

Characteristics of the Electro-Optical Camera(EOC)

Seunghoon Lee, Hyung-Sik Shim, and Hong-Yul Paik

Korea Aerospace Research Institute, Space Division

다목적실용위성탑재 전자광학카메라(EOC)의 성능 특성

이승훈 · 심형식 · 백홍열

한국항공우주연구소 위성응용연구그룹

Abstract

Electro-Optical Camera(EOC) is the main payload of the KOREA Multi-Purpose SATellite(KOMPSAT) with the mission of cartography to build up a digital map of Korean territory including a Digital Terrain Elevation Map(DTEM).

This instrument which comprises EOC Sensor Assembly and EOC Electronics Assembly produces the panchromatic images of 6.6 m GSD with a swath wider than 17 km by push-broom scanning and spacecraft body pointing in a visible range of wavelength, 510~730 nm. The high resolution panchromatic image is to be collected for 2 minutes during 98 minutes of orbit cycle covering about 800 km along ground track, over the mission lifetime of 3 years with the functions of programmable gain/offset and on-board image data storage. The image of 8 bit digitization, which is collected by a full reflective type F8.3 triplet without obscuration, is to be transmitted to Ground Station at a rate less than 25 Mbps.

EOC was elaborated to have the performance which meets or surpasses its requirements of design phase. The spectral response, the modulation transfer function, and the uniformity of all the 2592 pixel of CCD of EOC are illustrated as they were measured for the convenience of end-user. The spectral response was measured with respect to each gain setup of EOC and this is expected to give the capability of generating more accurate panchromatic image to the users of EOC data. The modulation transfer function of EOC was measured as greater than 16 % at Nyquist frequency over the entire field of view, which exceeds its requirement of larger than 10 %. The uniformity that shows the relative response of each pixel of CCD was measured at every pixel of the Focal Plane Array of EOC and is illustrated for the data processing.

요 약

1999년에 발사될 다목적실용위성1호의 주 탑재체인 전자광학카메라는 한반도의 디지털 지도(입체지도 포함) 작성을 위한 영상자료를 획득하는 것을 그 임무로 하고있다.

센서부와 전자부로 구성된 전자광학카메라는 파장 510~730nm의 가시광선영역에서 6.6m의 지상해상도와 관측 폭 17km 이상의 흑백영상을 위성체 자세제어에 의한 조준과 푸쉬브room 방식으로 촬영한다. 3년 이상의 임무수명을 가진 본 기기의 고해상도 흑백영상 촬영시간은, 98분인 위성궤도 당 2분간 연속 수집되어 그 지상영상의 길이는 800km에 이르며, 운용 중 프로그래밍이 가능한 이득률과 음섷, 그리고 자체 내에 영상을 저장할 수 있는 기능을 갖고 있다. F수 8.3인 비차폐 3면 반사식 광학계에 의해 수집된 영상은 각각 8 bit 전자신호로 처리되어 25Mbps의 송신율을 가지고 지상국으로 보내진다.

제작된 전자광학카메라는 각종 시험을 통하여, 그 설계에서 요구되었던 기술사양을 만족하거나 능가할 정도로 높은 완성도를 보이고 있는데, 본 논문에서는 전자광학카메라로 획득된 영상자료의 최종 사용자들을 위하여 그 분광특성, MTF(Modulation Transfer Function), 2592개 CCD 화소의 상대적 반응비 등의 중요 성능특성 측정값을 설명하였다. 이득율을 변화시키며 측정한 분광특성 결과는 전자광학카메라의 영상자료 사용자가 더 정확한 흑백영상을 만드는데 이용되리라 본다. 영상품질을 가름하는 중요한 특성인 MTF는 시계각 전부에 걸쳐 Nyquist 진동수에서 측정값이 요구값 10%를 넘어 16% 이상을 보이므로써 이 전자광학카메라가 우수한 성능을 가진 것이 입증되었고, 각 CCD 화소들의 상대적 반응도를 측정한 결과에서도 상당히 고른 특성을 확인함과 함께, 차후 전자광학카메라의 영상자료 처리과정을 위하여 정밀한 상대 비교값을 제공하였다.

