SNR Analyses for MSC and Camera Electronics Design for Its Improvement

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Abstract: SNR(Signal to Noise Ratio) is one of the most important performance for the electro-optical camera system. This paper shows not only the SNR analyses for the MSC system, which is the payload in the KOMPSAT2 satellite, but also the trials for its improvement in the electronics circuit design. The MSC deals with one panchromatic band and four multi-spectral bands. The SNR analyses are performed based on the MSC design for the each band and assuming that the defined radiance reached directly to the sensor entrance pupil. In the SNR calculation, shot noise, dark current noise, analog electronics noise and ADC quantization noise are considered as noise sources. In these noise sources, especially, the electronics noise depends on the camera electronics design. This paper shows the camera electronics design to increase SNR and its test results as well as the SNR analyses.

Keywords: SNR, MSC, Noise, Signal, Electronics

1. Introduction

The MSC(Multi-Spectral Camera) shall be integrated into the KOMPSAT 2, which is a LEO spacecraft and will be used to generate observation imagery data in two main channels: a panchromatic channel and a multi-spectral channel with 4 different spectral bands. They are called the PAN camera and the MS camera respectively. EOS(Electro-Optical Subsystem) in the MSC is to obtain data for high-resolution images by converting incoming light from the earth into digital stream of pixel data.

The PAN camera and the MS camera share the same mirror telescope. Both cameras can perform imaging at synchronous rate. The EOS shall cover a swath width of 15km from an altitude of 685 km. The PAN camera has 15,000 active pixels of 1m ground resolution. This is achieved by optically butting 3 CCDs each with 5200 elements. The MS camera has 3750 active pixels of 4m ground resolution in each of the 4 spectral bands. By combining 2 CCDs, in "parallel", having 3 arrays each and 5200 elements in each array this configuration is achieved. The incoming signal of the MS camera is split into 2 paths by a Neutral Beam Splitter block, and then filtered into the spectral bands in each detector. Each camera consists of the shared Mirror Telescope, CFA(Camera Focussing Assembly) and a CEU(Camera Electronic Unit). Each CFA consists of Field Correction Lenses Assembly with a focus mechanism assembly. Each CEU consists of a DFPA(Detection Focal Plane Assembly), FPE(Focal Plane Electronics) and CC(Camera Controller), that performs the communication and control functions, serves both the PAN-CEU and the MS-CEU.

The EOS performance such as dark noise, residual photo response non-uniformity, non-linearity, MTF, SNR affects direclty to camera system. Among these performance, the SNR and the MTF can be considered the most important performance in the electro-optics system. While the MTF is mainly to check the optics performance the SNR is for the check both of the optics and the electrionics performance. The SNR is defined as signal level comparing to noise level. In order to obtain high SNR, simply, we have to design signal higer and noise lower. In the electro-optics system, optics design is charge of making the signal higher and electronics design is charge of decresing the noise. That is to say in detail, when the optics system transmits much quantity of light to the CCD and the electronics obtains image data without noise from CCD, the SNR results can be higher.

This paper shows the SNR analyses for the MSC system and its results. In addition, it shows the electronics noise influence on the SNR and the trials for SNR improvement. Finally, the SNR test method for the actual system will be described.

2. MSC SNR Analyses

In fact, the SNR depends on the radiance from the earth and the integration time so much. It means that the SNR can be higher when the camera is imaging the bright area comparing to the dark area. Namely, if the camera can cover wider spectral bands even if the camera looks at the same area, the SNR can be higher. Table 1 shows the spectral bands for the PAN camera and the MS camera in the MSC system. As shown in Table 1, the PAN camera has wider spectral bandwidth than the MS camera. So, we can guess that the PAN SNR will be higher than the MS camera in the point of spectral bands.

Table 1. Spectral bands for PAN and MS camera

Camera	No.	Spectral Range[nm]	Center [nm]
PAN	0	500-900	700
MS	1	450-520	485
	2	520-600	560
	3	630-690	660
	4	760-900	830

When it come to say integration time, when the MSC system is operated in the space, the nominal line rates for the PAN camera and the MS camera are 6800 lines/sec and 1750 lines/sec. It means that the integration time for the MS camera is 4 times bigger than the PAN camera. The SNR for the MS camera has a benefit in the point of integration time.

