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A PATH FOR HORIZING YOUR INNOVATIVE WORK

OPTICAL DESIGN OF DIRECT VIEW DAY OPTICS FOLDED IN THREE CARTESIAN AXES

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Abstract: An optical design data of helicopter mounted direct view optical sight for day use wave length range of 350nm to 700nm is presented .The 10 x day sight is designed for 40 mm entrance pupil diameter and covers a full field of view of 4 x 6 degrees. The length of the sight is 1300mm. The clear apertures of optical elements of sight are equal to and less than the entrance pupil diameter of sight .The day sight optics includes main objective, collimating lens, double Dove, reversed Galilean telescope, imaging lens, Pechan prism , two relay lenses and an eyepiece. The sight is six fold day sight with folds in all the three Cartesian axes directions using front coated plane optical mirrors and a Penta prism. The sight is configured for maximum overall transmittance with single layer antireflection coating and ease of alignment. The sight configuration is entirely a novel complex optical configuration for improves illumination in image plane. A reversed Galilean in articulation axis of sight improves the illumination of image seen by the observer eye. A Penta prism is introduced in the eyepiece channel for constant deviation of line sight. The on- axis transmittance of the sight is 25% and the off- axis transmittance is 60% of on- axis The sight occupies the space above the helicopter roof and below the roof.. The portion of the optical sight above the helicopter roof rotates from +120 deg to -120 deg in azimuth to sweep across the distant tank targets in azimuth and the head mirror scans the distant tank targets in elevation with articulation angles from +20 to -10 deg. The sight occupies a volume space of 550mm x 300mm x200mm. The sight acquires and recognizes the 2.7m X 2.7m X5.3 m tank targets of 10% contrast at a range of 4000 meters in all ups and downs of Indian terrain. The maximum diameter of mechanical tube that holds the optical elements of day sight is 45.0mm.

Keywords: Military direct view day optical sight, optical design, complex optical sight, three Cartesian axes fold optics

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INTRODUCTION

The direct view day optical sights are popular as rifle sights , light machine gun sights, heavy machine gun sights in small arms , military tank periscopes and ship periscopes with parallax errors 40 arc seconds and less.. These day sights have improved performance in regard to target acquisition capability. This results from the larger field of view and resolution attainable with the direct view optical sights. The human eye accommodation in direct view sights provides dynamic focusing for targets at different ranges thereby optimizing the resolution of these targets. A focusing mechanism is hardly optical required in these systems to optimize the resolution of targets at different target ranges. This results in reaction time of observer in mille seconds of time without degrading the resolution and without degrading the recognition/ identification performance. Direct view optical systems provide color clues, different depth perception clues such as parallax and eye accommodation for military objects at different distances These clues are significant for target ranges up to 5 kilometers and relatively insignificant for target ranges beyond 5 kilometers. These systems are optical a focals with a graticule / reticle in objective image plane in few systems and in majority of optical systems , grticule/ reticle is placed in the eyepiece object plane.. In patients and text book articles many optical schemes with regard to direct view day optical systems are given. They only describe the different configurations of direct view systems which remain incomplete because the optical design data is not given to assess the potential of configurations in terms of performance , weight , length and volume space I have not been able to find a optical schematic and design data of direct view optical day sight which is folded in all the three Cartesian coordinate directions in optics literature.

1. The optical / mechanical characteristic requirements of day sight

- The day sight shall acquire frontal view of combat tank targets having a contrast of 10 percent at a range of 4000 meters in all day light conditions and in all ups and downs of Indian terrains .The parallax error of the sight shall not exceed 40.0 seconds of arc.
- The mechanical tube diameters of sight shall not exceed 45.0mm.
- The volume space of sight shall not exceed 550mm x 300 mm x 200 mm of space.
- The sight shall articulate in azimuth and elevation for line of sight of tank targets.
- The sight shall be in two sections and one section of sight be mounted above the roof and the second section shall be mounted below the roof of combat helicopter .

- Image rotation compensation optical characteristics shall be incorporated in the optical sight for +120 deg to -120deg sweep in azimuth and +20 deg to -10 deg sweeps in elevation. The image rotation compensation prisms shall be placed in the section of sight that is mounted above the roof.

- The optical components for compensating image rotations during azimuth and elevation sweeps of distant tank targets shall be positioned in the section of sight which is planned for mounting above the helicopter roof.

- The day sight shall have elbow type of eyepiece

- The pilot of the helicopter shall be able to see the images of tanks on terrains during flight without eye fatigue.

2. Definition of sight and its parameters

The magnification is the key parameter of day sight which raises the angular substance of target at eye for resolving the target at a desired range. It is decided to be 10x.The magnification and field of view is interlinked and interdependent. The apparent field of view is now limited to 60 degrees to minimize the complexity of day sight. The object space field of view attainable is then equal to 60 degrees divided by the required magnification which is 6 degrees. In this manner, a determination is made to specify the magnification and field of view for the present application. The depth of focus of a refractive objective of the day sight is increased by selecting small clear apertures to objective or large f – number. This larger depth of focus under high levels of illumination in day time improves the target resolution. It is also decided a narrow field –of- view and long focal length combination for objective to improve the range performance of day sight.

3.1 Type of direct view optics

The direction in object space and image space must be the same for day sight that acquires the target. This is true for an optical system that contains parallel rays in object and image spaces and all principal rays remain un refracted. Such an optical system is known as optical telescopic system. Such an optical sight shall have the following parameters to meet the above l requirements. And the field of view of the sight is 4 deg x 6 deg which is attained by placing the field stop at reticle plane. The aspect ratio of field – of – view of sight is decided by the 2:3 aspect ratio of human eye that sees through the sight. The placement of field stop is essential because the eye has only aperture stop and there no field stop in human eye.

