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Preliminary Optical Design for Spaceborne Cameras

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Abstract

Some kinds of precision optical systems for spaceborne high resolution cameras were designed at preliminary design level and an optical design for a hyperspectral imager was performed for its development model. A Cassegrain-based catadioptric system and an unobscured reflective triplet system are illustrated in detail for spaceborne high resolution electro optical cameras which have performance of 5m resolution at an altitude of 685km and the design are evaluated in its spot-diagram and MTF to prove they have good performance enough to implement the requirements for realistic satellite payload taking the fabrication conditions and the on-orbit operation into consideration. For the development of hyperspectral imager as a next-generation payload, an optical system has been designed and elaborated. It can be divided into two parts, a catoptric telescope forming an off-axis 2 mirror type and a dispersive spectrometer which comprises collimator, grating and reimaging lens cell. From its optical design to the system characteristics are shown with the MTF performance reaching 25% approximately.

5m resolution, 685km altitude, spot diagram, MTF, Catadioptric, Unobscured Reflective Triplet, (Hyperspectral Imager), HSI Development Model, Off-axis 2-mirror Telescope, Collimator-Grating-Reimaging lens cell, HSI DM, 25% MTF

: (optical design), (high-resolution), (spaceborne camera), (hyperspectral), (electrooptical camera)

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1 1

1.

1.1

가

		Hyperspectral Imaging System
		가 가 stabilization 가

가

가

가

가

4 5

가
가

가

(EOC) 1 685 km 6.6m

, 1

1
가

가

1.1.1.

		1
(Focal Plan Photo-detector Array)		multiband (10 μ m), (400pixel/line) 2 Focal Plane Photo-detector Array

1.1.2.

		가 , 가
		가
/		가

	UP-GRADE	가 가 interface up-grade 가
	DATA	가
		가

1 TRW

(OJT)

1
가
가

가

가

(Collimator)

가

가

MTF

가

, 가

2

2002

(Gedanken Experiment)

ELOP

MSC

가

가

가

1.2

가

1

685km

700 km

5

가

가

가 MTF (Modulation Transfer

Function) , (panchromatic band)
 MTF 10% color bands 가 ,
 5m, 4

1.2.1. 5

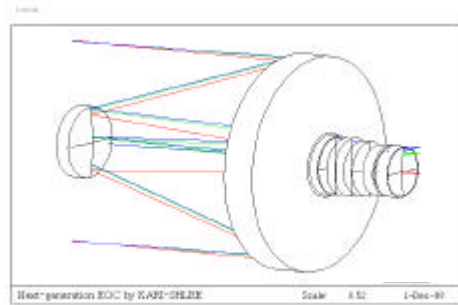
Ground Sample Distance	5 m @ 700 km altitude
Swath	30 km @ nadir view
Field of View	2.5° (±1.25°)
Focal Length	1500 mm
F #	7
Linear Obscuration	0.6
Modulation Transfer Function (Optics Design)	60 % @ Nyquist freq.
Bands (nm)	B1 : 430 490 B2* : 500 590 B3 : 610 680 B4 : 780 890

, Catadioptric Design
 1 , primary mirror
 tertiary mirror Unobscured
 Reflective Triplet
 5 가
 scale up and minor
 change

1.2.1 Catadioptric Design

1.2.1
 가 , 250mm, 1500mm
 5m , FOV ±1.25° 430 900nm

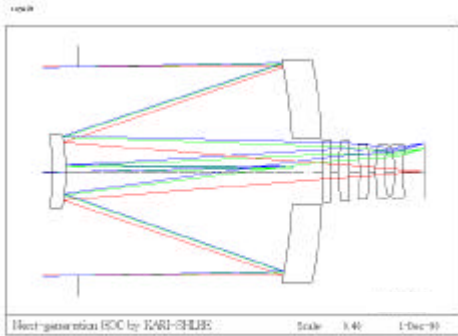
1 HRC
 Catadioptric Design (가 Cassegrain) ,
 EOC Unobscured
 Reflective Triplet Design , 가 (가
) 가
 430 890nm
 , (grating)
 hyperspectral image



