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Passive Night Sight using Image Intensifier Minimum Resolvable Contrast Model

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ABSTRACT

Performance study of a passive night sight has been carried out using an image intensifier minimum resolvable contrast (IIMRC) model. It has been shown that for two identically designed passive sights, the one incorporating super gen tube performs better by factor of 1.3 against the other incorporating second gen tube. Effects of spectral characteristics of night-sky illumination as also spectral reflectance of scene elements have been investigated. It has been concluded that field performance of passive night sight may be correlated to dark-tunnel measurements of limiting resolution at illumination level corresponding to near-starlit condition for acceptance or otherwise of the sight.

Keywords: Night vision, passive night sight, image intensifier tube, IIMRC, image intensifier minimum resolvable contrast, night-sky illumination, photopic illumination

1. INTRODUCTION

Image intensifier minimum resolvable contrast (IIMRC) mode[1-3] developed by the Night Vision and Electronic Sensor Directorate (NVESD) of the US Army offers a powerful tool for system design and analysis of second gen tube-based direct view passive night-vision devices.

The model has been used in present study to analyse the performance of a passive night sight designed at the Instruments Research & Development Establishment (IRDE), Dehra Dun, for a particular application and currently under production at the Bharat Electronics Ltd. (BEL), Machilipatnam. The passive night sight incorporates second gen tube under production at the BEL (OP), Pune. A comparative minimum resolvable contrast (MRC) and range performance study have been carried out for sights incorporating second and super gen tubes for different illumination levels as also for different background conditions.

2. IMAGE INTENSIFIER MINIMUM RESOLVABLE CONTRAST MODEL

2.1 Target, Background, and Illumination

A target of critical dimension H (m) at range R (km) subtends an angle H/R mrad at sensor aperture. Considerating the illumination level and its spectral characteristics as also the spectral reflectance of the target and the background, the modulation (M) at target plane can be defined as

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

where E_t and E_b are spectrally averaged luminance of the target and the background, respectively. The modulation (M) is attenuated due to the atmospheric scattering in the intervening path from target to sensor, and the effective modulation (M_e) presented at the sensor aperture is given by $M_e = t_a(R)\ M$, where $t_a(R)$ is the atmospheric transmission of path length R.

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The model ignores the spectral transmission characteristics of the atmospheric path. Instead, it uses Beer's law to predict transmission, ie, $t_a(R) = e^{-\alpha R}$, where a is the spectrally averaged attenuation coefficient. The model considers the spectral responsivity of tube's photocathode, which is S-25 for second and super gen tubes, and E_t and E_b are finally defined in terms of photocathode current (μamps/cm^2) which is the spectrally averaged value of illumination, scene reflectance, photocathode response and transmission of the objective lens over the wavelength range of interest (0.4 μm to 0.9 μm). The objective lens-integrated transmission can also be entered individually in the program for performance prediction.

The IIMRC has built-in library for night-sky illumination for all-practical conditions, viz., quarter moon, clear starlight, overcast starlight as also deep overcast starlight. Similarly, spectral reflectance of all possible targets of military interest (paint, camouflage net, etc) and all practically encountered background types (bushes, soil, sand, grass, etc.) are available in program library making it extremely user-friendly.

2.2 Minimum Resolvable Contrast

The model considers the optical design parameters of the objective lens and the eyepiece, viz., focal length, *f*-number, modulation transfer function (MTF) and transmission as also the tube characteristics, viz., photocathode spectral response, gain, S/N, equivalent background illumination (EBI), phosphor characteristics, display luminance and the contrast transfer function (CTF) of the eye. It describes the system in terms of minimum resolvable contrast as a function of spatial frequency in cycles/mrad, where the spatial frequency pertains to standard USAF 3-bar chart.

2.3 Range Prediction

A number of cycles ($N_{0.5}$) across the target for 50 probability of detection, recognition and identification can be chosen and have been taken 2,4 and 8 cycles, respectively for the above-mentioned tasks. For target contrast characterised by apparent modulation (M_e) at the sensor, the MRC gives the highest frequency (f_c), which can just be, resolved for input (M_e). Using the criterion $N_{0.5} = (H/R)\times f_c$, the maximum range to target is predicted.

