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Effect of Image Intensifier Tube Equivalent Background Illumination on Range Performance of Passive Night Sight

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ABSTRACT

Effect of increase in equivalent background illumination (EBI) with temperature of second generation (18 mm) proximity focused image intensifier tube on the range performance of a passive night sight has been studied using the image intensifier minimum resolvable contrast model. It has been shown that for ambient temperatures of 40 °C and above, the range performance of sight goes down drastically under low-illumination level due to increase in the EBI. Deterioration in range performance is negligible when ambient illumination is relatively high as in case of clear-starlit condition.

Keywords: Night vision, passive night sight, image intensifier tube, equivalent background illumination

1. INTRODUCTION

Performance of a passive night sight primarily depends on the optical parameters of the image intensifier tube, viz, photocathode sensitivity, luminance gain, MTF, signal-to-noise ratio (S/N) and the equivalent background illumination (EBI). The last parameter, viz., EBI is a measure of photocathode dark current and is normally specified as illumination on the photocathode in microlux of illumination of 2856 K light that is necessary to generate image intensifier (II) tube dark current. The EBI increases rapidly with temperature and can become a significant source of noise when the II tube is at elevated temperature. Tube manufacturers normally specify EBI at temperature of 21 °C. It has been reported[1] that for trialkali photocathodes, dark current almost doubles with every increase of 5 °C temperature. More recently, it has been stated in a review article by Bender[2] that EBI for second gen tubes rises almost exponentially with temperature and doubles with 3 °C rise in temperature. Experimentally, the effect of temperature on EBI has been studied by Bhasin[3], *et al*. and their results confirm these findings.

In tropical countries, ambient temperature even during summer nights in desert can be as high as 40 °C. Higher ambient temperature up to 45 °C may also be encountered for II tube-based sights fitted inside the turret of a battle tank, where the inside environment is hot. Relatively large EBI makes the target image hazy as seen on the phosphorus of the tube and makes target acquisition task difficult. It is, therefore, of considerable interest to study the effect of ambient temperature on the range performance of passive night sights.

In the present study, the image intensifier minimum resolvable contrast (IIMRC) model[4,5], developed by the Night Vision and Electronic Sensor Directorate

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(NVESD) of the US Army, has been used to study the effect of ambient temperature on the range performance of a passive weapon sight under different illumination conditions as also for different target/background spectral reflectance characteristics.

2. IMAGE INTENSIFIER MINIMUM RESOLVABLE CONTRAST MODEL

Considering the spectral illumination and the spectral reflectance of scene elements, the modulation contrast (M) can be expressed as

$$M = | (E_t - E_b)/(E_t + E_b) | \quad (1)$$

where E_t and E_b are spectrally averaged luminance of the target and the background, respectively. For simplicity if one uses spectrally averaged quantities then

$$E_t = B_{sk} \times R_t ,\ E_b = B_{sk} \times R_b \quad (2)$$

where B_{sk} is the scene illumination due to night sky, and R_t and R_b are the target and background reflectance respectively.

Modulation contrast (M) is attenuated in the intervening path from target to sensor due to scattering of light from night-sky illumination into the line of sight and effective modulation presented at sensor aperture may be denoted by M_e.

The relationship between scene illumination and photocathode illumination ignoring atmospheric attenuation is:

$$B_{fp} = B_{sk}\ R_{av}\ o/\{4(f\text{-}no)^2\} \quad (3)$$

where B_{fp} is the cathode face plate illumination, τ_o is the objective lens transmission, f-no is the objective f-number, and $R_{av}=(R_t+R_b)/2$.

The NVESD theory is formulated in terms of electron flux from photocathode. The EBI, however, is normally specified in terms of equivalent photocathode illumination and it adds to an average value of B_{fp}. Net result is reduction in modulation contrast and the reduction factor can be expressed as

$$M_{red}=(B_{fpt}+B_{fpb})/(B_{fpt}+B_{fpb}+2\text{EBI}) \quad (4)$$

where B_{fpt} and B_{fpb} are the cathode face plate illumination due to target and background, respectively. Sensor minimum resolvable contrast (MRC) at all spatial frequencies, hence, increases by factor of $[M_{red}]^{-1}$.

2.1 Minimum Resolvable Contrast

The MRC describes the system in terms of MRC as function of spatial frequency in cycles/mrad where the spatial frequency pertains to standard USAF 3-bar chart. It considers the illumination, scene, atmosphere, optics and II tube characteristics as also the contrast transfer function (CTF) of the eye.

2.2 Range Prediction

A target of critical dimension H (m) at a range R (km) subtends an angle H/R (mrad) at sensor aperture. For effective modulation (M_e) at the sensor, the MRC gives the highest spatial frequency (f_c) which can just be resolved by the sensor. Number of resolvable cycles across the target is $N=(H/R) \times f_c$. Number of cycles N-fifty across target for 50 per cent probability of detection, recognition and identification can be chosen and have been taken to be 2, 4 and 8 cycles, respectively in the subsequent analysis.

3. DESIGN PARAMETERS OF PASSIVE NIGHT SIGHT

3.1 Image Intensifier Tube

Passive night sight chosen to study the effect of II tube temperature on acquisition range performance incorporates an improved version of 18 mm proximity focused second gen tube from a European source with optical characteristics as shown in Table 1.

Value of EBI at 25 °C has been taken to be 0.125 µlx which doubles with every 5 °C rise in temperature, the EBI at 40 °C being 1.0 µlx. These values have been used in the subsequent analysis which is considered to be representative of tube performance with S-25 photocathode.

