Optical Design of Two Field of View Infra-red Objective in 3-5 Micron Band for Focal Plane Array Detector

M. Hammad Asghar
Optical Design Group
Advance Engineering Research Organization
E-5, Officer Colony, Wah Cantt.47040. Pakistan.
e-mail: hamasghar@hotmail.com, mailto:mha_19@yahoo.com

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Abstract

An easy and simple approach has been used in designing an objective with two fields of view working in 3-5 micron band. The field of view (FOV) in narrow mode is four degrees whereas field of view in wide mode is ten degrees giving a magnification of 2.5X. Priority is given to the use of conventional lens materials to make the design simple and practical. Use of aspheric and diffractive surfaces have been made to reduce the total number of elements in the design, and also to reduce the magnitude of the aberrations to an acceptable level. Four elements are used in narrow field of view mode and additional two element used as a clip-in group are used to change the field of view from narrow to wide field of view. Making a total number of six, in all.

The performance of the objective is reasonably good keeping in view the number of elements used in the design. The performance is reasonably close to diffraction limit as exhibited by modulation transfer function (MTF) curves, and spot diagrams at different field positions. The design can be used for commercial as well as military applications.

1. Introduction

In this paper an attempt has been made to explain the design of a 2 field of view objective for a focal plane array based system working in 3-5 micron band. The fields of view are narrow and wide. Narrow field of view design comprises of four elements where as wide field of view design has six elements.

The field of view change mechanism has been proposed to be a clip-in group which when inserted into the objective changes the field of view from narrow to wide. When removed out, switches back to narrow mode.

Beside refractive spherical surfaces, aspheric and diffractive surfaces are also used in the design. This not only helps in reducing the number of elements in the design but also helps in reducing spherical and chromatic aberrations [1,2].

Preliminary calculations are done to determine the first order values of the optics for both fields of view. Based on these values, the design in then optimized for better performance. The complete optical system for two field of view, along with its performance is shown in the figures 1-6.

2. Calculation of 1st order Values

Based on the following detector specifications, first order values are calculated as follows:

Detector Pixel Size	30X30 micron
Array Size(256X256 pixels)	10.72X10.72mm

Cold Filter Spectral Band	3.4 to 4.9 microns
Inter-pixel spacing	12 microns
Detector Pitch	42 microns

2.1 F-Number

F/# of the optics is calculated, so that the Airy-Disk diameter equals the Pixel size:
$D_{Airy} = 2.44 \text{ X } \lambda \text{ X F\#}$
$F/\# = D_{Airy} / (2.44\lambda)$
$F/\# = 30/(2.44 \text{ X } 4.95) = 2.5$

2.2 Field of View

Narrow Field of view: Total Diagonal FOV = 4 degrees, with same horizontal and vertical FOV, given as HFOV=VFOV=2.82 degrees. The array is a square, therefore the Aspect Ratio = 1
Wide field of view: The ratio between narrow and wide FOV is 2.5, so the field of view in wide mode is 10 degrees.

2.2 Focal Length in NFOV(Fn)

Focal length in narrow field of view is given as:
Fn=Detector Dimension/FOV
Fn=219mm

2.3 Entrance Aperture (Dn)

The narrow field of view entrance aperture is given as:
Dn=Fn/F#
Dn=88 mm (for narrow field of view)

2.4 Focal length in WFOV (Fw)

Focal length for wide FOV is given as:
Fw=Fn/2.5
Fw=219/2.5=87 mm

2.5 Entrance Aperture in WFOV (Dw)

The entrance aperture in WFOV is given as:
Dw=Fw/F#
Dw=35mm

2.6 Resolution

The resolution in object space using Rayleigh criterion is given as:
$\theta r = 1.22\lambda c/Dn$: where $\lambda c = 4.5$ micron
This gives: $\theta r = 0.062\mu rad$

2.7 Detector Pixel instantaneous FOV

It is abbreviated as IFOV and is given as:
IFOV=Detector Size/Fn
IFOV= 0.136 µrad (in the object space)

2.8 Cut-Off Frequency

The cut-off frequency in the image plane is:
$f_{cutoff} = 1/(\lambda \text{ X F\#})$
$f_{cutoff} = 1/(4.5\mu \text{X} 2.5) = 88$ cycles/mm

2.9 Cold-Shield Angle

The cold-shield half-angle is calculated from the relation between F# and numerical aperture(NA):
F#=1/2NA,
Or NA=1/(2X2.0)=0.25
Cold Shield angle=$\sin^{-1}$(NA)
Cold Shield angle=14.50 degrees

3. Optical Design Configuration

For the 100% cold-shielding requirements, the cold-shield inside the detector/dewar assembly should be made as the aperture-stop/exit-pupil of the system [3]. So, only two types of optical designs are possible. One with the re-imaging optics, and other with out re-imaging optics. Due to the long focal length associated with the narrow FOV and large entrance pupil, the re-imaging optics is the only choice, which results in smaller front-lens diameter (equal to the entrance aperture in narrow FOV mode). If re-imaging optics is not used, the front lens diameter will be much larger than entrance aperture due to the pupil wander to accommodate the off-axis beam.

