INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

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# LIGHT- WEIGHT MACHINE GUN OPTICAL SIGHT

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**Accepted Date: 13/11/2014; Published Date: 01/12/2014**

**Abstract:** The optical design of the smallest day use telescopic sight in the 0.4µm to 0.7 µm wavelength range for mounting on solider light – weight machine gun is presented. It is a 2X. Sight with an objective focal length of 53082mm and the combined focal length of eyepiece – erector is 26.13mm.the field – of view of the sight in object space is 15 degrees and the apparent field is 30 degrees. The vertex to vertex length of the telescopic sight is 260.15 mm. The eye relief or eye safe distance of sight is 54.2 mm. The telescopic sight acquires and recognizes 2 -400 meter distant ambient illuminated military targets of soldier interest in warfare. All the optical surfaces of optics are spherical the physical dimensions of the sight for viewing and aiming enemy military targets illuminated in day light are dimensioned so that it can be mounted to light – weight machine gun with the use of mounting brackets and hardware of a standard size and spacing.

**Keywords:** Visible spectrum, day light illuminated targets, soldier light- weight machine gun sight and compact telescopic sight.

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**Access Online On:**

www.ijpret.com

**How to Cite This Article:**

Rao PN, IJPRET, 2014; Volume 3 (4): 70-81

***PAPER-QR CODE***

## INTRODUCTION

Light- weight machine gun (LMG) is intended to be carried along with several belts of ammunition by individual soldier in combat and to deliver sustained firepower during enemy engagements. In a close quarter combat ,typically in the ranges of 2 – 800 meters, soldiers are required to rapidly acquire , identify and accurately fire an enemy targets. Soldiers use weapon mounted optical sights that works in visible light to assist in the aiming process during day time mission. In target shooting, the moving target is not a target for very long. The soldier must react to the initial vision of the target, bring the gun to sighting position, locate the target in the sight, fine tune the aiming the gun on the enemy target through the sight and fire. These activities must take place in time frame of a second or less. One of the most critical of these activities is target acquisition within the sight. That is, it is not enough merely to the soldier to see the target and shoot. Reliable accuracy is required actually finding the target within the gun sight. This is called target acquisition. Thus it is required to minimize the time or maximize the speed with which the target can be acquired within the sight. the quicker this can be done , the quicker the later steps of actually refining the aim and pulling the trigger can be accomplished .Soldier sees the visible target with a naked eye and direct the weapon towards the visible target. The sights used by military are to be short, light weight and small so that they are integral part of the weapon. These requirements are met by telescopic sights and can be mounted on a gun. The telescopes magnify the area of scene or the target area and enhances the ability of soldier to aim the gun during combat mission.. In addition to magnification, telescopic sights provide sufficiently bright images of dimly lighted distant military targets to the soldier under bright or dim light and against light or dark back ground conditions. The targets which the human eye cannot see, shall be seen through telescopic sight.

Refractive optics for telescopic sight is used in a wide variety of applications to obtain increased magnification of scene. In one common application, a viewing and aiming optics is affixed to the upper side of a small arm, in our case, soldier light–weight machine gun. The soldier sights through the viewing and aiming optics to acquire a target and aim the LMG towards the target to increase the likely hood of hitting the target with a bullet fired from the LMG. The telescopic sight for LMG sight will have limited field –of- view and magnification. The field –of –view and magnification are interlinked for such optics the larger the magnification, the smaller the field of view and vice versa. The field –of- view is smaller than the unaided eye.

In some situations, such as a soldier fighting in warfare, the LMG man is most effective in close range situation, typically less than 50 meters to the target. For intermediate ranges , typically 50

-400 meters to the targets, the soldier is more effective in viewing and aiming the target with a moderate magnification of2x -6x magnification using one eye.