3. 2 Parameter that contributed to the configuration of optical elements in the day sight

- The maximum permissible diameter of mechanical tubes that hold the lenses of sight
- Preferences on locations of image rotation compensation characteristics
- Resolution of day sight
- Section area for recognition and 6 cycles across the same cross section. The sight is designed for 4and 8 cycles for better recognition and identification of 2.3 m x 2.3m or 2.3m x 5.3m tank cross section.
- The size of the military tank is 2.3m x2.3m x5.3m The sight shall resolve 1 cycle across 2.3 m x 2.3m or 2.3m x 5.3m tank cross section for detection , 3 cycles across 2.3 m x 2.3m or 2.3m x 5.3m tank cross

The optical characteristics of direct view optics is shown in table 1.

Table 1: Direct view optics parameters

parameter	Value
Magnification	10x
Field of view (contributed by ,recognition range of target)	4^0x6^0
Exit pupil diameter (Eye pupil diameter in day light)	4.0 mm
Eye relief	>12.0mm
Entrance pupil diameter (contributed by the illumination requirements of image seen through the sight, 10% contrast tank target of size 2.7mx27.7mx1.7m and 4000m range ()	

	40.0 mm
elevation line of sight/articulation	+20 deg to -10 deg
azimuth line of sight/articulation	+120 deg to -120 deg
(contributed by the ups and downs of the Indian terrain)	
Permissible lelength of sight along X -,Y -,Z- Cartesian coordinate directions	1265.0 mm
Volume space of the sight	550.0 mm x 300.0 mm x 200.0mm

+ The field stop is located in reticle plane of day sight.

4. System design of day sight

Human eye that sees a distant targets or an eye that receives collimated light beam is a relaxed human eye .The relaxed eye shall see the images of distant targets without any fatigue to the eye for longer periods of time. This makes the pilot of a combat helicopter uses a telescopic direct view day sight for continuous observation of combat tanks on all ups and downs Indian terrains. A narrow field telescope is rotated continuously for pointing the sight for all line of sight angles of the targets in the desired azimuth and elevation ranges. and thus tank targets are observed on all ups and downs of terrain This kind of articulation of sight continuously vary the orientations of images of targets seen through the sight. The orientations of images are restored to the true orientations of the targets using image rotation compensation optical prisms called rhomboidal or Dove or Pechan prisms. For these requirements, a first order optical layout is prepared for direct view day sight for combat helicopter application. The simple day sight has objective, an erector and an eyepiece which are generally accommodated in a length ranging from 250 mm to 300 mm. The articulate day sights have lengths from 1000mm to 3300 mm depending on type of combat helicopter. Transfer of images of external targets to the pilots eye over lengths of 1265mm in the present case requires the use of more than one relay optics in the day sight.. A general practice in optical design of day sights is that Dove prism is used for image rotation compensation in elevation and Pechan prism for image rotation compensation in azimuth. Articulation in convergent and divergent light shall increase the lateral dimensions of the sight. With this reason, a Dove prism is preferred in collimated light beam and Pechan prism is in a convergent or divergent light beam. Thus the elevation articulation is planned in parallel light and the articulation in azimuth in convergent light.. The recognition of military tank target of size 2.1 m x2.1m x 1.7and 10% contrast at a range of 4000 meters require an optical magnification of 10 x , an entrance pupil diameter of 40.0mm and a full field -of -view of 4 deg x6deg. The sights designed earlier with 40.0 mm entrance pupil diameter acquired combat military targets at range of 4000meter in Indian terrains in all day light conditions.. The volume space constraint of day sight is fulfilled with a reasonable number of folds of optical path in all three Cartesian coordinate directions. The entrance pupil diameter of human eye is taken as 4.0 mm which gives the maximum resolution of eye in day light conditions. With the above conclusions, an optical lay -out of optical sight for helicopter mounting for day use is made with different alternatives. The most general lay –out iincludes an objective . three numbers of relay stems and eyepiece combination in afocal form .But this has increased the diameters of some optical components in the sight larger than 45 mm requirement which is not acceptable for the present r application. The second option is a combination afocal systems with different magnifications. Each afocal system contains an erector lens and the diameters of erector lenses exceeded the acceptable diameter of 45.0 mm. The inevitable use of Dove and Pechan prisms , length of the sight, day light illumination levels in Indian conditions, minimum diameters for optical components for day sight in mind , an optical layout is engineered using main objective lens , collimating lens , Galilean afocal, imaging lens, two relay systems ,graticule and an eyepiece which restricted the diameters of all optical elements of the sight to within 45.0 mm for a wave length range 350 nm to 700nm and shown in figure1.The left side view of day sight mounted in the pilot position in a typical tank target acquisition helicopter roof and a tank target is shown in figure 2 . This lay-out of the day sight is folded in three Cartesian coordinate directions using front surface coated mirrors and a Penta prism. The transmittance of day sight is the most important parameter and this parameter qualifies day sight for acceptance .. The minimum transmittance required for any day use sights is 10% on off –axis and 20% on-axis with single antireflection coating on all the optical surfaces of optical components . Absorption by optical glasses of lenses in sight , scattering from optical surfaces of sight ,Fresnel reflection loses from optical components of sight ,cos4 loss contribute to the overall transmittance of sight. Single elements contribute to more Fresnel losses compared with doublet elements. It is preferable to use more number of doublet lenses and less number of single lenses to improve the overall transmittance of sight The absorption loss of the sight is controlled through thickness of the optical components. Thicker the optical component larger the absorption loss.