Even if the radiance and the integration time are dominant factor in the SNR calculation, these do not have big meaning in the system design. This is because these two items are fixed automatically when the system requirement is determined. In the point of system design, it is important to design the optics to increase system response and transmittance and to design electronics to decrease the electronics noise.

In the optical camera, the SNR is given as in

$$SNR = \frac{Radiance(\lambda)\cdot SR(\lambda)\cdot OT(\lambda)\cdot TI}{\sqrt{SN^2 + EN^2}} \quad (1)$$

where *SR* is system responsivity, *OT* is optics transmittance, *TI* is Time Integration, *SN* is shot noise and EN is electronics noise.

In the Eq. (1), the system responsivity relies on the CCD pixel size, focal length, mirror diameter, CCD quantum efficiency and so on. The optics transmittance is determined by optics design, and time integration is decided by operation line rate and TDI mode. In the noise part, electronics noise is derived by detector noise, ADC quantization noise and analog noise, and shot noise is determined directly by input radiance as in

$$SN(\lambda) = \sqrt{Radiance(\lambda)} \quad (2)$$

In this paper, the SNR analyses are performed based on the MSC design for the each band and assuming that the defined radiance reached directly to the sensor entrance pupil. In the SNR calculation, shot noise, dark current noise, analog electronics noise and ADC quantization noise are considered as noise sources. Table 2 shows the MSC design parameters for this MSC SNR analyses.

Table 2. MSC Parameters for SNR Analyses

Description	PAN	MS
CCD pitch size	13μm	13μm
Focal length	9000mm	2250mm
Mirror Diameter	60mm	60mm
Transmittance	0.47	0.21
Dark Current noise	60 elec.	60 elec.
Quantization noise	38 elec.	38 elec.
Analog Electronics noise	100 elec.	100 elec.
Quantum Efficiency	According to spectrum	According to spectrum
TDI mode	32	MS 1 : 32 MS 2 : 16 MS 3 : 16 MS 4 : 8
Radiance	Standard	Standard

Using these parameters, the SNR analyses results are shown in Table 3. These results show us that the SNRs of all the bands satisfy the SNR requirement, which are more than 100 for the all bands. As in shown Table 3, especially the reason that the SNR of the MS4 band is much bigger than others, even though the TDI 8lines is used, is that its spectral band is wider than others as shown in Table 1.

Table 3. MSC SNR Analyses Results

Band	TDI	Sat [Ke]	Signal [Ke]	Noise [e]	SNR
PAN	32	156	51	257	198
MS1	32	149	37	227	161
MS2	16	365	98	336	291
MS3	16	436	127	377	337
MS4	8	398	168	428	393

3. Camera Electronics Design for SNR Improvement

In the MSC, the incoming light is converted to electronic analog signals by the CCD in the CEU. The analog signals are amplified, biased and converted into digital signals. The digital data is transmitted to the PMU(Payload Management Unit) for the pre-processing to correct for non-uniformity and to add header data for identification and synchronization. Fig. 1 describes the block diagram for acquisition process from the CCD. The analog signal from CCD is sampled by CDS(Correlated Double Sampling) method to minimize the analog noise. And then goes to the ADC through PGA(Programmable Gain Amplifier). By the ADC, the analog signal is converted to 10bits digital signal.