1. Introduction

The main mission of EOC is cartography to build up the digital map of Korean territory including Digital Terrain Elevation Map(DTEM). Its mission however, can be extended to the worldwide observation of the earth through direct oversea data reception or using a solid state recorder, whose capacity is 2.5 Gbit at end of life. EOC collects panchromatic image with the Ground Sample Distance(GSD) of 6.6 m and the swath width of 17 km at nadir through the visible spectral band of 510~730 nm. EOC scans the ground track of 800 km per orbit by push-broom and body pointing method. The image data shall be downlinked within 24 hours. In contingency state, the satellite shall have on-board fault diagnosis capability and shall be capable of recording the state of the telemetry. Spacecraft shall provide " ± 45 degree" tilting capability for in the cross-track direction. When in operation, the system shall be operated autonomously by KSG. The system shall allow the realization of 6.6 m high-resolution images and the composition of printed maps and digitized maps for domestic territories.

Many kinds of pre-launch tests were performed to verify the performance of EOC and it was confirmed that EOC unit successfully met all performance and interface requirements and it is ready to proceed to spacecraft integration. For the convenience of the end users, some of the test results are released.

2. Design

EOC collects ground image through 510~730 nm panchromatic spectral band by push-broom scanning and spacecraft body pointing. At the Ground station a stereo image can be generated from a pair of images which are obtained with different body tilt angles. The EOC system performance requirements are as follows.

Table 1. EOC Performance Requirements

Duty cycle for image collection	≥ 2 minutes/orbit (800 km image/orbit)
Ground Sample Distance	6.6 meters at 685 km in Nadir view
Swath width	≥ 17 km at 685 km in Nadir view
Mission life time	≥ 3 years
Reliability	≥ 0.94
Modulation Transfer Function	$\geq 10\%$ at Nyquist frequency
Signal to Noise Ratio	≥ 50 over entire filed of view
Focal Plane Array	2592 pixels (linear)
Digitization	8bits
Image data transmission rate	≤ 25 Mbps
Total weight	≤ 35 kg
Maximum power consumption	46 Watts

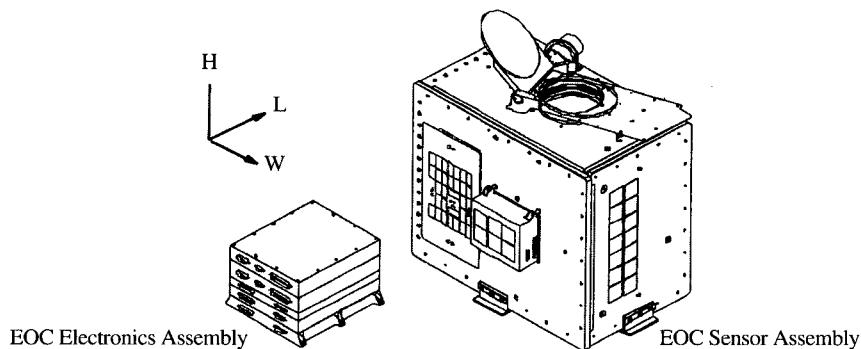


Fig. 1. KOMPSAT-1 Electro-Optical Camera

The on-board analog signal processing module of EOC has the function of programmable gain and offset to take the various conditions of ground reflected radiation into account (TRW, 1997).

The EOC (Figure 1) physically consists of two assemblies, the EOC Sensor Assembly (ESA) and the EOC Electronics Assembly (EEA), and each assembly is mounted on the payload platform of spacecraft. The ESA is thermally isolated from the payload platform and EEA is thermally coupled.

3. Operation

For EOC mission, S-band communication link is used to transmit command from the ground station and to receive the State Of Health (SOH) data of EOC. The On-Board Computer (OBC) controls S-band data with the MIL-STD-1553B interface (Youn *et al.*, 1996). EOC transmits the image data to ground station via X-band channel.

The EOC collects image for 2 minutes during 98 minutes of orbit cycle, which covers about 800 km along ground track. The EOC image can be transmitted to Korean Ground Station (KGS) in real time during Korean territory observation or be stored in the Solid State Recorder (SSR) of Payload Data Transmission Subsystem (PDTS) out of the KGS reception area. The stored image data can be transmitted when the data reception connection is available later. It is possible to observe earth globally using the image storage scheme or direct reception in the oversea ground station.