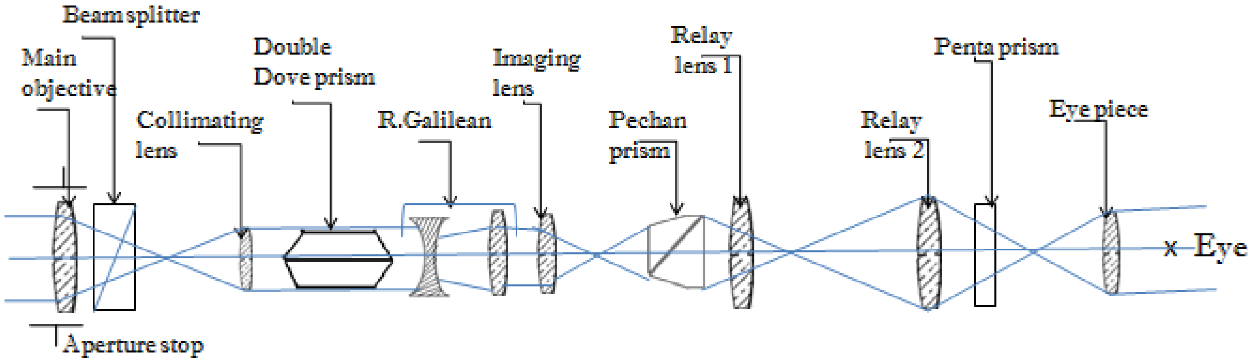

Figure 1: The first order optical lay-out direct view optical (DVO) sight

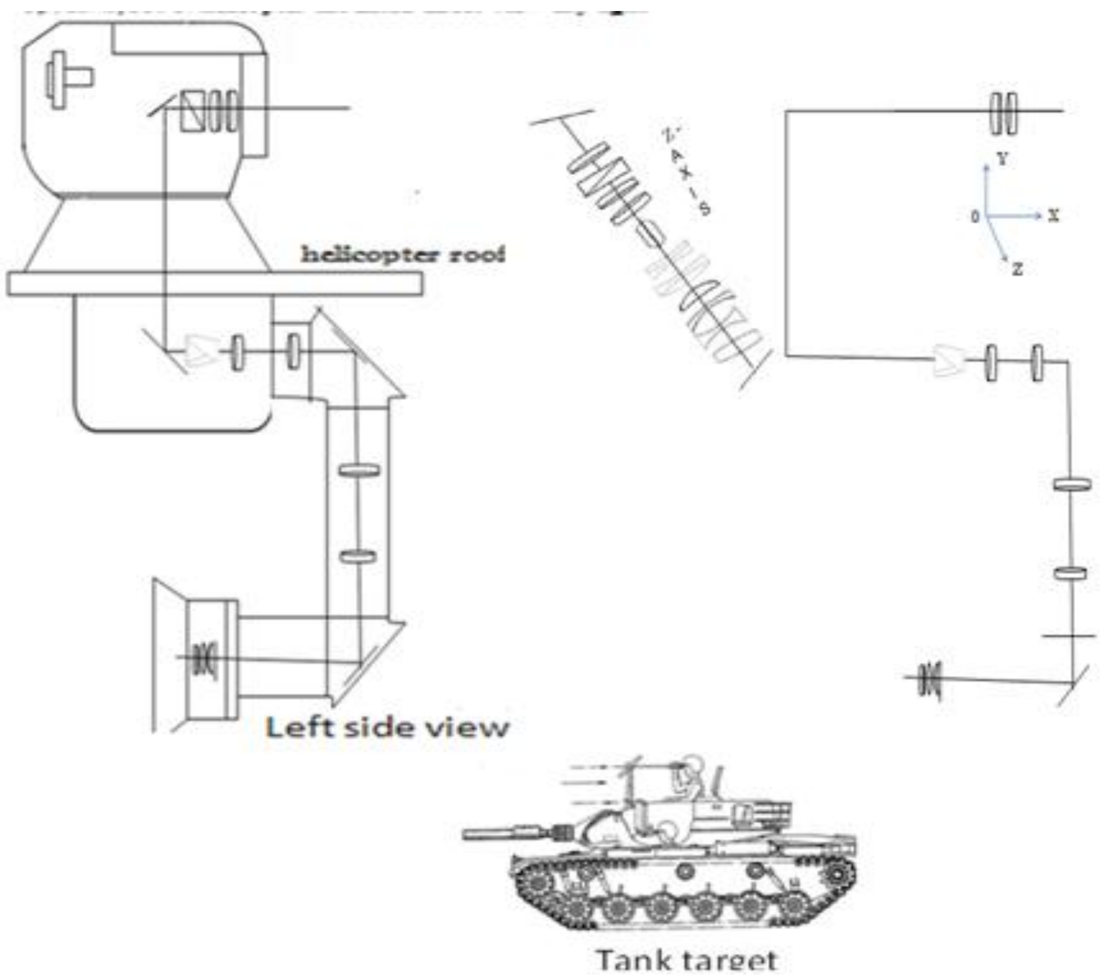

Figure 2: Left side view of day sight mounted in the pilot position in a typical tank target acquisition helicopter roof and a tank target

5. Configurations of main objective, collimating lens , imaging lens , relay lenses and eyepiece

5.1 Configuration of main Objective of day sight

The two doublet Petzval configuration covers a large aperture of f/2.0 and field –of - views up to 10.0 deg. at longer focal lengths. The available focal lengths in Petzval objectives ranges up to 1000mm. The length of the Petzval is 1.5 to1.9 times the focal length and this be can viewed as an advantage; considerable length of sight covered by Petzval itself. The zonal spherical aberration and coma of Petzval lens is small compared with other telescope objectives .This results a parallax errors less than 40.0 arc seconds depending on the coma at 0.7071 zone. Another advantage of Petzval lens is the wide air space available between two doublets which can be used to accommodate optical mirror for folding the optical path of the sight or to accommodate beam splitter in between to integrate day sight with a laser range finder / laser designator in future.. These advantages lead the preference of Petzval objective configuration for the main objective of the day sight.. In the context of day sights , Petzval configuration for main objective outsmarts all other telescope objective configurations.

5.2 Collimating lens

The collimating lens l covers an apparent field of 60 degrees .The collimating lens is a two cemented doublet system.. The length between first vertex to back focus is only60.12mm.

5.3 Imaging lens

The imaging lens is a all single lens four element lens system. The configuration is two closely space positive , negative menisci followed by widely spaced biconcave and biconvex lenses. The configuration is not a conventional one and a novel configuration is adopted for imaging lens. The vertex to vertex length of imaging lens is 57.37mm.