3. DESIGN PARAMETERS OF PASSIVE NIGHT-SIGHT TUBE

The passive sight chosen for case study incorporates a second gen proximity tube (18 mm) manufactured by the BEL (OP), Pune. A comparative performance study of same sight using super gen double proximity tube (18 mm) model XX1663 from PHOTONIS-DEP[4] has been carried out. Parameters of the two tubes are listed in Table1. Due to non-availability of the MTF data for the BEL (OP) second gen tube, the MTF values of pre-OMNI tube from the program library has been chosen as it closely matches the limiting resolution of BEL (OP) tube.

3.1 Optical System

For the sight under consideration, the objective lens has focal length (112 mm) at *f*/1.4. Average transmission has been taken to be 0.80. Eyepiece

Table 1. Parameters of second gen tube and photonis super gen tube

Parameter	Second gen tube	Photonis super gen tube
Photocathode sensitivity	240 μA/lm	550 μA/lm
Luminous gain	18,000 lm/lm	30,000 lm/lm
Signal-to-noise ratio	14	18
EBI	0.25 μlux	0.25 μlux
Resolution	32 lp/mm	45 lp/mm
Modulation Transfer Function		
2.5 lp/mm	–	86 %
5.0 lp/mm	75 %	–
7.5 lp/mm	–	65 %
10.0 lp/mm	50 %	–
15.0 lp/mm	29 %	45 %
20.0 lp/mm	19 %	–
25.0 lp/mm	9 %	25 %
30.0 lp/mm	4 %	17 %

focal length is 22 mm resulting in system magnification of 5X. Average transmission of the eyepiece has been taken as 0.83. An optical system MTF was not readily available, hence default values have been used in the model such that both the objective and the eyepiece MTF are around 60 near the cutoff frequency of the tube. The product optical MTF at tube cutoff frequency is around 40, which ensures that system performance is limited due to tube and not due to optical system.

3.2 Target and Background

Standard NATO target of 2.3 m x 2.3 m covered by the camouflage net has been used for range calculation. Two types of backgrounds have been selected, green grass and desert road-dirt. To cater for atmospheric attenuation, Beer's law coefficient has been taken as 0.9/km. Computations have been carried out for two types of night-sky illumination, viz., clear starlight and quarter moon.

4. RESULTS AND DISCUSSION

The MRC of second gen and super gen sights under starlit condition for the specified target against green-grass background as a function of spatial frequency has been shown in Fig.1. Photopic illumination available under clear starlight condition is in the range 1.0 mlx. As expected, the MRC of super gen sight is superior (ie, lower) as compared to second gen sight at all spatial frequencies. In the limit when resolvable contrast is unity, ie, for MRC=1.0, the cutoff spatial frequency (f_c) for super gen sight was found to be 2.5 cycles/mrad as against 1.94 cycles/mrad for second gen sight. Limiting resolution of the super gen sight is thus higher by a factor of 1.3X as compared to the second gen sight.

Acquisition ranges for second gen and super gen sights under starlit condition have been shown in Figs 2 and 3, respectively. Detection, recognition and identification ranges for second gen sight are 1.15 km, 0.62 km and 0.32 km, respectively with 50 probability assigned to each sight. For super gen system these ranges are 1.50 km, 0.80 km and 0.42 km, respectively. If theoretical prediction of ranges are found to be higher than that of field performance, the confidence level, ie, the probability associated with tasks of detection, recognition and identification can be chosen to be higher than 0.5 to tune the theoretical predictions to field measurements.

First observation that can now be made is that *R* (*det*), *R* (*rec*) and *R* (*id*) are approximately in the same ratio as the number of resolvable