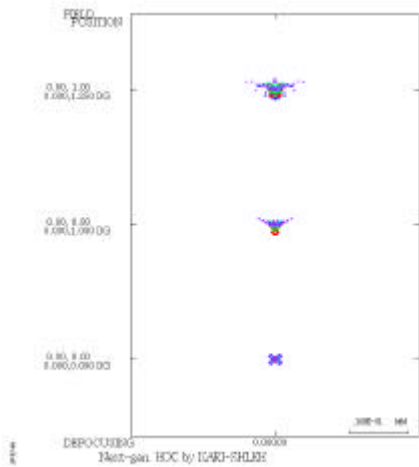
1.2.1. Catadioptric Telescope 3

, (Image Plane) 가 primary mirror 1.2.2 250mm
 CCD micro-optic filter 가 -1) (conic constant k
 가 , Be Zerodur
 facet mirror dichroic mirror

6) 가
 , $\lambda/20$ rms
 $\lambda/20$
 glass (browning)
 diamond turning and post-polish
 가 (aspect ratio 1 LRC
 가



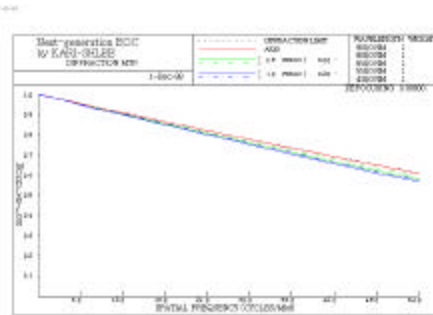
1.2.2. Catadioptric telescope Ray Trace



1.2.3. Catadioptric telescope Spot Diagram

Secondary mirror (window)

430 900 nm
 diagram 1.23 spot
 pixel size CCD 10 μ m 가



1.2.4. Catadioptric Telescope MTF

1.2.4 MTF
 Nyquist frequency 50 Hz MTF 가 60

obscuration
 Catadioptric

obscuration
 Reflective Triplet

3

multispectral hyperspectral

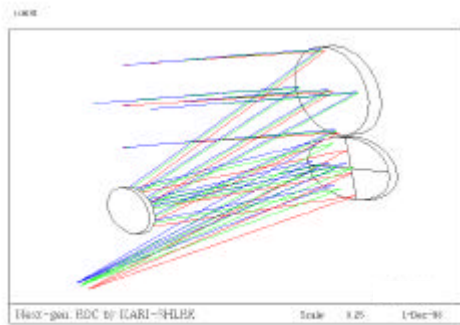
가 , 가
 , 5 m
 , 가
 .

duty cycle 20 %
 가 Beryllium mirror
 substrate
 trade off 가
 diamond turning and
 ,
 가

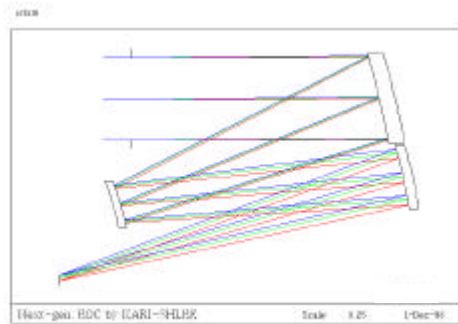
1.2.2 Unobscured Reflective Triplet Design

1.2.5 ,
 , 200 mm, 1500 mm
 5 m . Cross
 Track FOV 3. , In Track FOV 1.
 430 900 nm .

$\lambda/20$ rms
 $\lambda/20$



1.2.5. Unobscured Reflective Triplet 5



1.2.6. Unobscured Reflective Triplet Ray Trace

1.2.6 , primary
 mirror 가 ,
 secondary mirror (conic constant
 k -1) 가 , tertiary mirror
 가 .