Ground station performs the radiometric and geometric correction on the received image data, and performs several images processing steps with ancillary data. For calibration, observed reference area such as desert or Ground Control Point (GCP) is used. Spacecraft provides ancillary data such as image time, position and attitude of spacecraft for EOC image processing.

The EOC has four operation modes as follows (Kim *et al.*, 1997):

- Off mode: Power-off
- Safe-Hold mode: power-on for survival only
- Standby mode: EEA power-on, ESA power-off, SOH available
- Imaging mode: All power-on, Image collection

EOC collects stereo images of a target area from opposite sides on different passes by roll-tilting of spacecraft, then ground station can make DTEM with the stereo image. For cartography, up to ± 30 degree roll-tilting is used in practice. Korean Ground Station can obtain EOC images 20 times out of 39 times in this case.

4. Performance

EOC has a function of adjusting its gain and offset by the command from ground station. It has four levels of gain, 1/2, 1(default), 2, 4, and sixteen levels of offset, providing offset of digital count from -35 to +40 with 0 as default(Kim *et al.*, 1998). Being a high resolution imager, EOC has a function of active thermal control of its own and there are seven sets of heaters at each part of primary and redundant.

1) Spectral Response of EOC

The spectral response of EOC measured under vacuum condition is shown in the Fig. 2(Whitley *et al.*, 1998). The FWHM corresponds with the characteristics that EOC is cut-on near 510 and cut-off near 730. From the measurement of EOC spectral response, nominal output of EOC can be evaluated using Table 2. For the target which gives EOC the same input radiance as described in the table, within the wavelength range from 510 to 730 nm, EOC will produces about 26 counts with its default gain setting. Note that the real digital output can be a little larger owing to the signal for the light around EOC spectral band edge.

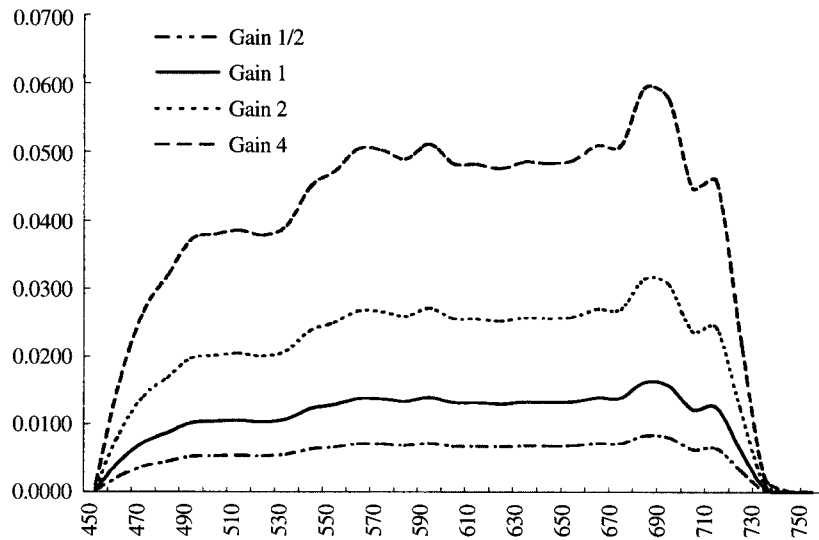


Fig. 2. EOC Spectral Response at Vacuum

Table. 2. EOC Spectral Response and Digital Output Count Evaluated at Nominal Input Radiance