The physical dimensions of telescopic sight for viewing and aiming are important to maintain so that it can be mounted to LMG with the use of mounting brackets and hardware of a standard size and spacing. Light rays in 0.4 µm to 0.7 µm wavelength band reflected or emitted from an observed distant ambient illuminated target enter the telescopic sight of soldier LMG through a fixed objective portion passes through each optical element of the telescopic sight and exit the optics through eyepiece for viewing by the soldier. The lens design of telescopic sight for LMG delivers a resolution better than 1.0 minutes of arc in eye relief space for day use (or photopic use) for both magnification and field –of- view when the soldiers eye is at an eye relief distance of >25.0 mm The 1.0 minutes of arc resolution mentioned is also the limiting resolution of human eye of observer under best working conditions. Since the best conditions are not prevailed in ware field, the telescopic sight is designed for 2.0 minutes of arc resolution.

The telescopic sight also delivers long eye relief to accommodate eye guard made of resilent material which protects the soldier eye from LMG recoil. The publication presents the optical design and design data of 260.15 mm vertex to vertex length , 15 degrees field- of –view , 2x, sixteen element telescopic sight for mounting on soldiers lmg. The reticle is incorporated in the image plane of objective lens the design uses five optical glasses and sixteen lenses. The all spherical optical design delivers an eye relief of 54.2 mm. The all spherical optics is preferred here because it is easy s easy to fabricate and test the spherical optics .This is an added advantage when the required number of sights are in thousands. The optical design results 40 arc seconds on – axis and off- axis parallax errors due to the targets at different ranges. The optical design places the equal diameter lenses at equal distance from the centre of optical path of the sight for minimum deviation of Centro gravity of the sight so that the minimum bore sighting error appears between sight and gun barrel after mounting the sight on LMG

1. **Requirements of telescopic sight for mounting on soldiers LMG**

Requirements of telescopic sight for mounting on soldier light – weight machine gun (LMG) is summarized Table1 and a typical soldier LMG is shown in figure 1:

**Table 1: Requirements of telescopic sight**

| Parameter | Value/advantage |
|---|---|
| wave length range | 0.4 µm - 0.7 µm |
| Magnification ( With in the 2x -6x for recognition and acquiring distant targets) | 2 X |
| Field – Of- View | 15 degrees |
| Entrance pupil diameter | 12.0 mm Minimum |
| Exit pupil diameter (for various illumination condition of day light) | 6.0mm |
| Vertex To Vertex Length | 250+_ 10 mm |
| Long Eye Relief | >25.0 mm |
| Parallax error during acquisition of distant targets in 50 – 300 meters range | Low |
| Resolution of optics (in target space in warfare conditions.) | 2.0 Minutes Of Arc |
| Target Range | 2 – 400 Meters |
| Deviation of centro gravity(cg) of lenses from center of optical path of optics | Minimum |
| All spherical optics | For easy Of fabrication and testing |
| Repeated radii of curvature values for optical surfaces for elements in optics | So that the entire optics can be tested with a minimum number of test plates |
| Sufficient air surfaces between optical elements | For easy assembling of elements in to system |

**Figure 1: Typical soldier LMG**

### 3.0 Configuration of telescopic sight for LMG mounting

The soldiers' telescopes for shooting are erected class of focal systems with long eye relief. The telescopic sight is constructed with an objective lens , a reticle in the image plane of the objective , an erector lens with an aperture stop in the object space of the erector and an eyepiece. The focal lengths of objective, erector and eyepiece of telescopic sight of vertex to vertex length of 250+ -10mm for mounting on soldiers LMG are shown in Table2.

**Table 2: Focal length of Objective, Erector and Eye piece**

| Lens system | Focal length |
|---|---|
| **Objective** | 53.82mm |
| **Erector** | 25.74 mm |
| **Eye piece** | 45.27 mm |
| **Eye piece plus erector** | 26.13 mm |

### 4.0 System design of telescopic sight

The soldier supported with a LMG views and aims the combat targets at a range of 50 to 400 meters As the targets are at short ranges, short focal length and a wide field of view lens is considered for objective lens of sight., Magnification and vertex to vertex length of telescopic sight make the focal lengths of erector and eyepiece smaller than objective. In view of the desired long eye relief, the aperture stop is considered in between in between reticle and erector first lens the aperture stop location at this position provides long eye relief and place the elements in the optical path of sight at a minimum deviation position of CG of telescopic optics [1-3].