5.4 Two Relay systems 1 and 2

Each relay is a widely spaced two cemented doublet configuration and designed for long finite conjugates. The Pechan prism is accommodated in the image space of the first relay.

The long conjugate relays are configured for day sight so that optical plane mirrors accommodated in conjugate spaces for folding of sight

5. 5 Eye piece

The eyepiece is configured with a positive meniscus field lens, biconvex lens middle and a cemented doublet eye lens. The focal length of eyepiece is 20.0mmThe vertex to vertex length of eye piece is 21.38mm.

5.6 Image compensation optical components

The portion of day sight mounted on roof of the helicopter rotate to sweep the distant targets in azimuth and the head mirror rotate in elevation to sweep the distant targets. These rotations cause image rotation in both azimuth and elevation of image. Image rotation compensation is one of the fundamental requirements in day sights. It is decide to compensate the image rotation in elevation using Dove prism. Double Dove prism is preferred over single Dove prism to reduce the length of prism as well as to double the clear aperture of prism to meet the axial and off- axis beam diameters in the sight. Pechan prism corrects image rotation in azimuth.

6. Optical Design of direct view optics

The five monochromatic aberrations namely spherical aberration (change of on –axis focus with aperture), coma(change of magnification with aperture), astigmatism(distance between sagittal focus and tangential focus), Petzval curvature(basic field curvature of image for straight line object), distortion (image height less than f tan 0 which is pin cushion distortion and image height more than f tan 0 which is barrel distortion) , two color aberrations that is longitudinal chromatic aberrations(change of focus with wavelength) and lateral color(change image height with wavelength), longitudinal secondary spectrum(longitudinal movement of image with wave length), lateral secondary spectrum(lateral movement of image with wavelength)are corrected by altering the lens parameters in optical system. Power distribution of lenses in the system and air separation between lenses quantifies the amount of petzval curvature whether it is small or large which is inevitable. The other four monochromatic aberrations depend on powers of individual lenses, lens shapes and air spaces between individual lenses and stop position. The two color aberrations depend on individual powers of lenses, air spaces among them, V -numbers of optical glasses used for lenses and refractive indices of lenses .Glass pairs with a large V -difference and large air spaces in doublet lens exhibit negligible longitudinal chromatic aberration (Lch).Glass pairs that have small V- difference rapidly introduce large amount of longitudinal chromatic aberration. The glass pair of equal V -number difference raising the refractive index of positive lenses in the doublet lenses reduce longitudinal chromatic aberration is relatively unaffected by transverse color in optical system Hence reduction of Lch can be accomplished in the doublet lens by increasing the V- number difference between two glasses or by raising the refractive index of the positive lens to as high a value as possible. Instead of choosing a zero lateral color, it is found desirable to choose a solution with a little positive lateral color at the center of the field in order to compensate the negative higher order lateral color at the outer part of the field .Lateral color may be further reduced if the lens system is slightly over corrected for axial color. A Seidel analysis of lens system is quite instructive on the choice of lens shapes in systems whether it is objective or eyepiece or rely lens to be made between various lenses. In setting limits for these aberrations the criteria is used on the resolving power of the human eye namely 1 or 2 minutes of arc and the magnification of sight is chosen for this resolution, The distortion can be taken care in the sight by a suitably designed reticle for the sight. For infinite focal length system like a day sight in the present case, Petzval curvature of sight at field angles is eliminated with proper magnitudes of astigmatism in eyepiece and other lenses . The aberrations due to tilt and de-center of optical components in the sight are brought to tolerable limits so that rays in object space and image space are parallel and direction of distant object in object space is identical to the direction image in image space ,the two main properties of a focal day sight are retained. An aperture stop in between objective and eyepiece increases the diameters of optical elements of sight. As the field of view requirement of day sight in object space is 6 degrees, it is decided to locate the aperture stop on the main objective of day sight to reduce the lens diameters of optical components which follow the objective. All most of all lenses in the sight are brought as close as possible or edge contacted for minimum aberration contributions and minimum vignetting which improve the illumination in image plane. The sight is designed for 6 degrees circular field of view. A rectangular field stop in the reticle provides a 4 deg x 6 deg field of view in the object space of day sight. When a field stop is in the image plane, the exit window lies on the stop itself and the entrance window coincides with distant object in all visual instruments like day sights[1,2].

6.1 Aberration correction of direct view optics

The a brief description of aberration correction of and the entire optical characteristics of sight is shown as optical characteristics of two different optical assemblies along with their optical design data This provides complete optical characteristics of subsystems in the sight

, number of optical elements in the sub systems, number of sub systems in the sight , components for folding optical path and the number of folds in x-, y- .z- Cartesian coordinate directions. The day sight is a focal system. The focal length of a focal is infinity and power is zero. The entrance and exit pupil positions of a focal are totally different from objective, collimating lens. Imaging lens, two relays and eyepiece. For this reason, objective, collimating lens. Imaging lens, two relays and eyepiece are treated as Independent subsystems and designed for desired tolerances [3-5]. Then objective, beam splitter, collimating lens. Dove prism, Galilean a focal, imaging lens ,two relays , Pechan prism and reticle together treated as one optical assembly 1and corrected for aberrations. The optical assembly 2 consists of eye piece only.

6.2 Aberrations Dove and Pechan prisms

The prisms are represented by thick plane parallel optical glass plate in optical design. The Dove and Pechan prisms are tilted thick glass plates. The aberrations of these prisms are equivalent to aberrations of thick negative lens .All the aberrations of prisms are negative in sign. The aberrations of Dove prism is compensated by imaging lens whereas the aberrations of Pechan prism is compensated by first relay lens.