$\lambda(\text{nm})$	Input-R	EOC Response [counts/radiance]				DN for	DN for	DN for	DN for
	$W/(\text{m}^2 \cdot \mu\text{m} \cdot \text{sr})$	Gain 0.5	Gain 1	Gain 2	Gain 4	Gain 0.5	Gain 1	Gain 2	Gain 4
510	83.62	0.005227	0.010162	0.019738	0.037201	0.4370817	0.8497464	1.6504916	3.1107476
520	81.82	0.005334	0.010372	0.020145	0.037967	0.4364279	0.8486370	1.6482639	3.1064599
530	89.02	0.005417	0.010532	0.020457	0.038557	0.4822213	0.9375586	1.8210821	3.4323441
540	83.62	0.005313	0.010332	0.020065	0.037818	0.4442731	0.8639618	1.6778353	3.1623412
550	90.26	0.005516	0.010725	0.020831	0.039261	0.4978742	0.9680385	1.8802061	3.5436979
560	89.92	0.006320	0.012288	0.023867	0.044982	0.5682944	1.1049370	2.1461206	4.0447814
570	86.77	0.006623	0.012877	0.025012	0.047141	0.5746777	1.1173373	2.1702912	4.0904246
580	93.07	0.007084	0.013773	0.026753	0.050421	0.6593079	1.2818531	2.4899017	4.6926825
590	85.76	0.007053	0.013713	0.026635	0.050200	0.6048653	1.1760269	2.2842176	4.3051520
600	90.93	0.006874	0.013366	0.025961	0.048929	0.6250528	1.2153704	2.3606337	4.4491140
610	93.07	0.007180	0.013961	0.027117	0.051107	0.6682426	1.2993503	2.5237792	4.7565285
620	97.24	0.006783	0.013188	0.025616	0.048278	0.6595789	1.2824011	2.4908998	4.6945527
630	93.30	0.006770	0.013162	0.025565	0.048183	0.6316410	1.2280146	2.3852145	4.4954739
640	96.67	0.006681	0.012990	0.025230	0.047552	0.6458523	1.2557433	2.4389841	4.5968518
650	95.10	0.006818	0.013257	0.025749	0.048530	0.6483918	1.2607407	2.4487299	4.6152030
660	98.48	0.006788	0.013198	0.025634	0.048314	0.6684822	1.2997390	2.5244363	4.7579627
670	99.26	0.006845	0.013308	0.025848	0.048717	0.6794347	1.3209521	2.5656725	4.8356494
680	99.60	0.007153	0.013908	0.027014	0.050913	0.7124388	1.3852368	2.6905944	5.0709348
690	82.83	0.007152	0.013906	0.027011	0.050908	0.5924002	1.1518340	2.237321	4.2167096
700	86.88	0.008340	0.016215	0.031496	0.059360	0.7245792	1.4087592	2.7363725	5.1571968
710	90.93	0.008091	0.015731	0.030555	0.057588	0.7357146	1.4304198	2.7783662	5.2364768
720	64.60	0.006283	0.012216	0.023728	0.044721	0.4058818	0.7891536	1.5328288	2.8889766
730	74.17	0.006427	0.012495	0.024270	0.045742	0.4766906	0.9267542	1.8001059	3.3926841
					SUM	13.5794050	26.4025658	51.2823491	96.6529461

2) Linearity and Gain Linearity

The linearity of the EOC output for the increase of input signal was tested at each gain setting(Whitley *et al.*, 1998). The Fig. 3(a), 3(b), 3(c), and 3(d) show the linear characteristics of EOC.

The set of gain setting is to show doubling the output of lower gain, e.g., the output count at gain 2 is almost double the count at gain 1. The figure 3(e) shows the gain linearity of EOC.

3) Uniformity in the Response of Focal Plane Array

The relative response of each pixel was measured(Whitley *et al.*, 1998). All of the 2592 pixels were tested, taking the 1000th pixel as a reference, and it was proven that EOC FPA has good

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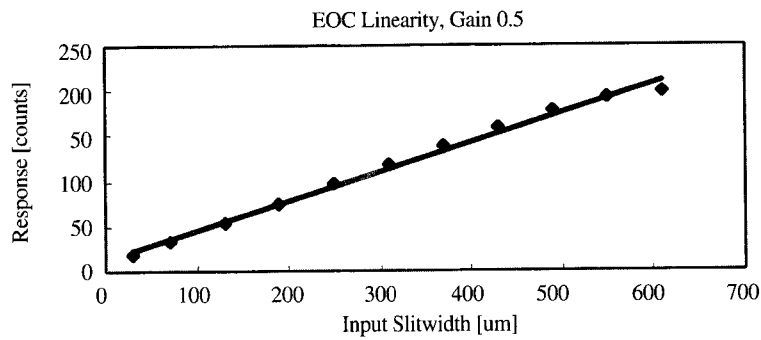