4. Design Explanation

As mentioned, there are four elements in the narrow field of view design. The basic lens element in the design is silicon lens. Element 1, 2 and 4 are silicon lenses and element 3 is a germanium lens. Aberration have been tried to control with the help of a group of elements comprising of high dispersion elements (silicon) and low dispersion element (germanium). Also aspheric and diffractive surface have been used (surface 1 and surface 2 respectively) in order to further reduce the aberrations as well as the number of elements, and improving the performance of the system. The use of diffractive optics is popular these days to make the design compact with improved performance [4,5,6]. Exit pupil is made as aperture stop in order to control the diameter of the front lens and beam wandering.

When clip-in group comprising of a negative (ZnS) and positive (Si) elements is inserted in the narrow design, the focal length and field of view of the system is changed. ZnS element is used with its right side as diffractive surface to reduce the problem of color and other aberrations in wide field design. First surface of the positive element in the clip-in group is made as conic, with a concept to further reduce the magnitude of aberration for improving the systems performance.

Figure 1 shows the optical design in narrow field of view with aperture stop on surface 9, which is simulated as cold shield of the system. Figure 2 exhibits MTF plots at different field points for narrow field objective. From the MTF plots it is clear that the performance of the system is reasonably good i.e. very close to 80% diffraction limit. Figure 3 & 4 shows the optical design in wide field of view with aperture stop located at surface 13 and MTF plots at different field points respectively. Again the MTF of the system is within an acceptable limit. Figure 5 & 6 shows the multi-color spot diagram for narrow and wide fields at different field points. It can be seen that nearly 80% energy in the spot diagram lies within the desired spot size value given in the calculations above.

5. Conclusion

An attempt has been made to give an acceptable design by using minimum number of lens elements. As an example only four elements are used in narrow field design and two additional elements in wide field design. Further, emphasis has been given to the maximum use of the lenses of conventional materials like silicon and germanium. Only one ZnS element is used in clip-in group. The design is showing a reasonably good performance with 4-6 lenses in narrow and wide field of view, and can be used in commercial or military applications.

