflectivity of green vegetation is more in the near-infrared region as compared to the visible region. Keeping this in view, considerable efforts have been made to improve the quantum efficiency in the near-infrared region, which has led to the development of third-generation image intensifier tubes using *GaAs* photocathode and super generation image intensifier tubes using high sensitive tri-alkali photocathode. The photocathode luminous and radiant sensitivities of these image intensifier tubes is quite high compared to S-25 photocathode used in second-generation image intensifier tubes. The typical response of

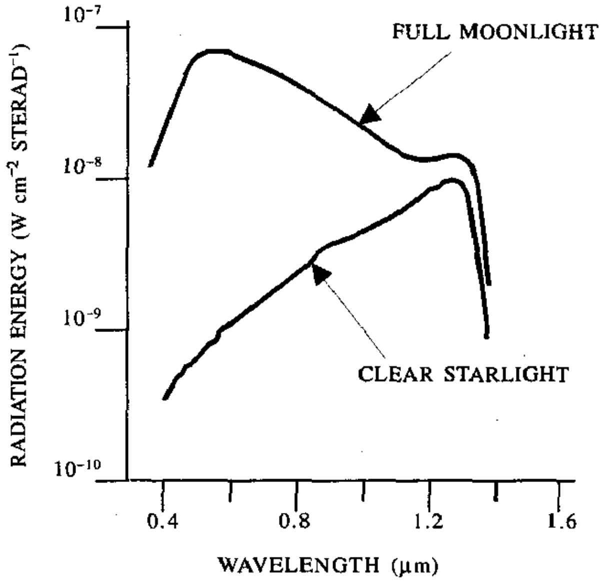

Figure 3. Starlight and moonlight characteristics

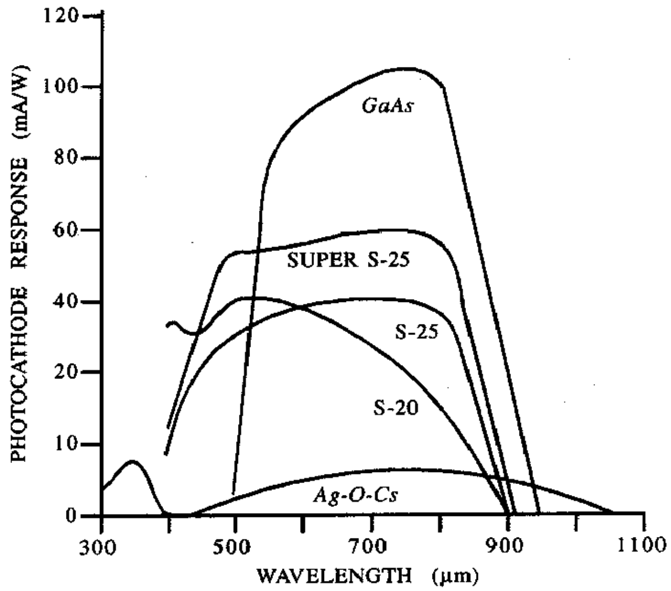

Figure 4. Comparison between the spectral sensitivities of S-20, S-25, Super S-25, *Ag-O-Cs*, and *GaAs*.

S-25 photocathode, *GaAs* photocathode, and super generation photocathode are shown in the Fig. 4.

The luminous sensitivity is measured in A/lm by measuring the photocathode current for 1 lumen incident flux on photocathode at 2856 K. Similarly, the radiant sensitivity is measured in mA/W by measuring the photocathode current for 1 watt incident flux at 800 nm, 850 nm, and 900 nm on a setup shown in the Fig. 5. These measurements can only be made on an image intensifier tube prior to coupling the high voltage oscillator multiplier assembly. Hence, these measurements are only possible in the manufacturer's premises. To verify the claims of the firms, radiant gain may be measured.

5. RADIANT GAIN

The radiant gain can be measured on the setup as shown in the Fig. 1 using a flat response EG&G radiometer and Pritchard photometer 1980-A, and a set of interference filters of 800 nm, 850 nm, and 900 nm wavelength. The 800 nm interference filter is mounted on the filter mount. The distance between the source and the integrating sphere, and iris diaphragm aperture are adjusted to get irradiance $1-3 \times 10^{-4}\ \mu W/cm^2$, which can be measured using EG&G radiometer and the corresponding screen luminance are measured using Pritchard photometer-1980 A. The 800 nm filter is then replaced by interference filters of 850 nm and 900 nm and again input irradiance $1-3 \times 10^{-4}\ \mu W/cm^2$ are adjusted at these wavelengths and the corresponding screen luminance is recorded. The ratio of screen luminance in lamberts (lm/ cm^2) to the input irradiance at 800 nm/850 nm/900 nm in W/cm^2 is the measure of radiant gain in lm/W at these wavelengths.