### 4.1 Aberration corrections of telescopic sight Optical glasses for sight

As large number of sights is required, readily available and low cost optical glasses are considered in the optical design of telescopic sight for LMG. The number of optical glasses used in the sight is restricted to five considering their future availability and to store the glass stock for future needs. Design efforts are made to use low density optical glasses in order to reduce the weight of the telescope optics.

#### 4.1.1 Optical design of objective lens

A cemented doublet covers only 5 degrees field – of – view at a speed of f/5.0 for a focal length of 250.0 mm. When the focal length is small, the lens contains deep curvatures and the aberration contributions are large. The correction of aberrations in short focal length lenses needs more than three lenses in its construction depending on the field and aperture requirements. In order to restrict the length of the telescope to the requirement, it is inevitable to select the focal length of objective lens to 50.0 to 60.0 mm. Two cemented doublet configuration for objective lens resulted poor performance the objective lens is configuration is finalized with a single positive element and two cemented doublets with reticle in the image plane of objective lens. The Petzval sum of the objective depends on refractive index difference of optical elements and individual powers of elements in the objective. It is independent of shapes of the lenses in the objective. A proper balance of Petzval sum is obtained with appropriate powers for individual powers and index differences. The selection of powers and index differences for lenses in objective lens resulted a Petzval sum contribution of 0.006520 mm by single element and 0.011349mm by two cemented doublet which are in desired limits. It is expected that a minimum Petzval contribution in objective lens may contribute a minimum astigmatism when bending technique is applied to the objective. The longitudinal spherical aberrations, OSC, astigmatism are corrected in the objective by bending of lenses in objective. The combination of optical glasses and powers of lenses played critical role in balancing longitudinal chromatic aberration and lateral color. The desired eye relief of telescope do not permit the aperture stop location on or within the lenses of objective lens. As a result the aperture stop location is not a degree of freedom in the correction of field aberrations in objective lens. The efforts are not made in the design of objective to reduce the distortion .It is decided to correct the distortion of objective in the design of telescope reticle. [4-8]. The well corrected objective lens for telescopic sight has a positive meniscus element in front ,a first biconvex-negative meniscus cemented doublet and second negative meniscus- biconvex cemented doublet behind. It covers a 15 degrees field of view at 53.82 mm focal length. The Seidel aberrations of objective including a reticle in 0.4 µm - 0.7 µm wave length range is given in Table 3.

**Table 3: Seidel aberrations of objective including reticle in 0.4 µm-0.7 µm wave length range**

| S NO | SAB | OSC | AST | DIST | AC | TC | PTZ |
|---|---|---|---|---|---|---|---|
| 1 | 0.033671 | 0.002582 | 1.595625 | 0.072117 | 0.293731 | 0.022523 | 0.005698 |
| 2 | 0.010224 | -0.000029 | 0.000675 | 0.000058 | 0.130767 | -0.000374 | 0.0008222 |
| 3 | -0.003288 | -0.000322 | -0.254247 | 0.001514 | 0.116703 | 0.011430 | 0.005693 |
| 4 | 0.234090 | -0.011855 | -4.057428 | -0.095956 | 0.944127 | -0.043782 | -0.001618 |
| 5 | 0.062432 | 0.001553 | 0.311185 | 0.003869 | 0.437094 | 0.010869 | 0.000000 |
| 6 | -0.006808 | 0.000225 | -0.059536 | -0.003315 | -0.137654 | 0.004549 | 0.005202 |
| 7 | 0.000120 | 0.000039 | 0.103650 | 0.003189 | -0.034780 | -0.011374 | -0.001670 |
| 8 | 0.171644 | 0.008213 | 3.167496 | 0.080276 | 0.175888 | 0.008545 | 00.003751 |
| IMAGE | -0.004649 | -0.000183 | -0.057744 | -0.001133 | -0.016984 | 0.000274 | 0.000000 |
| SUM | 0.029314 | 0.001225 | 0.749947 | 0.060633 | 0.033424 | 0.002116 | 0.016226 |