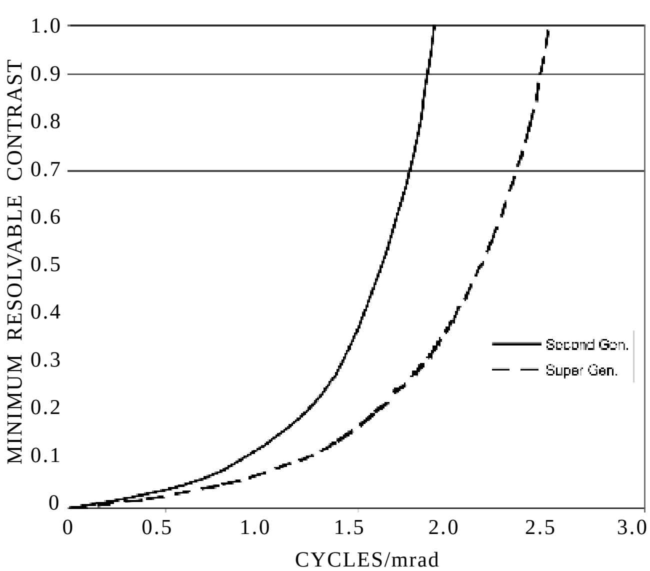

Figure 1. MRC values of second gen sight and super gen sight under starlit condition as a function of spatial frequency.

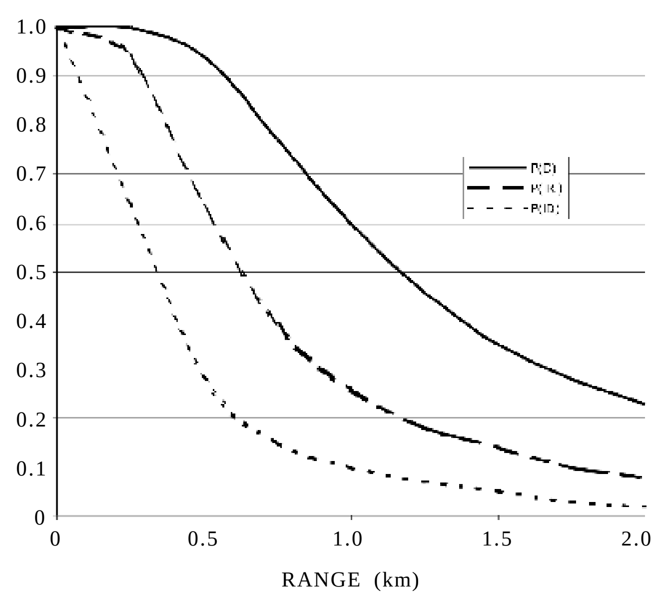

Figure 2. Detection, recognition and identification range performance of second gen sight under starlit condition.

cycles ($N_{0.5}$) across the target chosen for each of these tasks. Second more interesting observation is that acquisition ranges for super gen system are higher by factor of 1.3X wrt to second gen system thus exhibiting a correlation between the limiting resolution and the acquisition ranges.

Then, one considers the quarter moon condition which amounts to photopic illumination of around 10.0 mlx. The MRC for second gen sight for starlit and moonlit conditions has been compared in Fig. 4. Limiting spatial frequencies for super gen and second gen systems under moonlight illumination was found to be 3.49 cycles/mrad and 2.75 cycles/mrad, respectively which is again in the ratio of 1.3X. Corresponding acquisition ranges have been shown in Figs 5 and 6, respectively. From Figs 5 and 6 recognition range values are 0.97 km and 1.25 km for second gen and super gen sights and the improvement factor is 1.3X. Correlation between the limiting resolution and the acquisition range exists even though the illumination level has gone up by an order of magnitude. It may, however, be emphasised that correlation has been found while comparing the two passive sights under identical illumination. Further more, the target and the background characteristics have remained identical while making the comparison.

Individual system performance has now been examined as a function of illumination level. It may be recalled that for second gen sight, the limiting resolution under quarter moon and clear starlit conditions were 2.75 cycles/mrad and 1.94 cycles/mrad, respectively the second gen sight being higher by a factor of 1.4X. On the other hand if acquisition ranges are compared for the two illuminations, the recognition range 0.62 km for starlit goes up to 0.97 km for quarter moon, ie, an increase by factor of 1.6X. Identical results are found for super gen system as well. Thus, the correlation between the limiting resolution and the range did not exist anymore when illumination level changes. Lack of correlation can be explained if spectral characteristics of starlight and quarter moon illuminations are examined. Moon illumination has been derived from the spectral radiance of the sun, the moon's spectral albedo and the spectral transmittance of moon/earth atmosphere. Spectral content of earth surface illumination also includes the contribution provided by clear starlight. Second tube photocathode current being the integrated value of wavelength dependent parameters, viz., illumination, scene reflectance and tube responsivity has led to quite different E_t and E_b and hence Modulation (M_e) for starlit and moonlit conditions.