Fig. 3(a). EOC Linearity with Gain 0.5

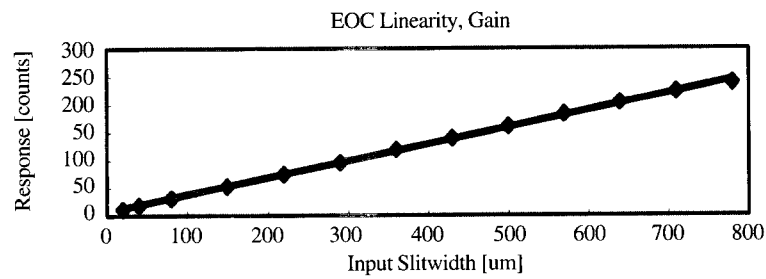


Fig. 3(b). EOC Linearity with Gain 1

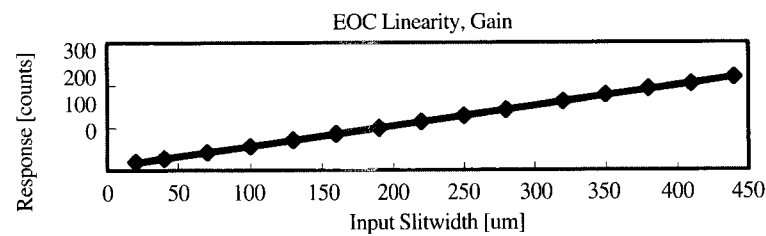


Fig. 3(c). EOC Linearity with Gain 2

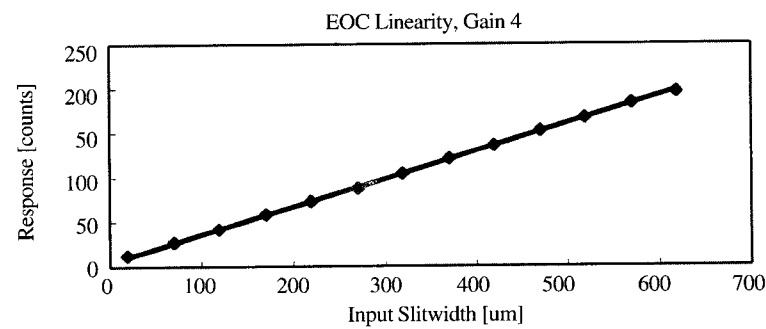


Fig. 3(d). EOC Linearity with Gain 4

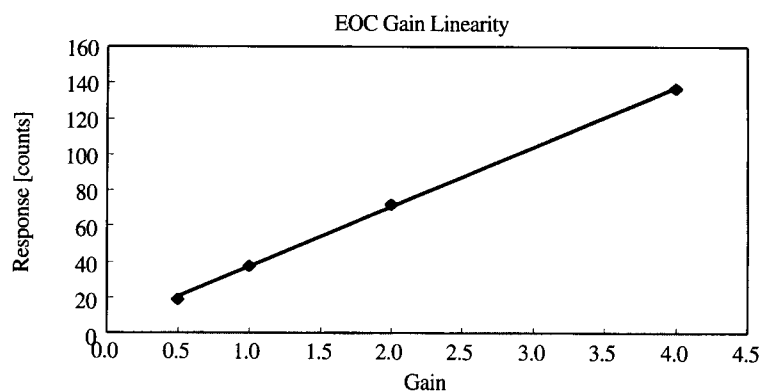


Fig. 3(e). EOC Gain Linearity

uniformity in response. Excluding the first and the last pixel, only a few near the pixel number 615 showed near 10 % difference. The others showed nearly uniform response with average difference less than 2 % rms.

4) Modulation Transfer Function

EOC system MTF was measured as shown in the Figure 4(a)~(c)(Whitley *et al.*, 1998). The MTF values at Nyquist frequency of 50 lines/mm were 24 % for left field, 20 % for center, and 16 % for right field, while the requirement had been larger than 10 %