### 4.1.2 Erector lens

The erector in telescopic sight for LMG, shall cover field angles above 10 degrees and large apertures at finite object and image conjugates. the aperture stop is associated with erector lenses the focal length of erector is short and it is 24.74 mm the minimum length between object and image conjugates of erector is four times the focal length. The off axis rays make significant angle and as a result contributes to large off axis aberrations. The angles of incidence of rays on erector lenses can be reduced using negative lenses. The use of negative lenses contributes to negative aberrations which balance the positive aberrations of positive lenses of erector. Since the power of erector is positive and large, the erector is configured with three negative lenses in three cemented doublets .which considerably reduced field aberrations at finite object and image conjugates. As the objective lens and eyepiece lens work at one infinite conjugate, their field aberrations are small compared with finite conjugate erector. The length of the erector is controlled using closely spaced doublets and a short focal length for erector [4-8]. The well corrected erector lens for telescopic sight is constructed with three cemented doublets using a biconcave element in each doublet. The positive elements in the erector doublets are positive meniscus and Plano convex lenses. The erector covers a 15 degrees field of view at 25.74 mm focal length. The Seidel aberrations of the erector lens are shown in table.

### 4.1.3 Eyepiece

The eye pieces are designed for wide angles and small apertures (4.0mm) for different eye safe distances. The conventional eye pieces have optical elements ranging from two to eight. The eye relief of these eyepieces varies from 0.8 to 1.5 times the focal length. They all designed for unit or one inch focal length. The eyepiece for use in telescopic sight for mounting on lmg shall have a focal length of 45.26 mm and an eye relief of not less than 50.0 mm. A long focal length eyepiece is constructed with two cemented doublets and a single negative lens that meets the requirements of telescopic sight for mounting on soldiers LMG .

### 4.1.4 Aberration corrections of erector and eye piece

The erector and eye piece are designed separately for minimum on–axis and off- axis aberrations. The Seidel values qualified the lens systems for Petzval sum and two color aberrations. They are improved for coma and astigmatism using bending technique. The actual aberrations are calculated by trigonometric ray trace .Bending and optical glassy substitutions are implemented for satisfactory solution for aberrations of these systems. The corrected erector and eyepiece are combined into a single system with aperture stop in the image space of eyepiece and erector combination and again corrected for aberrations of the combined system [4-8]. The combined focal length of eyepiece and erector is 26.13426mm. The Seidel aberrations of erector and eyepiece combination are calculated by ray tracing from eye end and are shown in Table4.

**Table 4(a): Seidel aberrations of Eye piece plus erector from Eye piece end in 0.4 µm - 0.7 µm wave length range**

| S NO | SAB | OSC | AST | DIST | AC | TC | PTZ |
|---|---|---|---|---|---|---|---|
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.08042 | 0.000000 | 0.014155 | 0.000000 |
| 10 | -0.056365 | 0.003700 | -0.195695 | 0.007370 | -0.297826 | 0.019550 | 0.001792 |
| 11 | 0.348769 | -0.404765 | 3.838629 | -0.235769 | 0.206446 | -0.024130 | 0.012132 |
| 12 | 0.006453 | -0.000198 | 0.004912 | -0.003494 | 0.095549 | -0.002937 | 0.013794 |
| 13 | -0.694524 | 0.065810 | -5.023735 | 0.241468 | -0.224836 | 0.021304 | -0.004520 |
| 14 | 0.127027 | -0.107258 | 1.88936 | -0.129871 | 0.145567 | -0.019777 | 0.001392 |
| 15 | -0.039428 | 0.006861 | -0.961833 | 0.077175 | -0.137913 | 0.023999 | 0.004640 |
| 16 | 0.001075 | -0.000320 | 0.076723 | 0.007575 | 0.038591 | -0.011488 | -0.001602 |
| 17 | 0.369555 | -0.035890 | 2.761157 | -0.140444 | 0.1055313 | -0.010142 | 0.009646 |
| SUM | 0.062562 | -0.017760 | 2.389130 | -0.183068 | -0.069110 | 0.010535 | 0.033689 |