430 900 nm
 , spot diagram 1.2.7

10 μ m pixel size CCD
 가 ,

1.2.8 MTF Nyquist frequency 50Hz
 60 .

MTF 60%
 1 .
 (substrate)
 Al6061T6 가
 optomechanical structure
 ,
 가 (thermally monolithic system)

Unobscured Reflective Triplet
 in-track FOV , cross-track
 FOV .

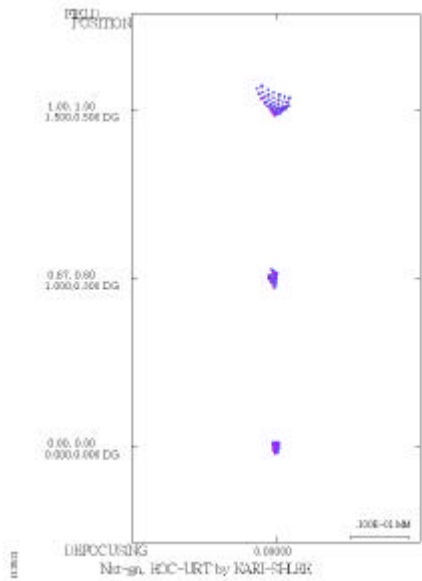
decenter ,

(duty cycle) compactness

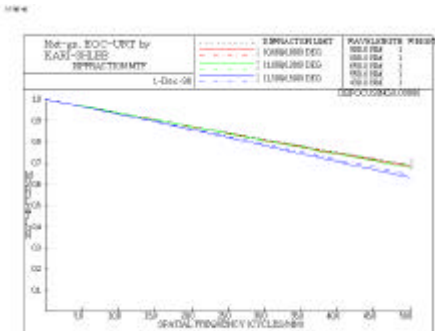
가

tilt

decenter catadioptric design compactness



1.2.7. Unobscured Reflective Triplet Spot diagram



1.2.8. Unobscured Reflective Triplet MLF

reflective triplet diameter)

, unobscured (entrance pupil

(FOV)

breakthrough

2.

2.1

가 가 가

Multi-spectral

10 Hyperspectral Imager Spectral Band Spectral Signature 가

가 (aberration) higher order terms 가 Signature 가 Spectral Spectrum (overall length)

, , ,) .

21

가 가 .

가

2.2 Hyperspectral Imager

2.2.1

Hyperspectral Imager

300 \$

2.2.1
spectral Imager

가 Hyper-
4 ,

:

2.2.1.

2.1.1. Hyperspectral Imager

	<ul style="list-style-type: none"> ▪ , Spectral Signature ○ , , , , ○ , , , , ○ , , , , ○ , , , , ▪ 300 \$ ▪ Spectrometer
	<ul style="list-style-type: none"> ▪ OO/ OO () ▪ Spectral Signature (/) ○ () ○ / Hyperspectral 가 가

	400 900nm	
Spectral Band	50	
Spectral	10nm	
Co-registration	Pixel 30%	Spatial Co-registration of Spectral Bands
	30m	@ 685 km (1 m 가)
	75 km	@ 685 km
Frame Rate	240 Hz	
Quantization	10 bits	
MTF @ Nyquist Frequency	10%	
	60 kg	
		<ul style="list-style-type: none"> • : 28 VDC • : MIL-SID-1553B • EMI/ EMC : MIL-SID-461 •
		MIL-Spec

, Hyperspectral

2.2.2 Hyperspectral Imager Development Model

Hyperspectral Imager
feasibility study

path finder

"Hyperspectral Imager

Development Model"

(Grating)