Table 1. Optical characteristics of 18 mm proximity focused image intensifier tube

Parameters	Optical characteristics
Photocathode sensitivity	700 µA/lm
Photocathode radiant sensitivity at 830 nm	50 mA/W
Luminance gain at 50 µlx	50,000 lm/lm
Maximum screen luminance	7 cd/m^2
Resolution	57 lp/mm (min)
Modulation transfer function	
2.5 lp/mm	90 %
7.5 lp/mm	70 %
15 lp/mm	45 %
25 lp/mm	25 %
30 lp/mm	17 %
Signal-to-noise ratio at 108 µlux	20
EBI	0.25 µlux
Screen phosphor	P 22

3.2 Optical System

For the night sight under consideration, the objective lens has an effective focal length of 130 mm at *f*/1.5. Average OG transmission has been taken to be 0.80. Design values for on-axis MTF has been used in the following analysis. This may result in theoretically predicted ranges which may be higher than those which will be achieved for the night sight in actual field conditions. This is not of much concern as the issue being addressed pertains to effect of EBI on MRC and range. At 30 lp/mm, the objective MTF is 60 per cent as against tube MTF of 17 per cent, hence system resolution is essentially limited by tube MTF. Eyepiece EFL is 23.6 mm resulting in magnification of 5.5X. Average transmission of eyepiece has been taken to be 0.85.

4. RESULTS AND DISCUSSION

For EBI to cause any significant reduction of contrast, certain general inferences may be drawn from Eqns (3) and (4). For instance for night-sky illumination of 10^{-4} lx, if total scene reflectance R_{av} = 0.2, then for *f*/1.5 optics with 0.8 transmission is reduced by factor of 0.64 for EBI of 1.0 µlx. Effect of EBI will be less pronounced if scene elements have higher reflectance or if higher speed optics with better transmission is used. The EBI will have negligible effect on contrast reduction and consequently on range performance if ambient illumination is much higher as in the case of clear-starlight illumination.

Table 2. Limiting resolution and recognition range as function of temperature

Temperature (°C)	Limiting resolution (cycles/mrad)	Recognition range (m)
25	1.265	350
30	1.23	330
35	1.167	310
40	1.058	270
45	0.890	190

Certain specific cases have been studied using MRC model. In all the cases, target dimension has been taken to be standard NATO size of 2.3 m x 2.3 m.

Case I

Illumination	:	Overcast sky-light (1.2×10^{-4} lx)
Target type	:	Green paint
Background type	:	Small twigs/leaves

Limiting resolution (cycles/mrad) for which MRC = 1.0 and recognition range as a function of ambient temperature have been shown in Table 2 and also in Figs 1 and 2.

It is seen that for temperature rise from 25 °C to 40 °C, the range is reduced by a factor of 0.77 and for 45 °C it is reduced to almost half.

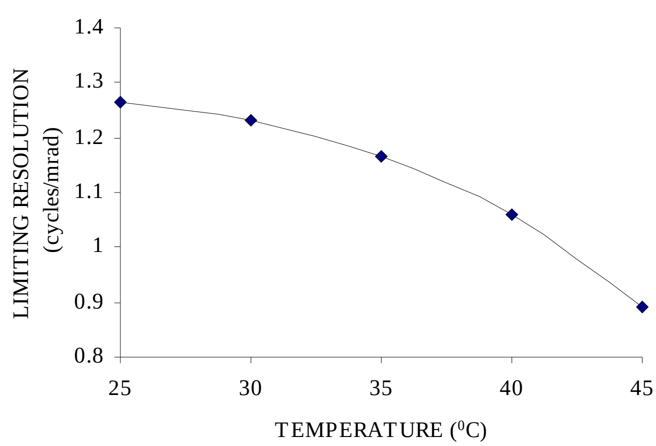

Figure 1. Limiting resolution as function of ambient temperature.

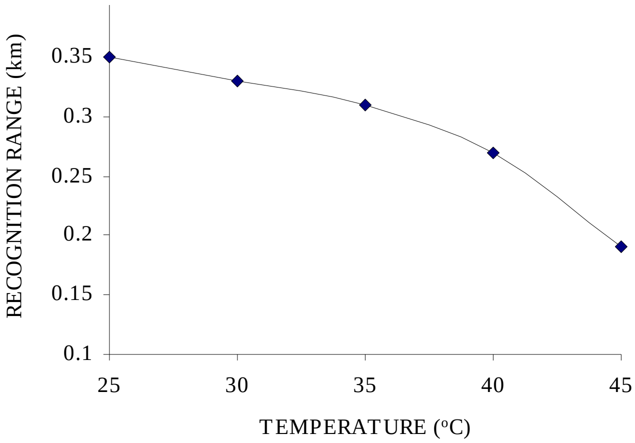

Figure 2. Recognition range as function of ambient temperature.

Case II

Illumination	: Overcast skylight
Target type	: Desert camouflage net
Background type	: Dirt road

Recognition range is found to drop from 350 m to 250 m as temperature changes from 25 °C to 45 °C, i.e., 29 per cent drop in range. In this case, the average scene reflectance is significantly higher than that in *Case I*. In both the cases, if clear-starlight illumination is considered, the effect of EBI even at an elevated temperature is negligible on the acquisition range performance. It is further added that the detection, recognition and identification ranges are in the same ratio i.e., 2:4:8, as the *N*-fifty criteria selected for these tasks.

5. CONCLUSIONS

It has been shown that the temperature dependence of EBI has significant effect on range performance of passive nightsights for illumination levels in the range of 10^{-4} lux for second gen tubes with *S*-25 photocathode.

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