**Table 4(b): Seidel aberrations of Eye piece plus erector from Eye piece end in 0.4 µm - 0.7 µm wave length range**

| S NO | SAB | OSC | AST | DIST | AC | TC | PTZ |
|---|---|---|---|---|---|---|---|
| 18 | 0.003076 | 0.000219 | 1.046486 | 0.061624 | -0.3222220 | 0.022963 | 0.004641 |
| 19 | -0.006738 | -0.000263 | -0.888833 | -0.023710 | -0.484589 | -0.021503 | -0.001222 |
| 20 | 0.131395 | 0.002213 | 2.497504 | 0.029742 | 0.412015 | 0.006940 | 0.007026 |
| 21 | -0.000311 | -0.000069 | -1.038344 | -0.003381 | 0.032958 | 0.007363 | 0.0068547 |
| 22 | -0.047101 | -0.001184 | -1.994671 | -0.027347 | -0.627517 | -0.015778 | -0.001227 |
| 23 | 0.093463 | 0.001410 | 1.425266 | 0.012889 | 0.586667 | 0.008852 | 0.001925 |
| 24 | -0.089246 | -0.001326 | -1.319164 | -0.011721 | -0.569446 | 0.008459 | -0.001760 |
| 25 | 0.030443 | 0.000135 | 0.040316 | -0.000301 | 0.328252 | 0.001460 | 0.001193 |
| SUM | 0.114981 | 0.001100 | -0.321439 | 0.037847 | 0.000561 | 0.001837 | 0.015044 |

### 4.1.5 Optical design of telescopic sight

The individually corrected objective reticle combination and eyepiece –erector combination are integrated into a telescopic sight. An axial ray tracing through the sight provides the focal length, back focal length, entrance and exit pupil distances of sight. The exit pupil distance is the eye relief of the sight. The axial and field bundle ray trace gives the apertures of lens elements of sight. The optical characteristics, optical configuration and optical design data of complete telescopic sight, objective -retile combination, erector, eyepiece and eyepiece- erector combination are shown in Table5, figure 2and Table 6.

**Table 5(a): optical characteristics of telescopic sight**

| Parameter | Value |
|---|---|
| wave length range | 0.4 µm - 0.7 µm |
| Magnification | 2.06X |
| Entrance pupil Diameter | 12.36 mm |
| Exit pupil Diameter | 6.0 mm |
| Field –of view | 15.0 Degrees |
| Apparent field | 30.0 Degrees |
| Focal length | ∞ |
| Back Focal length | ∞ |
| Entrance pupil Distance | 54.23 mm |
| Exit pupil distance | +42.82 mm |
| Vertex to Vertex Length | 260.15 mm |

| | |
|---|---|
| **Number of lenses** | 016 |
| **Number of optical glasses** | 05 |
| **Reticle** | In the objective image plane |
| **Targets** | military ambient illuminated targets of soldier interest in combat at a range of 50 – 400 meters |

**Table 5(b): optical characteristics of telescopic sight**

| Lens system | Entrance pupil Distance | Exit pupil distance |
|---|---|---|
| **Objective** | -150.0 mm | 25.48mm |
| **Eye piece plus erector** | -54.0mm | +0.351229mm |