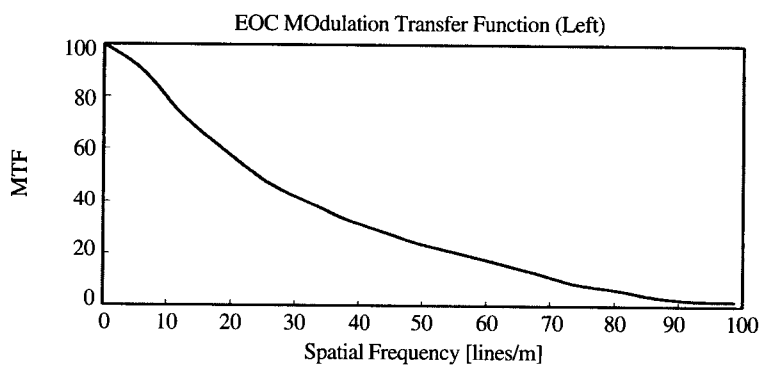


Fig. 4(a). EOC MTF Curve Measured at Left Field

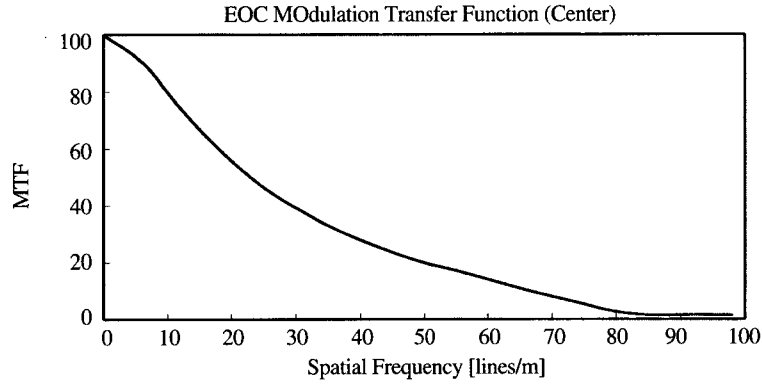


Fig. 4(b). EOC MTF Curve Measured at Central Field

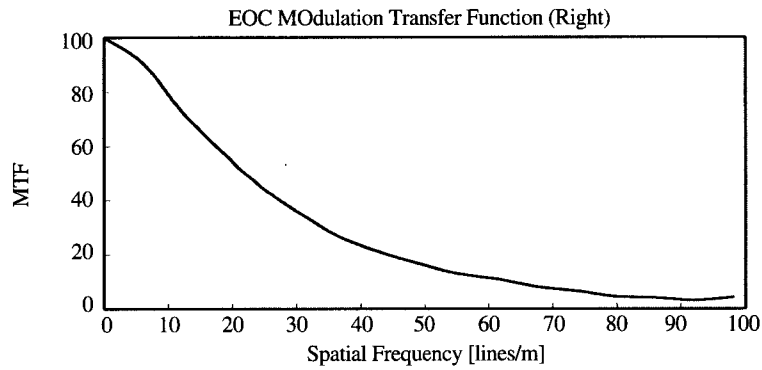


Fig. 4(c). EOC MTF Curve Measured at Right Field

5) Boresight (Alignment Knowledge)

EOC boresight angle is defined as the angle between EOC Instrument Line of Sight (LOS: +Z axis) and Alignment Cube +Z axis. The positive azimuth angle is from the +Z-axis to the -Y-axis and the positive elevation angle is from the +Z-axis to the +X-axis.

The measured values of EOC boresight were 31.7'' for the azimuth angle and -1'1.9'' for the elevation angle(Whitley *et al.*, 1998).

5. Summary

EOC, a spaceborne high resolution panchromatic imager with F8.3 reflective triplet, 8 bit digitization and 25 Mbps data transmission rate, was elaborated to perform its full scope of high

technology. Complete set of pre-launch tests was performed to verify the performance of EOC : Functional Test, Performance Test, Thermal Vacuum test, Vibration Test, Vacuum Performance Test, Electromagnetic Interference and Susceptibility Test, and Alignment Verification, etc. Among the results of Vacuum Test, the characteristic of spectral response, linearity, and the performance of modulation transfer function were illustrated. The gain linearity, alignment angle and the uniformity of all the 2592 pixels of CCD were informed to EOC end-users for their convenience. This knowledge is expected to enable the end-users to generate more accurate image from the EOC data.

The modulation transfer function of EOC system was measured as greater than 16 % at Nyquist frequency over the entire field of view, and the relative response of EOC focal plane array was nearly uniform. It is convinced that EOC meets all the requirements successfully in performance and interface. EOC is now ready to proceed to the spacecraft integration and then to provide invaluable data for its users.

Acknowledgment

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