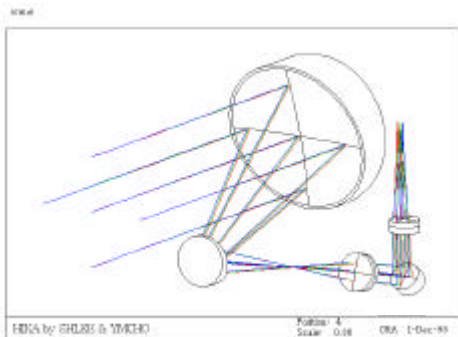
가 Off-the-shelf Item 가 가 가 , 가

1 Off-axis 2-mirror Telescope
off-axis paraboloid
substrate Al/ MgF2
2
1
customization Ni substrate Al/
MgF2 overcoat

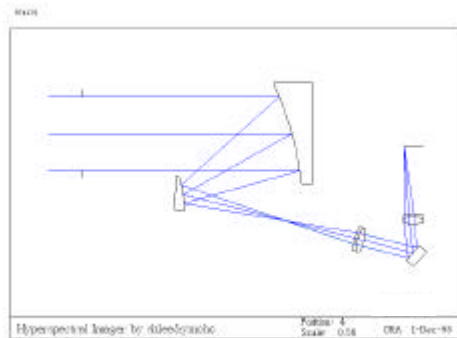
Hyperspectral Imager Development Model

Effective Focal Length 450mm
(FOV) $\pm 1.0^\circ$ (spatial) , Full
Image Size 16mm가 MTF
Nyquist 25 cycles/mm 25 %
CCD pixel size 20 μm 가
CCD pixel size 50 μm
2 Nyquist 10 cycles/mm MTF
55 % Achromatic
Doublet Lens Effective Focal Length 450mm
(FOV) $\pm 0.5^\circ$ (spatial) Full
Image Size 8.5mm 450
700 nm MTF
Nyquist 7.7 cycles/mm 60%

1 (LRC) TRW



2.2.1. Hyperspectral Imager 3



2.2.2. Hyperspectral Imager Ray Trace

Hyperspectral Imager Off-axis 2-mirror system 가 1 (2.2.1)

2 Doublet Lens (Collimating Lenses),

Cell , Collimating & Reimaging Lens 1 4

μm 3.5 mm

60%

Grating()

(Hyperspectral Imager)

, Grating

HSI Development Model

Size : 30mm x 30mm, Grating Constant : 600 grooves/mm, Blaze Angle : $8^\circ 37'$ @ 500 nm

Telescope

, Off-axis 2-mirror

Collimator-Grating-Reimaging

1:1

lens cell

MTF 25%

. Catoptric

telescope Spectrometer System

1 Design Wavelength : 450 ~ 700nm,

FOV : $\pm 0.5^\circ$ (spatial), MTF : 60 % @ 3.5 cycles/mm, Image Size : 7.99mm(spatial) x 17.55mm

(spectral), Optics System Spectral Resolution 0.15nm

1. , , 55 , "

가

GSD 685

(2000)

km 208m,

11.86km

2. , "EOC-OJT "

$35 \times 25 \times 20$ cm

(1997)

. Lens telescope Spectrometer

3. Seunghoon Lee, Hyung-Sik Shim, and Hong-Yul Paik, "Characteristics of the Electro-Optical Camera (EOC)", J. of the Korean Society of Remote Sensing, 14 No.3, 213-222 (1998)

System

2

Design Wavelength : 450 ~ 700nm, FOV : $\pm 0.5^\circ$ (spatial), MTF : 60 % @ 5.2 cycles/mm,

Image Size : 8.52mm(spatial) x 17.60mm(spectral), Spectral Resolution 0.15

4. Heong-Sik Youn, Seunghoon Lee, et al., Electro-Optical Camera System Design to Accommodate on KOMPSAT, The 3rd Asia-Pacific Conference On Multilateral Cooperation in Space Technology and Applications (1996)

nm,

685km

141m,

11.96km

1

, $50 \times 30 \times 14$

cm

3.

5. TRW Space & Electronics Group, " (LRC) End Item Data Package" (1998)

, 685km

6. , 4 , " 1 (EOC)

5m 가

", Proceedings of International Symposium on Remote Sensing (1999)

Catadioptric

Unobscured Reflective

Triplet

spot diagram

MTF

가

MTF

7. TRW, Space & Electronics Group, "Final Acceptance Test Report KOMPSAT Electro-Optical Camera, Functional Tests (EOC End Item Data Package)", Appendix 10 (1998)

8. , , "