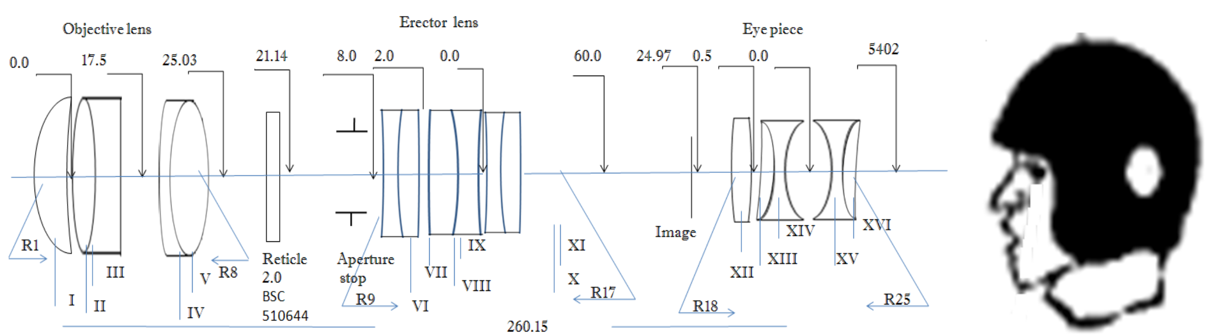


**Figure 2: optical characteristics of telescopic sight**

**Table 6(a): optical design data of telescopic sight**

| LENS | GLASS | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | CT | CA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I | LAC 697562 | 72.10 VEX | 500.0 CAV | | | | | | | 6.0 | 16.0 |
| II | BSC 510644 | | | 59.3 VEX | 49.5 VEX | | | | | 10.0 | 16.0 |
| III | DEDF 717295 | | | | 49.5 CAV | ∞ | | | | 5.0 | 16.0 |
| IV | DEDF 717295 | | | | | | 80.3 VEX | 47.7 CAV | | 1.5 | 14.5 |
| V | BSC 510644 | | | | | | | 47.7 VEX | 90.0 VEX | 8.0 | 14.5 |

CT= Centre thickness, CA= clear aperture

ALL THE DIMENSIONS ARE IN MM

**Table 6(b): optical design data of telescopic sight**

| LENS | GLASS | R9 | R10 | R11 | R12 | R13 | R14 | R15 | R16 | R17 | CT | CA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VI | BSC 510644 | 35.0 CAV | 50.0 CAV | | | | | | | | 8.0 | 14.0 |
| VII | DEDF 717295 | | 50.0 VEX | 90.0 VEX | | | | | | | 3.0 | 14.0 |
| VIII | DEDF 717295 | | | | 300.0 CAV | 17.0 CAV | | | | | 3.0 | 14.0 |
| IX | BK7 517642 | | | | | 7.0 VEX | 24.7 VEX | | | | 6.0 | 14.0 |
| X | MBC 572577 | | | | | | | 30.0 CAV | 30.0 VEX | | 6.0 | 14.0 |
| XI | DEDF 717295 | | | | | | | | 30.0 CAV | ∞ | 1.5 | 14.0 |

CT= Centre thickness, CA= clear aperture

ALL THE DIMENSIONS ARE IN MM

**Table 6(c): optical design data of telescopic sight**

| LENS | GLASS | R18 | R19 | R20 | R21 | R22 | R23 | R24 | R25 | CT | CA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| XII | DEDF 717295 | 350.0 VEX | 237.4 CAV | | | | | | | 10.6 | 14.0 |
| XIII | DEDF 717295 | | | 217.0 CAV | 43.8 VEX | | | | | 2.9 | 14.0 |
| XIV | MBC 572577 | | | | 43.8 CAV | 53.1 CAV | | | | 12.6 | 14.0 |
| XV | MBC 572577 | | | | | | 51.8 CAV | 44.0 CAV | | 12.0 | 14.0 |
| XVI | DEDF 717295 | | | | | | | 44.0 VEX | 90.0 VEX | 2.9 | 14.0 |

CT= Centre thickness, CA= clear aperture

ALL THE DIMENSIONS ARE IN MM

**5.0 CONCLUSIONS**

A sixteen element telescopic sight is designed for mounting on soldier light – weight machine gun. The telescopic sight consists of objective, erector and an eyepiece. The magnification, field-of – view entrance pupil diameter and exit pupil diameter of the optics are 2.06x, 15.0 degrees, 12.36 mm, 6.0mm respectively. The vertex to vertex length of the telescopic sight is 261.34mm. The telescopic sight is designed using only five optical glasses in sixteen elements. The telescopic sight images 2 -400 meter distant day time ambient illuminated military targets in objective image plane which is reimaged by erector lenses in the object plane of eyepiece. Soldier sees the images of distant targets through an eyepiece from a distance equal to the eye relief of 54.23mm. All the optical surfaces of telescopic sight are spherical. The optical design is unique in its optical characteristics.

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