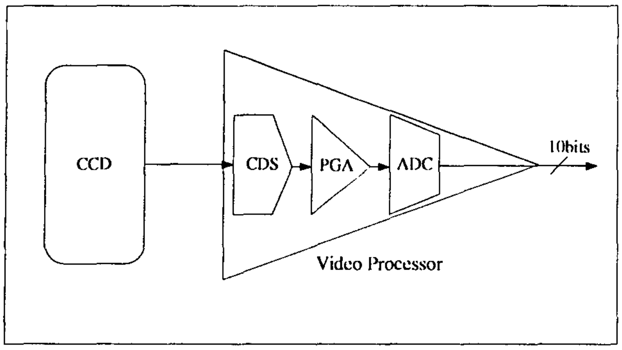


Fig. 1. Image Acquisition Block Diagram

As mentioned above paragraphs, it is important to decrease the electronics noise in the electronic design in order to increase the SNR. However, CCD itself noise, and analog noise, ADC quantization noise exists in this process, even if CDS method is used.

Table 4 shows the SNR analyses results for total electronics noise is 4GL(Gray Level) case and 2 GL case, respectively. This electronics noise includes CCD dark current noise, quantization noise, and analog electronics noise. In these analyses, the MSC design parameters described in Table 2 are used except electronics noise.

As shown in Table 4, in the case that electronics noise is 4 GL, the SNR for PAN and MS1 is less than 100. But in the case that electronics noise is 2 GL, the SNRs for all bands satisfy the MSC requirements. So it gives us that in order to meet MSC SNR requirement, it is important to reduce electronics noise to 2GL or less.

Table 4. SNR Effects of Electronics noise

Band	EN=4GL case		EN=2GL case	
	Total Noise	SNR	Total Noise	SNR
PAN	568	90	345	148
MS1	555	66	323	113
MS2	607	161	407	240
MS3	631	201	441	287
MS4	663	254	486	346

For the electronics design for the good SNR, it is better to consider reducing the analog noise, because CCD noise and ADC quantization noise is already fixed at the CCD specification and MSC system level specification, respectively. If the CDS method is adopted for the analog data sampling, the analog noise can be reduced so much. In addition to CDS method, LPF(Low Pass Filter)s in front of the emitter follower and the video processor can reduce analog high frequency noise much more. Fig. 2 shows the electronics design block diagram for the SNR improvement. As shown in this figure, these two LPF can filter high frequency noise.

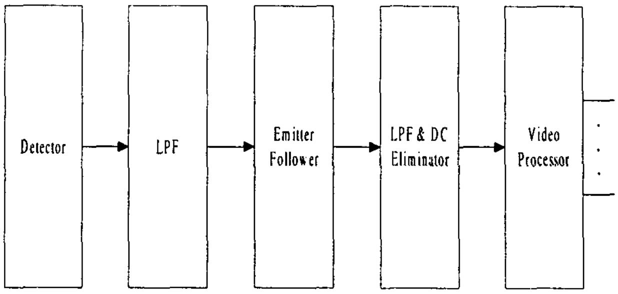
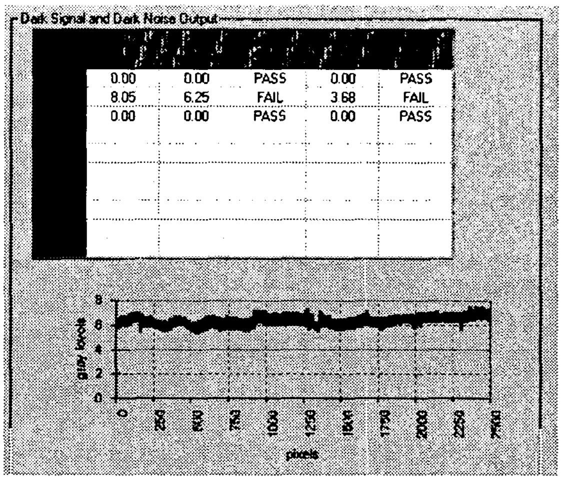


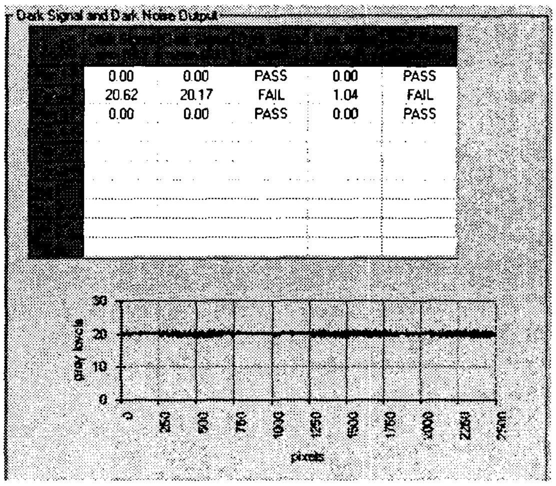
Fig. 2. Electronics Design for SNR improvement