6.3 Optical design of optical assembly1

The beam splitter is added in the optical assembly1 for integrating laser range finder and laser designator later. The aperture stop is placed on first surface of objective The Dove prism , Pechan prism ,reticle along with the independently corrected sub systems which are objective, , collimating lens., Galilean afocal , imaging lens ,two relays are assembled in to an optical assembly1,

In the initial stage of Seidel aberration corrections, the optical assembly1 calculated. The optical surfaces in optical assembly 1 that contributed to large Seidel values are identified and the sub systems that contained these optical surfaces are redesigned for five Seidel monochromatic aberrations and two Seidel chromatic aberrations. The process is repeated until the individual Seidel surface contributions are low and aberrations of each sub system is within the desired limits. Again optical assembly1 is formed with these subsystems and the Seidel aberrations of optical assembly1 is brought to desired limits by the repeated correction of subsystems for aberrations. The trigonometrically ray tracing is performed on the optical assembly1 for actual aberrations. Until the actual aberrations are within the limits, Seidel aberration corrections of subassemblies and optical assembly1 are repeated. Thus the optical assembly1 is qualified for Seidel and actual aberrations and actual aberrations as well.[6]

6.4 Optical design of optical assembly2

The optical assembly2 is only eyepiece. In a eyepiece design , the aberrations are controlled either by bending technique or appropriate matching with associated with optical assembly2.. As the focal length of eyepiece is small, there is high concentration of positive power. Moderate control on Petzval sum exists for eyepiece configuration. Large petzval sum is neutralized by introducing over corrected astigmatism but too much of this, of course badly blur the image at extreme field angles [7,8]. The compromise is the designer who must consider the end use of day sight. Eye does not significantly notice sagittal curved image which lie within 1.0 diopter of the cental focus, and the images will be reasonably are defined over the field. In the absence of astigmatism, a young observer can focus on the edge of the field angle and accommodated about 3.0 diopters for the central field, although the outer portion of the field will swim considerably as the eye is moved about in the field. A flat tangential field combined with a 3.0 diopter of sagittal field image will just about correspond to the largest astigmatism that can be tolerated by the eye; in this case the outer field is useful only for identifying the presence of a possible target. Yong or old observers can observe 3.0 diopter of sagittal field curved image comfortably with a ocular focusing (diopter setting) of 0 diopter on -axis and -2.0 diopters at extreme field . r. The detailed design of these lenses require large space in this article .the correction of aberrations is discussed in their usual order.

- **Spherical aberration**

The telescope objectives and photographic objectives are corrected for under corrected spherical aberration. The under corrected spherical aberration is difficult to control in wide angle lenses like eyepiece, collimating lens and imaging lenses. And may be possible to a minor extent. This is because of short focal lengths small pupil size involved with these lenses. The actual spherical aberration is small in these lenses and in most cases undetectable and amounting to a few length of a millimeter. A slight over correction of spherical aberration in preceding lenses can compensate easily for these lenses.

- **Coma.**

A monocular eye piece is used in day sight. The f- number of collimating, imaging lens and eyepiece is very large. Coma in these lessees are compensated by bending technique and appropriate matching with the associated lenses preceding to eyepiece.

- **Astigmatism and field curvature**.

Moderate control of Petzval sum exists for eyepiece because of short focal length. The astigmatism and field curvature are compensated together. The optimum amount of over corrected astigmatism of proceeding lenses balance these aberrations in eyepiece. The bending techniques that usually used for correction of spherical aberration and coma in telescope objectives and photographic objectives are used for eyepiece to correct astigmatism to the desired limit.

- **Distortion**

This aberration is compensated in eyepieces by the preceding lenses and the balance distortion amount is accepted as it turnout. Later this balance distortion is compensated in the reticle design of the day sight.

- **Lateral color**

This is the most important aberration in eyepieces in setting the configurations of eyepieces. The grouping of individual lenses in these lenses involve positive elements of a low dispersion and negative lenses of high dispersion So that lateral color compensation is achieved. For telescope objectives, the compensation is for longitudinal chromatic aberration and the lateral color is relatively unimportant. For wide angle lenses like eyepieces the reverse is true. However the presence of higher order effects make the procedure of designing eyepieces more complex A satisfactory solution for aberrations in eyepiece is obtained using proper V-number values for positive and negative lenses in eyepiece. The aberration corrections of direct view optic are shown in the Table 2.

Table 2: Aberrations at the end of day sight Trigonometrically ray trace

Aberration	System minus eye piece	Tolerance	Eye piece	Tolerance	Total aberration at the end of day sight	Aperture / field
spherical aberration	-0.022257	+0.126043	+0.140560	+0.125782	+0.118303	Full aperture
	+0.109399	+0.188502	+0.070178	+0.188842	+0.179577	0.7071 aperture
OSC'	+0.002271	+0.002500	+0.002219	+0.002500	+0.000052	Full aperture
	-0.000751	+0.002500	+0.001110	+0.002500	+0.001861	0.7071 aperture
Lch	-0.389306	+0.126043	+0.052150	+0.125782	-0.337156	Full aperture
	-0.174979	+0.000000	+0.053133	+0.000000	-0.121846	0.7071 aperture
X_s	+1.482606	+0.764420	+0.4088909	+0.764761	+1.891515	Full field
	+0.778110	+0.764420	+0.213211	+0.764761	+0.991321	0.7071 field
X_t	-0.167197	+0.764420	-0.87500	+0.764761	-1.042197	Full field
	-0.407258	+0.764420	-0.453177	+0.764761	-0.860435	0.7071 field
X_t-X_s	-1.649803	+0.764420	-1.283909	+0.764761	-2.933712	Full field
	-1.185368	+0.764420	-0.666388	+0.764761	-1.851756	0.7071 field

	+0.006899	+0.002500	+0.007902	+0.002500	-0.001003	Full field
CDM	+0.010512	+0.002500	+0.009536	+0.002500	+0.000976	0.7071 field
	9.9%	5.0%	6.5%	5.0%	3.4%	Full field
DIST	5.0%	5.0%	3.5%	5.0%	1.5%	0.7071 field