6. EQUIVALENT BACKGROUND ILLUMINATION

Background noise is expressed in terms of equivalent background illumination[3,4], which is the input illumination required to give an increase in screen luminance equivalent to the background luminance. With input voltage applied and no illumination incident on photocathode, the screen will have a finite background luminance, which may be caused by thermonic emission of the photocathode, electron or ion scintillations. The equivalent background illumination can be measured on a setup as shown in the Fig. 6. For this measurement, three observations

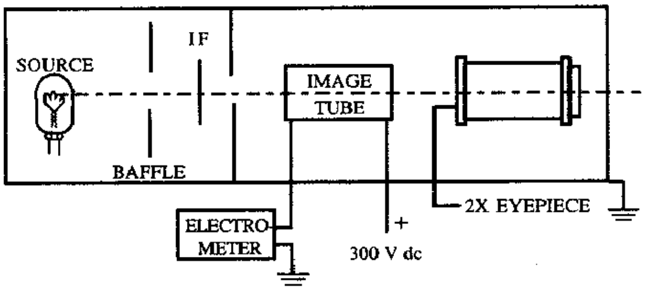

Figure 5. Photocathode sensitivity (image tubes)

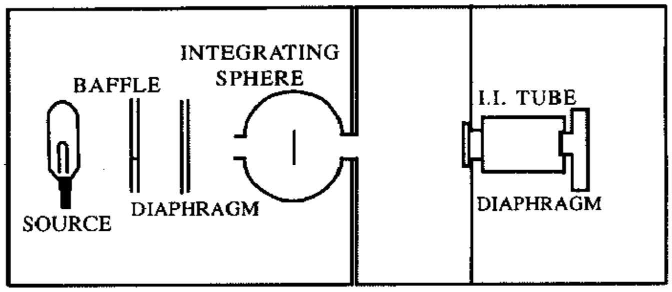

Figure 6. Measurement of equivalent background illumination (image intensifier tube).

Table 1. Set of data recorded to show the effect of rise in temperature on the equivalent background illumination (EBI)

Temperature (° C)	EBI (μ lux)
25.7	0.123
27.7	0.160
30.0	0.210
32.0	0.260
35.1	0.500
40.2	1.120
43.7	1.870

are taken, ie, I_1, I_2, I_3 and the equivalent background illumination measured are as illustrated below:

$$EBI = \frac{I_2 - I_1}{I_3 - I_4} \times \text{Input illumination}$$

where input illumination is the 0.20 μ lux, I_1 is the dark current of PM 200 C (source and image intensifier tube OFF), I_2 is the current due to background luminance of image intensifier tube and dark current of PM 200 C (source OFF and image intensifier tube ON), and I_3 is the current due to screen luminance (source and image intensifier tube ON).

The effect of temperature on equivalent background illumination has been studied and it has been found that equivalent background illumination increases with rise in the temperature and with the rise of every 5 °C, equivalent background illumination becomes double. A set of data recorded is shown in the Table 1.

7. MAGNIFICATION & DISTORTION

Magnification and distortion in electrostatically focused image tube influence resolution, image alignment, and gain, and hence are very important parameters to measure. Magnification can be measured on a setup as shown in the Fig. 7. Magnification varies from centre-to-edge, and hence, causes pincushion distortion. For measuring magnification, a raticle when projected by a camera lens on the photocathode yields lines spaced 1 mm apart. The magnification can be calculated by measuring the object size at photocathode and image size at the screen using a travelling microscope. The distortion, D can be calculated by