Fig. 3 and Fig. 4 show the electronics noise results for the without LPF and with LPFs, respectively. These results are measured in the dark condition. So it can be called dark noise. The dark noise can stand for all electronics noise because there is no shot noise. From these figures, if the LPFs are used, electronics noise can be less than 2 GL and can also meet the system SNR requirement.



0.00	0.00	PASS	0.00	PASS
8.05	6.25	FAIL	3.68	FAIL
0.00	0.00	PASS	0.00	PASS

Fig. 3. Electronics noise without LPF



0.00	0.00	PASS	0.00	PASS
20.62	20.17	FAIL	1.04	FAIL
0.00	0.00	PASS	0.00	PASS

Fig. 4. Electronics noise improvement

4. SNR Test Method

In order to test the SNR, all the noises have to be assumed as random Gaussian noise. If it is established, we can make the SNR test method as follows :

Step1) Calculate the average value of the gray level values for the each pixel over the enough sampled lines.
Step2) Calculate the standard deviation value of the gray level values for the each pixel over the sampled lines.
Step3) Calculate the SNR of each pixel. And obtain *SNR(i)* value using the following formula :

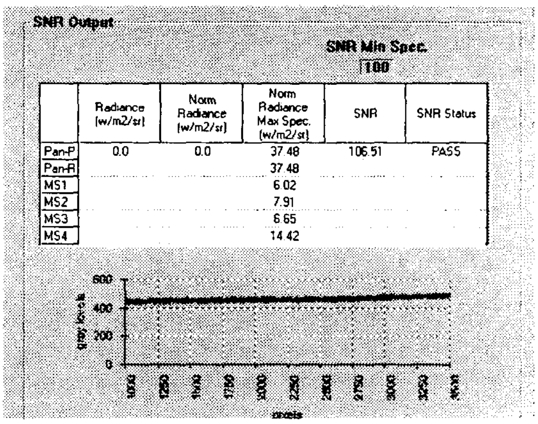
$$SNR\ (i) = \frac{MEAN\ \ (i)}{SD\ (i)} \qquad (3)$$

where i is the pixel index in the selected range.

Step4) Finally get minimum SNR for the all pixels as in :

$$SNR = \min |\, SNR(i)\, | \qquad (4)$$

Fig. 5 shows the SNR test software MMI and the simple test result. For this test software verification purpose, PAN camera's SNR is tested. However, even if standard radiance for the PAN camera should be provided to the EOS input, the half of saturation radiance is given to the EOS on the only test software verification purpose.


SNR Output

SNR Min Spec.
100

	Radiance (w/m2/sr)	Norm Radiance (w/m2/sr)	Norm Radiance Max Spec. (w/m2/sr)	SNR	SNR Status
Pan-P	0.0	0.0	37.48	106.51	PASS
Pan-R			37.48		
MS1			6.02		
MS2			7.91		
MS3			6.65		
MS4			14.42		

Fig. 5. SNR Test S/W and test result

5. Conclusions & Further Work

In this paper, the SNR analyses were performed based on the MSC design for the PAN camera and the MS camera assuming that the defined radiance reached directly to the sensor entrance pupil. This paper analyzed the electronics noise influence on the SNR in detail. This analyses result showed that if the electronics noise is 2 GL or less, all the SNR satisfy the requirement, if not, the SNR for the PAN and the MS1 band do not. And this paper showed the electronics design to increase the SNR using low pass filter techniques and its results. Finally, the SNR test method for the actual system was described and verified.

As the further work, the SNR test shall be performed with standard radiance based the Korean peninsula.

References

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