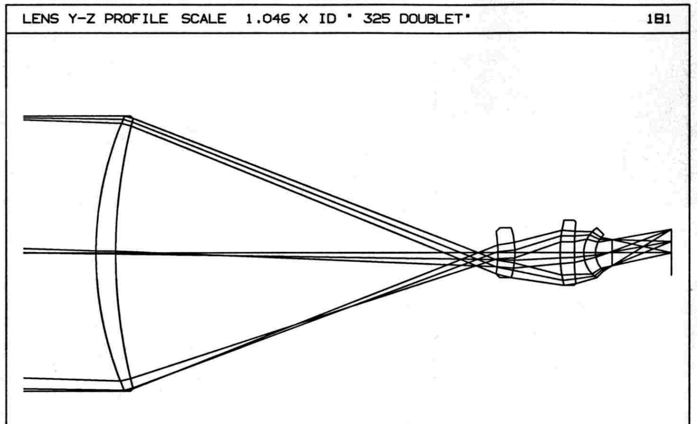

FIG 1: OPTICAL DESIGN FOR NFOV OBJECTIVE

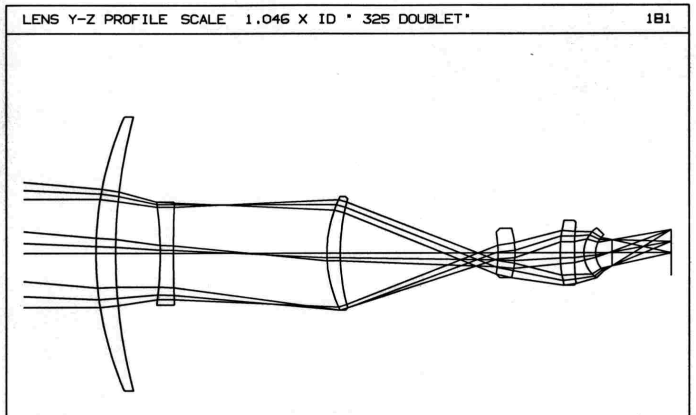

FIG 3: OPTICAL DESIGN FOR WFOV OBJECTIVE

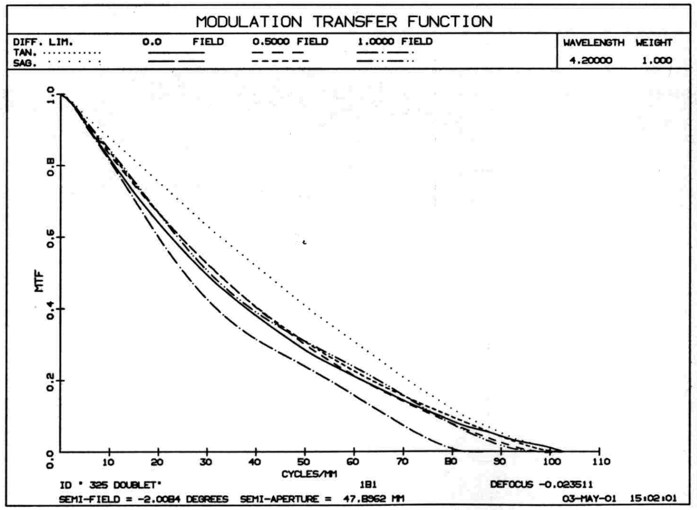

FIG 2: MTF PLOTS (NFOV) AT DIFFERENT FIELD POINTS

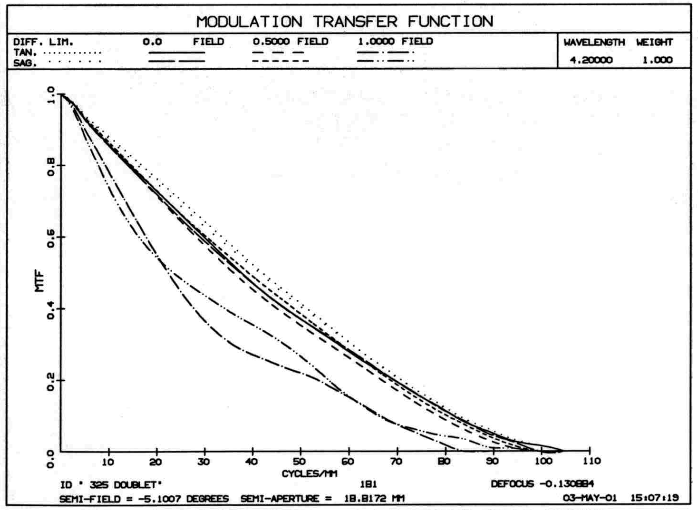

FIG 4: MTF PLOTS (WFOV) AT DIFFERENT FIELD POINTS

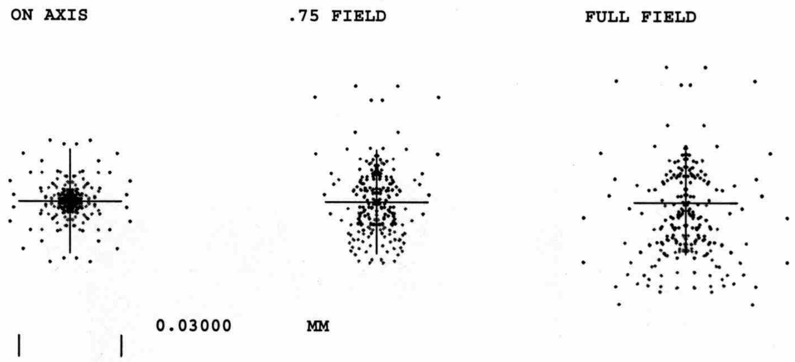

FIG 5: Spot diagram (NFOV) at different field points

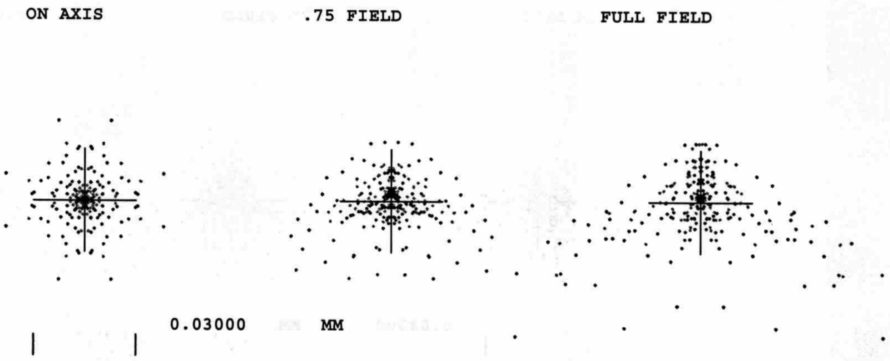

FIG 6: Spot diagram (WFOV) at different field points

6. References

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