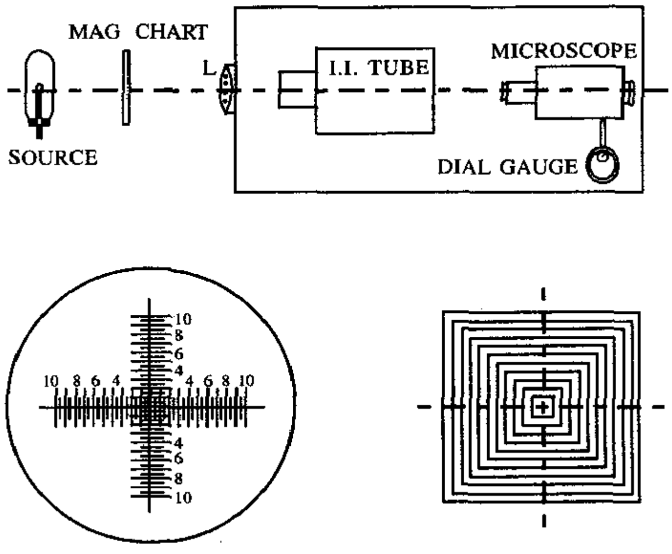

Figure 7. Measurement of magnification and percentage distortion.

$$D \text{ percentage} = \frac{M_x - M_c}{M_c} \times 100$$

where M_c and M_x are the magnification at the centre and at x mm displacement from the centre, respectively.

8. SIGNAL-TO-NOISE RATIO

The signal-to-noise ratio is measured on a setup shown in the Fig. 8. A circular spot of 200 μm (0.200 mm) diameter is imaged on to the photocathode of image intensifier tube using the lens L_1. The circular spot uniformly illuminates the photocathode with 1.2×10^{-6} ft cd. The intense image of circular spot is formed at the phosphor screen and this spot is focused on a pin hole of 200 ± 50 μm (0.200 ± 0.050 mm) diameter using the lens L_2. The pin hole is aligned to obtain maximum signal using two micrometer positioners (not shown in the diagram) mounted at right angles to each other. A low, dark current photomultiplier tube is placed just behind the pin hole. The ac and dc components of light (ie, signal output and noise) are recorded using suitable electronic system

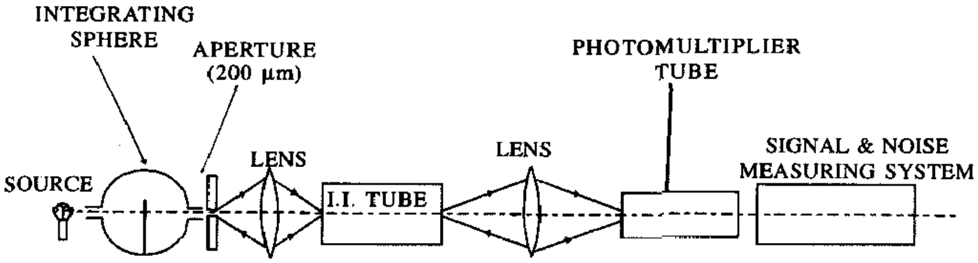

Figure 8. Signal-to-noise measuring test setup

over an electronic bandwidth of 10 Hz and a dedicated computer. The signal-to-noise is the ratio of the dc signal to the rms noise as shown below

$$S/N = \frac{(So - Sbkd)}{K\sqrt{(No^2 - Nbkd^2)}}$$

where K is the phosphor correction factor to obtain S/N over an equivalent bandwidth at 10 Hz ($K = 1.19$ for P-20 phosphor), S is the dc signal, N is the rms noise, So is the signal output with input illumination, and $Sbkd$ is the background signal without input illumination.

The signal-to-noise ratio is measured in a light-shielded area as slight ambient light can give the false signal.

9. VEILING GLARE

As experienced in an optical system, veiling glare is also present in the image intensifier tubes. This is one of the factors responsible for the degradation of image contrast as well as its quality. There are mainly two types of veiling glares in the image intensifier tubes, namely optical veiling glare and electron veiling glare. Although this test is not specified in MIL specifications of image intensifier tubes, it is essential to evaluate veiling glare index of an image intensifier tube as it affects its performance. To overcome this problem, though some measures are being taken by the tube manufacturers, but veiling glare cannot be completely eliminated in image intensifier tubes incorporating microchannel plates. The veiling glare can also be called nearly-zero frequency M.T.F., ie, M.T.F. at 0.1 to 1 LP/ mm frequency. The veiling glare can be measured using a novel concept of Half-Moon method. The half portion (semicircular) of the photocathode of image intensifier tube is covered with a black strip of paper with the dividing line along any diameter and the screen is fully covered with another black paper with a 2 mm rectangular aperture at the centre. By this arrangement, screen will be seen as in the Fig. 9. The photocathode is uniformly illuminated with 5×10^{-5} ft cd by means of a suitable photometer like Pritchard photometer 1980-A, luminance in 1 mm aperture is recorded at two points situated at 1/6 of the screen diameter on each side of the boundary between the illuminated and the non-illuminated halves. The veiling glare may be calculated as follows:

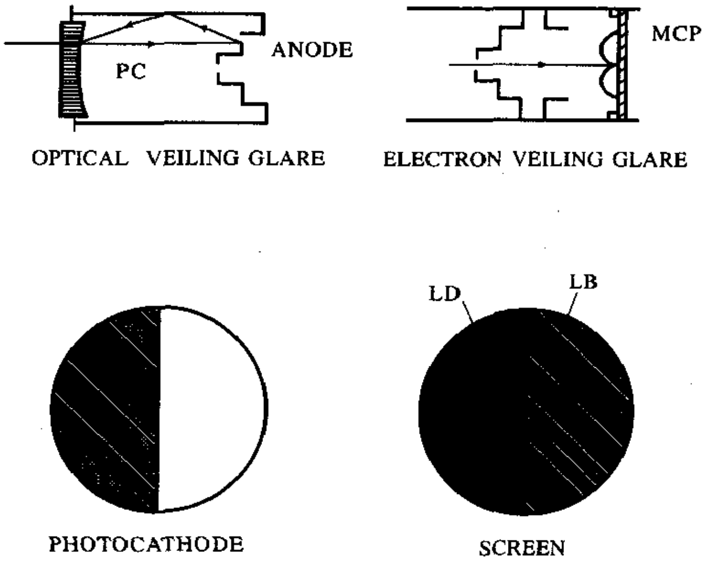

Figure 9. Veiling glare measurement

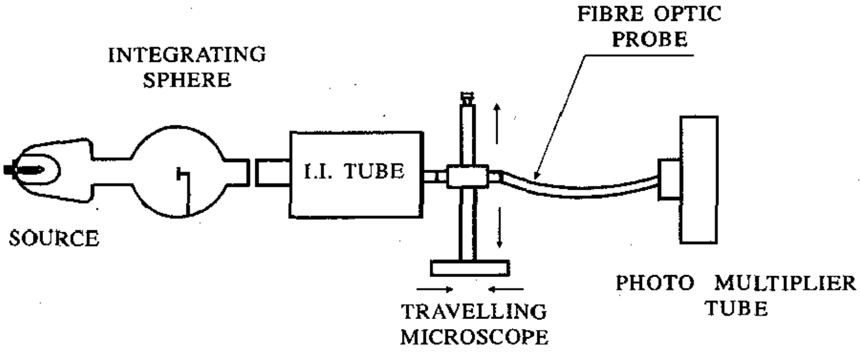

Figure 10. Measurement of screen brightness variation

$$\begin{pmatrix}\text{Veiling glare} \\ \text{percentage}\end{pmatrix} = \frac{\begin{array}{c}\text{Screen luminance} \\ \text{in dark zone}\end{array}}{\begin{array}{c}\text{Screen luminance} \\ \text{in bright zone}\end{array}} \times 100$$

10. SCREEN BRIGHTNESS VARIATION

The screen brightness variation is an unwarranted evil which cannot be avoided taking into considering the geometry of the image intensifier tube. In electrostatically focused image intensifier tubes, the electron lens normally introduces a small amount of distortion into the image. This is caused by the variation in magnification across the diameter of the device and is normally seen as pincushion effect. In proximity-focused image intensifier tubes, magnification throughout is unity and there is no distortion in such image intensifier tubes. However, tube manufacturers have succeeded in reducing the variation in the ratio 1:4 in the first-generation image intensifier tubes and in the ratio 1:2 in the second-generation image intensifier tubes.

To measure this, photocathode is uniformly illuminated by an integrating sphere arrangement as shown in the Fig. 10. A fibre bundle attached with a photomultiplier tube is used to scan the screen brightness from the centre to the edge.