- Eye resolution is 5lines/ millimeter at 2 minutes of visual acuity The depth of focus of eye is 0.040millimeter.the lelaxed eye sees the distant target. Visual latency of eye in day light conditions are 200 to 300 m sec.4 mm eye pupil diameter is the diameter of maximum visual acuity. Amplitude of accommodation or defocus of eye is 0 to 5 diopters for an age group of up to 60 years age. They eye exhibits positive spherical aberration when it sees distant object, negative spherical aberration for near objects and zero spherical aberration for an object at 50 cms. The chromatic resolving power of eye is about 3.0 A.UTHE LIGHT GATHERING POWER of day sight is 40 mmx40mm/5mmx5mm which is 64 times the light gathering power of eye. On the special marks of n the reticle at the centre of the image, the observer sees the angular dimensions of tank at 4000 meter range as 0.6 m. rad. Length and 1.5m.rad. Width. The pilot of the helicopter sees the terrain with a naked eye and the selected sectors of terrain is seen through day sight for recognition of the tank targets at 4000m range.

- **Comments on the aberration data**

The astigmatism is somewhat beyond the tolerance at the edge of the field and rapidly converges to tolerance value at about 0.7071 fields for that reason it is considered acceptable. The eye can tolerate 2.0 diopters of astigmatism in visible sights like direct view optics which is the present case. Suitably designed reticle takes care of distortion in the sight. The sight is better corrected for aberrations than the resolution requirements for of 4 cycles across front end view of 2.3mx2.3m or side view of 2.3mx5.3m of a combat tank target.

The final optical characteristics of the articulated day direct view optics is shown in table 3.

Table 3 Final optical characteristics of the articulated direct view optics for day use .

Parameter	Value
Focal length of optical assembly 1	208.7748 mm
Focal length of optical assembly 2	20.0 mm
Magnification	10.4
Full field – of – view	4^0x6^0
Apparent field – of- view	41.6^0x62.4^0
Entrance pupil diameter	40.0 mm
Exit pupil diameter	4.0 mm
Eye relief	16.64 mm
Length of the optical path	1243.0 mm

The articulated direct view optics is configured with the above six optical assemblies using front coated plane mirrors at appropriate locations in the optical paths of optical assemblies. The optical path in the three Cartesian coordinate axes directions are shown in figures 3 to 9and the optical design are shown in Tables 4 to 8.

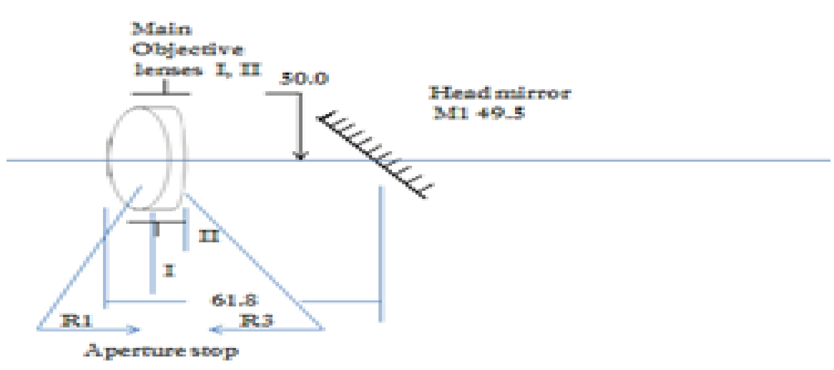

Figure 3: Optical path 1 along x-axis above the helicopter roof

Table4: optical design data of Optical path 1 along x-axis above helicopter roof

Lens	Glass	R1	R2	R3	CT	CA
I	BSC 517642	102.4 VEX	120.96 VEX		8.7	40.0
II	EDF 648338		120.96 CAV	1281.36 VEX	3.1	40.0

ALL THE DIMENSIONS ARE IN mm

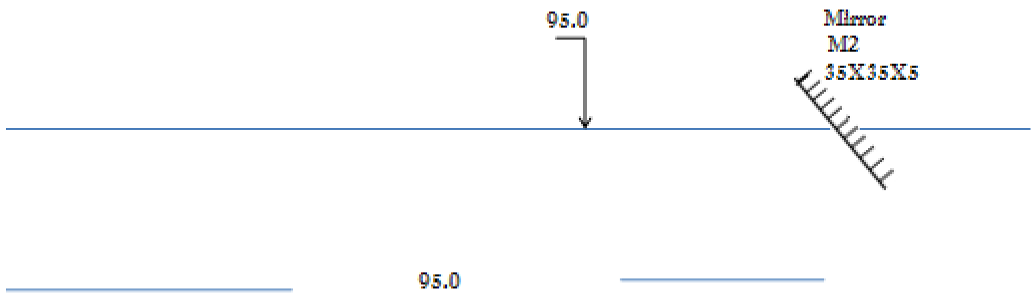

Figure 4: Optical path 2 along Y –axis above the helicopter roof

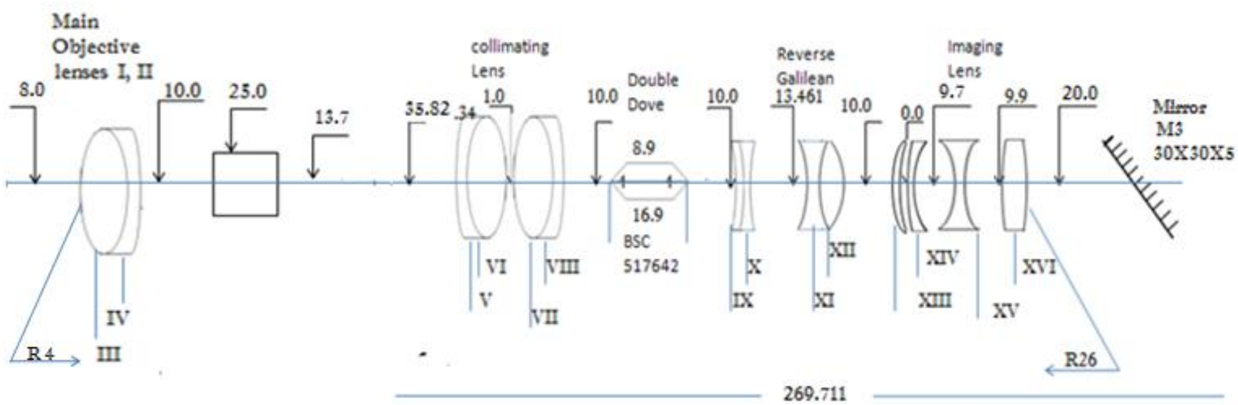

Figure 5: Optical path 3 along Z-axis above helicopter roof

Table 5(a): optical design data of Optical path 3 along Z –axis above the helicopter roof