To further illustrate the effect of spectral characteristics of target, background and the tube, desert road-dirt background have been considered with other conditions remaining the same. For second gen system under starlit condition, the recognition range 0.62 km against green-grass background, goes up to 0.77 km against desert road-dirt background, ie by factor of 1.2X though limiting resolution changes only marginally. Similar results are found for quarter moon illumination. Correlation between limiting resolution and range thus did not hold good even for identical illumination if background changes. Lack of correlation can now be attributed to different spectral reflectance characteristics of green-grass and desert road-dirt backgrounds.

5. DARK-TUNNEL EVALUATION OF PASSIVE SIGHTS

Passive sights for diverse applications are under bulk production within the country and there have to be inspected for performance before user acceptance. Field trial of thousands of sights is not practical and there is always the uncertainty related to illumination level and background characteristics. There is a strong case for evaluation of sight in a well-calibrated dark-tunnel simulating the illumination level and spectral characteristics of night-sky. This could be done by having a benchmark sight meeting field performance specification tested for limiting resolution in a dark-tunnel against USAF 3-bar target. Such a proposal has been made by the BEL, Machilipatnam, wherein correlation of range performance with limiting resolution is proposed to be used for acceptance testing of passive night sights. Theoritical study carried out above supports this view.

Further study has revealed that range performance did not correlate with limiting resolution if field conditions of illumination level or background terrain

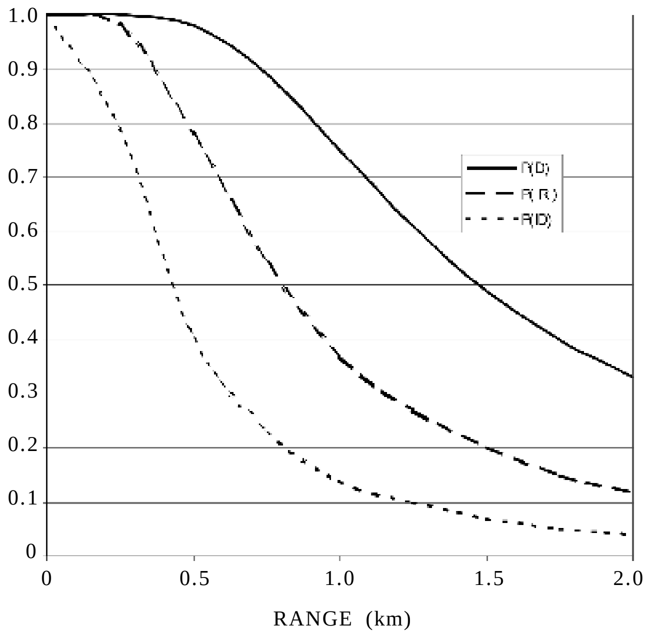

Figure 3. Detection, recognition and identification range performance of super gen sight under starlit condition.

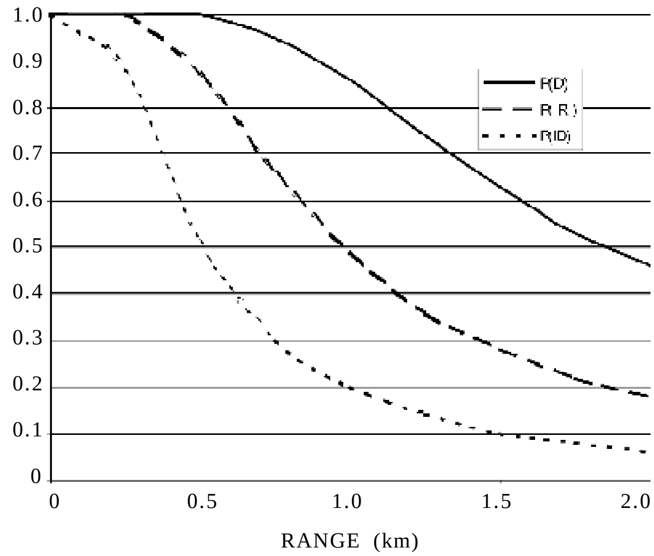

Figure 5. Detection, recognition and identification range performance of second gen sight under quarter moon condition.

