OPTICAL PAYLOAD DESIGN FOR CUBESAT

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Abstract-- Telescope Objective is very essential component of overall optical payload design of Cube Sat [1] .In this paper, a design of objective operating in visual band is done using ZEMAX software. The refractive design is chosen since reflective one provides smaller FOV. In order to get high resolution we picked up a detector with pixel pitch of 3.6 µm with a high MTFA value of .5 at spatial frequency resolution boundary (NY Quist frequency) of 139 cycle/millimeter, in order to cover wide FOV this detector pixel pitch and small focal length value provides so. The limitation to this design was size of this objective as in the 3U Cube Sat, the objective uses 2U as other papers show we have restrict on the size only limited to 1U and every U is 10*10*10 cm. In this paper, we have managed to avoid this limitation on size presenting an objective design with very high performance image within the pixel pitch of chosen OV7670 sensor 3.6 microns pixel pitch.

Keywords— Optical payload, Refracting Objective, Cube Sat Telescope design, Average Modulation Transfer Function (MTFA), RMS spot radius.

I. INTRODUCTION

The optical instrument is the main payload, guiding the photons to the detector in the best way possible depending on the mission strategy .It is composed of an assembly of optical surfaces which can be reflective, refractive or diffractive [2].

In this paper, the compactness of refractive design in the Cube Sat telescopic design resulting in high image performance despite of limitation in size discussed. Therefore, in this paper, we introduce design theory, calculations of design, layout and results of design.

II. DESIGN THEORY

This design is expected to have high performance optically and compactness mechanically. So from optics point of view high resolution is achieved with MTFA equal to 0, 5 and RMS spot radius centered at the pixel pitch of the detector. From mechanics point of view it should have small dimension and weight as much as possible in order to lower the cost of manufacturing and production [3].For our objective detector model (OV7670) may be used. This detector dimension is 640*480 pixel, with pixel dimension 3.6µm [4]. The mission is at an altitude of 480km with resolution of 35m.The parameters of optical payload is calculated using figure 1 and results is shown in table 1.

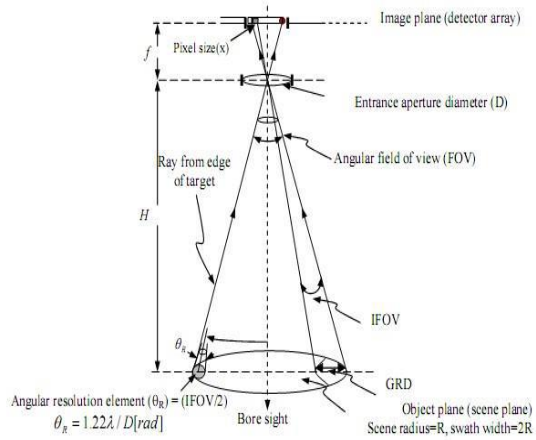

Fig.1 shows optical design parameters of an optical payload

Table 1 shows our objective required Specifications, detector characteristics and optical payload parameters used in design calculations **[5].**

Swath width	28km
Resolution at altitude of 480km	35m
Spectral wave band	,4-,7µm
Effective focal length (EFFL)	50 mm
Entrance Pupil Diameter	10mm
F/#	5
Detector type	640*480 CMOS.
Detector model	OV7670
Pixel pitch	3,6 µm

Table1.required specifications, parameters used and detector characteristics for our objective

III-DESIGN CALCULATIONS

In this section design, calculations containing the field of view (FOV) with start point calculations are shown.

A. field of view

HD=number of horizontal pixels * pixel pitch (1)

VD= number of vertical pixels * pixel pitch (2)

$$\text{HFOV}=2\tan^{-1}\left(\frac{\text{HD}}{2*EFFL}\right) \quad (3)$$

$VFOV = 2\tan^{-1}(\frac{VD}{2*EFFL})$ (4)

Then HD, VD, HFOV and VFOV are about 1,728mm, 2.304mm, 2°, 2.7° respectively. According to these results, our objective design is analyzed at three fields of view on axis FOV, .5FOV=2° , Full FOV=4°.

B. *start design calculations*

We used the Cooke triplet to design the refracting telescope as shown in figure 2.The Cooke Triplet consists of three elements.

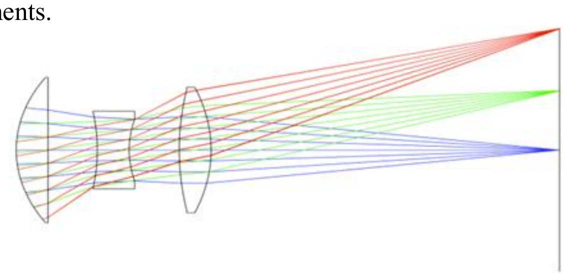

Fig.2.The Cooke Triplet design

In this post, I will walk through the procedure for designing a Cooke Triplet from scratch using first-order thin lens calculations, then optimizing it with real thicknesses in ZEMAX [6].