11. RESULTS & CONCLUSIONS

The test setups described are simple, inexpensive, and can be easily rigged up in the laboratory. These setups are in regular use in the laboratory for evaluation of various types of image intensifier tubes, eg, first-generation, electrostatic inverter-type and proximity-focussed second-generation, and super generation image intensifier tubes. The experimental measurement results of luminous gain, radiant gain, equivalent background illumination, signal-to-noise ratio, and veiling glare are given in the Tables 2 and 3. The test data measured on these setups help in assessing the usefulness of the second-generation image intensifier tubes used in passive night vision devices. It is relevant to point out that the accuracy of measurement of

Table 2. Luminous gain and equivalent background illumination (EBI)

I-GEN. tube No. MULLARD	Gain		II-GEN. tube No. VARO	Equivalent background illumination	
	Claimed	Measured		Claimed at 23 °C (μLux)	Measured at 25 °C (μ Lux)
74618	76 K	76.5 K	139918	0.041	0.06
74624	82 K	83.5 K	143521	0.045	0.065
74752	70 K	72.5 K	149422	0.081	0.107
74754	78 K	79 K	150479	0.161	0.15
74756	114 K	109 K	201019	0.179	0.165

Table 3. Veiling glare and signal-to-noise ratio

I-Gen. tube No.	Veiling glare		II-Gen. tube No.	S/N Ratio	
	Claimed	Measured		Claimed	Measured
139918	-	3.92	02944224	6.41	6.28
143521	-	3.46	02942424	7.10	6.22
149422	-	3.81	00214188	6.90	6.20
150479	-	3.30	00214147	6.70	6.10
201019	-	3.00	99981850	5.70	5.10

luminous gain, equivalent background illumination, photocathode sensitivity, and signal-to-noise ratio depends upon the calibration accuracy of the photodetector used for the measurement. Hence, it is essential to calibrate photodetectors periodically against working standards like luminance standard LS-65, illuminance and colour-temperature standards.

For the measurement of screen luminance for luminous gain, two methods have been proposed, ie, using luminance barrel method and Pritchard photometer 1980-A. The barrel method is very simple and inexpensive.

Equivalent background illumination is an important parameter to assess the range of passive night vision devices in the field conditions. The equivalent background illumination is temperature-dependent and should be measured at the controlled and stipulated temperature. Signal-to-noise ratio is yet another important parameter affecting the performance of a passive night vision device. Equivalent background illumination of an image intensifier tube should be as low as possible, whereas signal-to-noise ratio should be high for a good image intensifier tube.

Table 4. Measured values of radiant gain

	Claimed photocathode sensitivity, (mA/W)		Measured lum. gain	Measured radiant gain (lm/W)		Radiant gain/ lum. gain	
	0.8 µ	0.85 µ		0.8µ	0.85µ	0.8µ	0.85µ
			I-Generation tube No				
211121	20.5	12.5	60 K	5154	3115	85.9	51.9
212020	20.5	14.0	57K	4606	3256	80.8	57.1
205058	26.5	14.9	56K	5795	3191	104	57
205064	18.3	10.9	39.5K	2990	1484	75.7	37.6
			25 mm II-Generation I. I. T				
145820	24.1	18.1	45.2	4573	3351	101	74
209393	26.6	21	46	4770	3592	104	78
209417	26.2	18.3	44.8	4382	2890	98	65
			50/40 II-Generation I.I.T				
17591	15.6	20.7	13	1240	681	79.5	43.7
20180	16	16.1	11	1159	716	72.4	44.8
22683	18.2	15.9	10	1338	784	73.5	43.1

The photocathode luminous and radiant sensitivities can only be measured on the bare image intensifier tubes prior to coupling high voltage power supply. Hence to verify the claims of the manufacturers, a new parameter, called radiant gain has been suggested. It is observed that the ratio of radiant gain and luminous gain gives quite close approximation to the photocathode luminous and radiant sensitivities. The experimental results are given in the Table 4.

It is essential to measure magnification of an image intensifier tube at various distances from the centre. Distortion is more if there is a large difference in the centre and the edge magnifications.

The veiling glare has not been specified in the US MIL specifications of image intensifier tubes. This is one of the important parameters which affects both the image contrast and image quality. It should be incorporated in the US MIL specifications.

Screen brightness variation measurement is essential parameter, specially for cascaded First-generation tubes and electostatic inverter-type tubes. It is not convenient to observe military targets through passive night vision devices if screen brightness variation is more. The method proposed for the evaluation of screen brightness variation is inexpensive and simple in nature compared to complicated method specified in the US MIL specification using spot brightness scanner. The setup can easily be rigged up in the laboratory and measurement time is also less.

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