change. To eliminate any ambiguity, benchmarking of reference sight may preferably be carried out at two illumination levels, one corresponding to clear starlight (illumination level 1-3 mlx) and the other for near-quarter moon condition (illumination level 8-12 mlx). Two different spectral characteristics of illumination will better exploit spectral responsivity of tube as also the spectral reflectance characteristics of scene elements. Moreover, weightages associated with tube parameters such as gain, responsivity, EBI, S/N and MTF on range performance vary with illumination level. Furthermore the CTF of eye also depends upon the brightness level of the second tube phosphor, which may vary with changing illumination level.

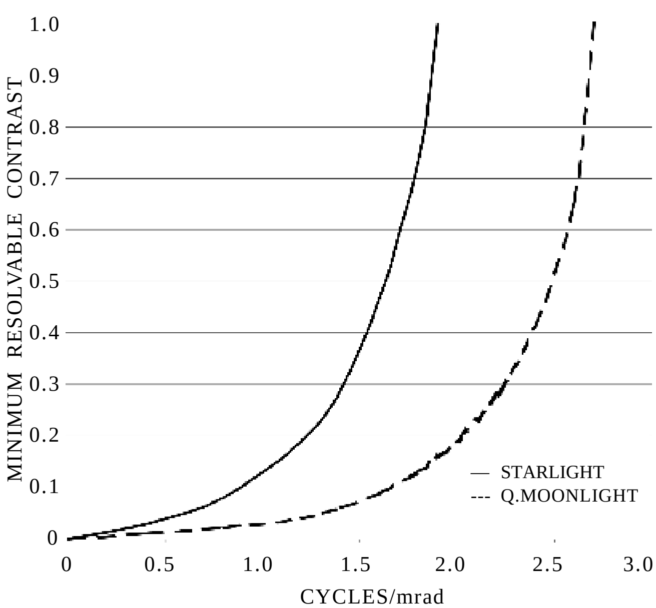

Figure 4. MRC values of second gen sight under starlit and quarter moonlit conditions.

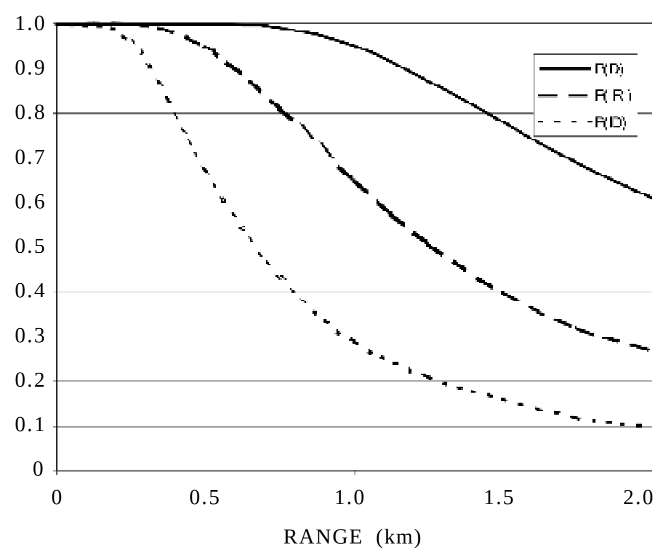

Figure 6. Detection, recognition and identification range performance of super gen sight under quarter moon condition.

6. CONCLUSION

Performance study in terms of limiting resolution and acquisition range of passive night sight has been carried out using image intensifier minimum resolvable contrast (IIMRC) model. It has been shown that sight incorporating super gen tube performed 1.3X better than sight incorporating second gen tube. The study can be extended to high-performance tubes, viz., SHD-3, XD-4 and XR-5 now being offered by PHOTONIS-DEP as also to the third gen tubes of the US origin. Effects of spectral characteristics of night-sky illumination as also spectral reflectance of scene elements on system performance have been investigated. Based on the results, it is found that benchmarking of passive night sights in terms of limiting resolution against 3-bar target may be carried out at near-starlit illumination levels in dark-tunnel as criteria for acceptance or otherwise of the sight. It is desirable to carry out the bench marking at quarter moon illumination as well.

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