LENS	GLASS	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	CT	CA
III	BSC 517642	87.65 VEX	220.4 VEX											9.7	27.80
IV	EDF 648338		220.4 CAV	358.78 VEX										3.5	27.80
V	DEDF 717295				900.0 VEX	60.0 CAV								4.0	12.0
VI	DBC 620603					60.0 VEX	54.0 VEX							8.0	12.0
VII	DBC 620603							54.0 VEX	60.0 VEX					8.0	12.0
VIII	DEDF 717295								60.0 CAV	300.0 VEX				3.3	12.0
IX	SF61 751275										49.04 CAV	26.71 VEX		5.4	10.8
X	LAC 641601											26.71 CAV	34.87 CAV	3.0	10.8

ALL THE DIMENSIONS ARE IN mm

Table5(b): optical design data of Optical path 3 along Y –axis above the helicopter roof

LENS	GLASS	R16	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	CT	CA
XI	F7 625356	1326.26 CAV											3.0	25.2
XII	LaF2 744447		29.16 CAV	29.16 VEX									9.27	25.2
XIII	DBC 607595				60.0 VEX	550.0 CAV							10.0	28.0
XIV	DBC 607595						34.94 VEX	16.24 CAV					7.9	28.0
XV	SF53 728287								150.8 CAV	26.41 CAV			3.5	24.0
XVI	LAC 734517										58.0 VEX	47.81 VEX	17.36	32.6

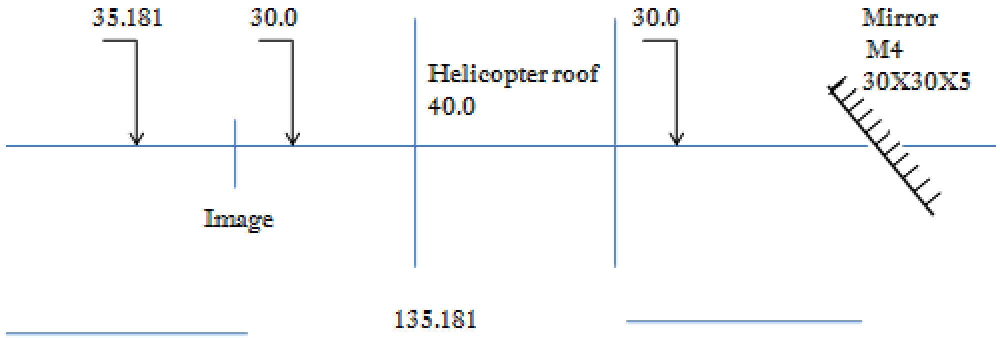

Figure 6: Optical path 4 along Y – axis above the helicopter roof.

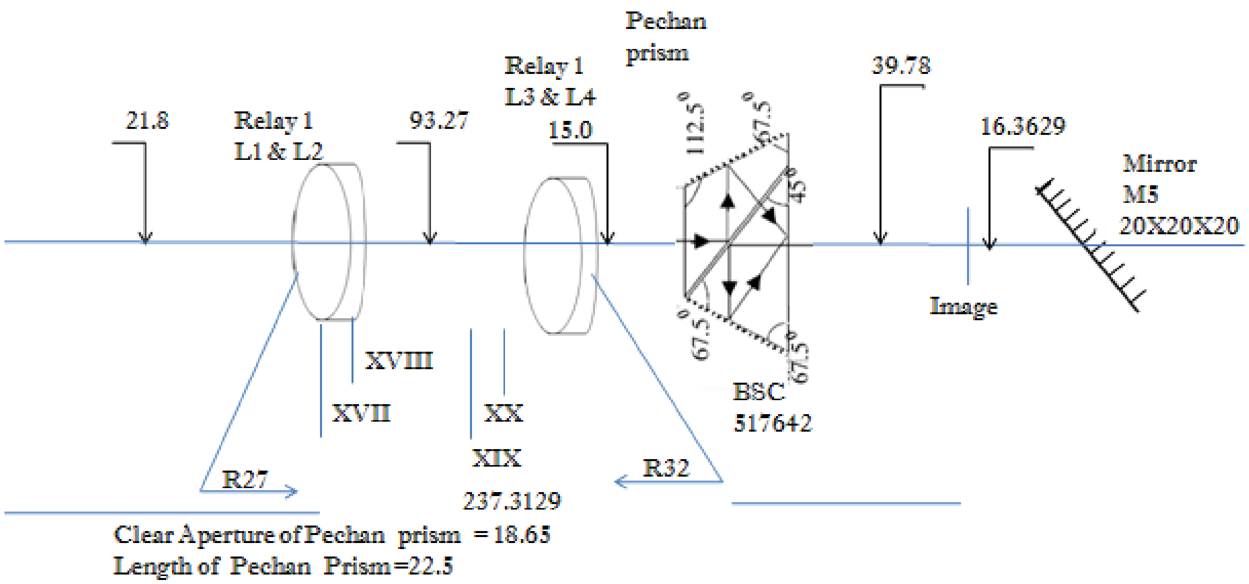

Figure 7: Optical path 5 along x – axis below the helicopter roof.