System specification:

Focal length of (EFFL) = 50mm
Entrance pupil diameter which is found to be (d) = 10mm
Glass: N-SK16 (ND=1.620410, V=60.323649) and N-SF2 glass (ND=1.647690, V=33.820209).
Field angles: 0°, 2°, 4°
Wavelengths: (587.56 nm), F (486.13 nm), and C (656.27 nm)
Paraxial F/#: 5

The Starting Point:

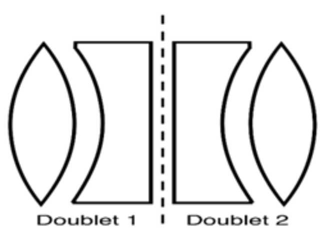

Fig.3 Objective Layout Design

The starting point of the first-order design is to imagine the Cooke Triplet as a pair of air spaced achromatic doublets. The second achromatic doublet (Doublet 2) has exactly the same radii of curvatures as the first except with opposite signs. The Gaussian reduction equation for total power of two elements is:
$\phi_E=\phi_1+\phi_2-\phi_1\phi_2 t$

Each doublet has half the power of the total system power:
$\phi_E=\phi_1+\phi_2$ such that $\phi_1=\phi_2$

Thus the power of each air spaced achromatic doublet is:
$\phi_1=\phi_2=0.01mm-1$

So we have $\phi_{11}+\phi_{12}=0.01$ mm−1

Since we have two equations and two unknowns, we can solve for the power of the positive and negative element:
$\phi_{11}=.0227606$ mm−1
$\phi_{12}=-0.012760$ mm−1

We can use the thin lens equations to solve for the radii of each element in the achromatic doublet:
(N_d2−1)(C_3−C_4)=ϕ_12
(N_d1−1)(C_1−C_2)=ϕ_11

For an achromatic doublet, the following formula must hold to put the F and C wavelengths at the same focus:
ϕ_11 V_1+ϕ_12 V_2=0
Since the fourth surface is flat:
C_4=0
Assume the second and third have the same radii of curvature:
C_2=C_3
Which results in the parameters in
Table 2:

C_1	0.01698mm−1	R_1	58,76mm
C_2	−0,019701 mm−1	R_2	−50,75mm
C_3	−0,019701 mm−1	R_3	−50,75mm
C_4	0.0 mm−1	R_4	∞ mm
C_5	0.0 mm−1	R_5	∞ mm
C_6	0.019701mm−1	R_6	50,75mm
C_7	0.019701mm−1	R_7	50,75mm
C_8	−0.01698mm−1	R_8	−58,76mm

Table 2 shows design parameters for our objective

We input these parameters into ZEMAX software as a starting point.

C. *optimization*

For our objective, we used the start point mentioned before and by making right constraints and operands in the default merit function we reach our goal of compact size and high performance image relying on different figures of merit such as RMS spot diagram and MTF plot.

IV. LAYOUT

Objective Layout:

The objective shaded model layout displaying the used material for each lens in our objective design is represented in figure 4.

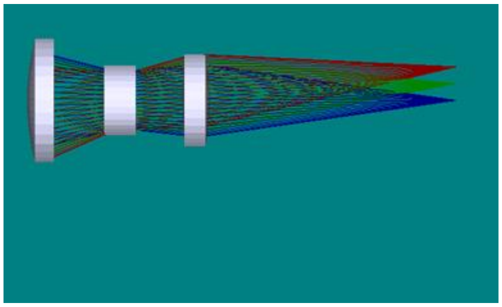

Fig.4 Shaded model layout with used materials for each lens

IV. RESULTS AND PERFORMANCE

A. spot diagram

Our simulation shows the RMS spot diagram, which is clearly concentrated at the airy diameter, which equals to approximately the pixel pitch of the used detector.

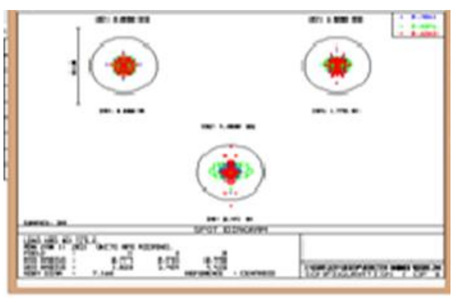

Fig.5 spot diagram for our objective design at focal length of 50mm and pixel size 3, 6µm

B. *modulation transfer function (MTF)*

We estimated the MTFA, which is about .5 at the spatial frequency resolution boundary (139cycle/ millimeter) which is equal to .5 leading to high-resolution image and clearly affects the performance of the system to higher value.

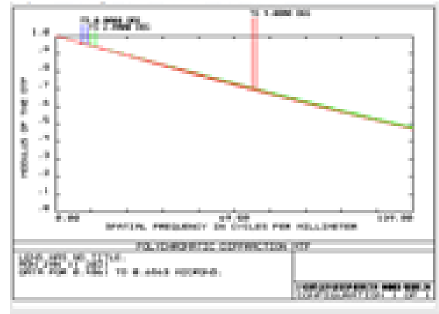

Fig.6. MTF of our objective design for different analyzed FOV.

CONCLUSION

A compact high-resolution objective operating in (0, 4-0, 7µm) spectral band show its high performance in optical and compactness point of view has been successfully modeled and designed. Our results achieved the design constraints since its MTFA is approximately 0, 5 and near diffraction limit at spatial frequency (139cycle/ millimeter) which means no aberration in our designed objective. In addition, the spot diagram of the objective shows the image to a point source formed by objective is focused in the pixel pitch with value for RMS radius less than pixel dimension. In addition, the main limitation of size was encountered [7]. These achieved limitations show that high quality of formed image. In addition to that, the design has simple construction that leads to relatively low cost in manufacturing. So both good qualities for imaging and relatively low cost device are well achieved.

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