Table 6: optical design data of Optical path5 along X – axis below the helicopter roof.

LENS	GLASS	R27	R28	R29	R30	R31	R32	CT	CA
XVII	EDF 648338	82.95 VEX	33.53 CAV					1.86	30.0
XVIII	HC 524592		33.53 VEX	134.68 VEX				12.44	30.0
XIX	HC 524592				134.68 VEX	34.82 VEX		12.44	30.0
XX	EDF 648338					34.82 CAV	74.62 VEX	1.86	30.0

ALL THE DIMENSIONS ARE IN mm

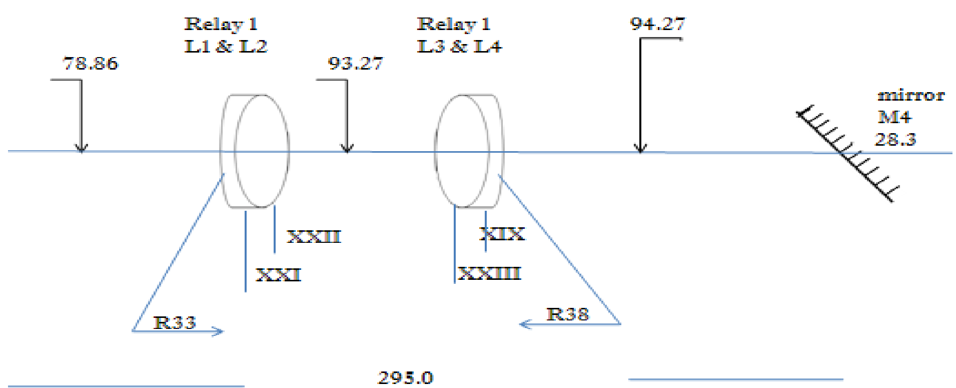

Figure 8: Optical path 6 along Y –axis from the helicopter roof to the observer end

Table 7: optical design data of Optical path 5 along Y –axis from the helicopter roof to the observer end

LENS	GLASS	R33	R34	R35	R36	R37	R38	CT	CA
XXI	EDF 648338	82.95 VEX	33.53 CAV					1.86	5.2
XXII	HC 524592		33.53 VEX	∞				12.44	5.2
XXIII	HC 524592				134.68 VEX	34.82 VEX		12.44	12.0
XXIV	EDF 648338					34.82 CAV	74.62 VEX	1.86	12.0

ALL THE DIMENSIONS ARE IN mm

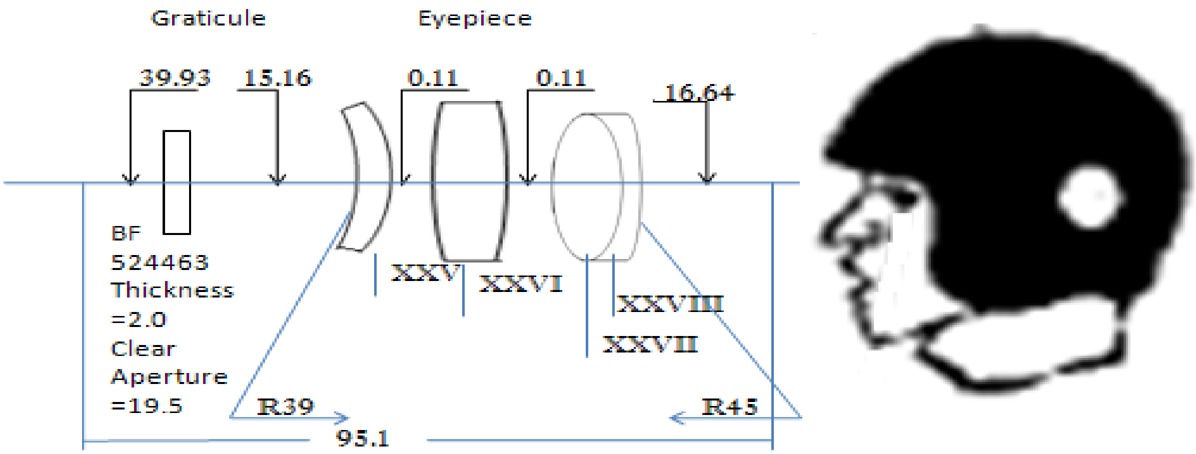

Figure 9: Optical path 6 along x –axis towards observer eye below the helicopter roof

Table 8: optical design data of Optical path 7 along x –axis towards observer eye below the helicopter roof

LENS	GLASS	R39	R40	R41	R42	R43	R44	R45	CT	CA
XXV	DBC 620603	239.73 CAV	26.85 VEX						5.22	20.0
XXVI	DBC 620603			107.18 VEX	45.54 VEX				5.33	17.7
XXVII	DBC 620603					28.76 VEX	28.76 VEX		9.27	16.0
XXVIII	SF18 722293						28.76 CAV	57.11 VAC	1.34	16.0

ALL THE DIMENSIONS ARE IN mm

7.0 CONCLUSIONS

The optical configuration and optical design data of panoramic sight with articulation of +120 deg to -120 deg in azimuth and articulation of +20 deg to -10 deg in elevation for military helicopter application is presented The sight is configured in volume space of 550mm x 300mmx 200mm The optical path of sight is folded in all the three Cartesian coordinate directions. The sight acquires military tank targets at a range of 4 Kilometers in all day light conditions on Indian terrain. The optical transmittance of sight is 25 percent on –axis and 60 percent of 25 percent on .off-axis with all optical components coated with single antireflection coating. A transmittance of 10 percent is required for recognition of frontal view of tank having contrast of 10 percent. This helicopter mounted day sight met all the requirements to recognize the tank target on Indian terrains.. This is entirely a novel compact and complex optical configuration folded in three Cartesian coordinate directions for articulated panoramic direct view day sight for helicopter application. There is no such sight so far reported in patents and text book literature to my knowledge.

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