Non Uniformity Error of MSC (Multi Spectral Camera) System

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Abstract: MSC (Multi Spectral Camera) system is a remote sensing payload to obtain high resolution ground image. In this application, uniformity characteristic is important as well as GSD (Ground Resolved Distance) and SNR (Signal to Noise Ratio). MSC image chain is consisted of OM (Optical Module), CCD, Video processor, NUC and DCSU (Data Compression and Storage Unit). Each block makes and corrects MSC's non-uniformity response. This paper shows the cause of non-uniformity error and the correction scheme of MSC system from the electronic point of view.

Keywords: MSC, RNU, NUC, uniformity.

1. Introduction

The MSC, a payload of KOMPSAT2, has data compression and storage unit (DCSU) to retain and transfer image data efficiently. To maximize data storage and data transmission efficiency, the MSC uses lossy compression method (JPEG like). So high frequency component of image is weakened and it cannot be restored on the ground station. In most case the image has not so much high frequency components that does not remarkably affect on image quality. But when each detector pixel or output channel has different gain and offset, even if target has uniform radiance, output image data may have a vast amount of high frequency component. And if high frequency component weakened, it appears as a form of pattern noise. On orbit non-uniformity correction (NUC) is needed to minimize this effect. The MSC has NUC function in payload management unit (PMU). Due to its on orbit operation concept, several limits exist and degrade performance. Perfect non-uniformity correction table generation is not possible. And analog to digital conversion resolution and calculation precision limits make some error in correction exact value. By careful system design this error can be minimized.

2. Image signal flow

The MSC payload is electro-optical camera which has 1 panchromatic (PAN) and 4 multi spectral (MS) channel. Its image signal flows is configured as following order: OM, CCD, Video processor, NUC and DCSU. Each block has own characteristic contribute to non-uniform response. First of all, OM has maximum 3% vignetting specification which makes difference radiance on edge CCD pixels. DFPA block also makes different transmittance on each CCD. Optical butting makes dip on butting region by optical diffraction.

1) CCD (Charge Coupled Device)

CCD refers to a semiconductor architecture in charge is transferred through storage areas. The CCD architecture has three basic functions: charge collection, charge transfer and the conversion of charge into a measurable voltage. At the first stage, due to processing variations in making CCD, it is impossible to make each pixel to have exactly same response characteristic. Actually, each pixel has different pixel size and doping depth that differences appeared as a form of non-uniformity error. Dark current variation makes fixed pattern noise (FPN) and photo residual non-uniformity (PRNU) makes difference number of electron on same illumination level. Especially the MSC uses a big line CCD so that the variation from pixel to pixel is considerably high.

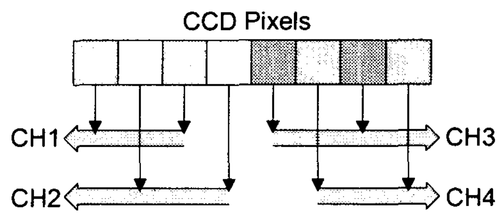

Fig. 1. MSC CCD channel structure (PAN)

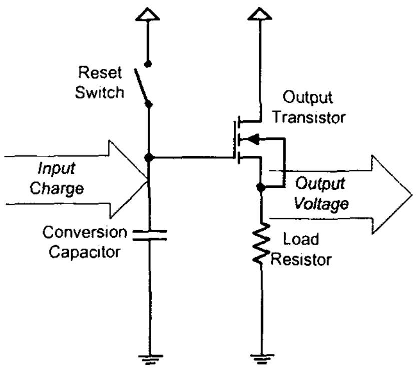

Fig. 2. Charge conversion amplifier

Another important factor effects on non-uniformity is output channel difference. As we can see on Fig.1, one CCD module has 4 output ports to increase line rate speed. Each channel has own charge conversion amplifier (Fig. 2) which convert number of electrons to a voltage level. Because of differences in conversion capacitor size and output transistor transconductance its conversion gain varies from channel to channel. Besides, output transistor threshold voltage difference makes different offset.

Especially, we must take notice that even and odd pixel has different output channel. That difference makes high frequency non-uniformity. As we can see on Fig. 3 practical CCD output shows complex response on same illumination. Globally its output level follows illumination level. But channel differences induce non-uniform factor (dashed line). On that error, pixel to pixel variation effect is added. CCD uniformity specification is summarized on following Table 1.

Table 1. PRNU of the average responsivity

TDI MODE	PRNU
Mode 0	±10%
Mode 1	±8%
Mode 2	±7%
Mode 3	±6%
Mode 4	±5%

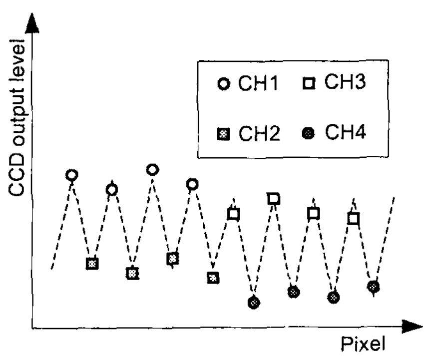

Fig. 3. Expected CCD output on same illumination

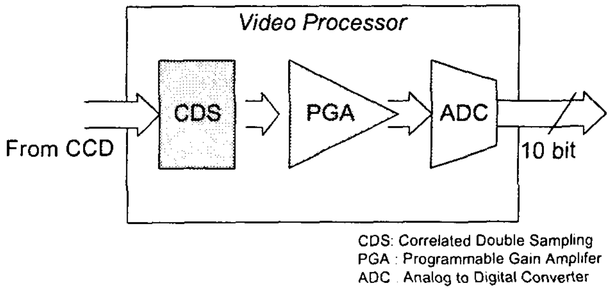

Fig. 4. Video processor block diagram

2) Video processor

Per each CCD output channel video processor is attached. The main role of video processor is analog to digital conversion of image signal. The device consists of a Correlated Double Sampling (CDS) circuits, a digitally Programmable Gain Amplifier (PGA), a black level clamp and a 10bit Analog to Digital Converter (ADC) as following Fig. 4. An internal CDS decreases CCD output transistor's non-uniform characteristic by two subtractical sampling. Fig.5 shows its operation concept. When reset signal applied to CCD first sample stored as a reference level. And after photo electron transfer to the output conversion capacitor, second sample is made. By subtract first reference sample from second image data sample, offset error caused by output transistor can be completely canceled. Proper PGA gain and the ADC clamp level can be selected according to each channel characteristic. PGA gain and clamp control archived by serial digital interface and its gain adjustable range is 36dB (in steps of 0.1dB) ADC also contributes to the non-uniformity. Due to the limit of modern semiconductor process, each video processor's characteristic is different from chip to chip. Such non-uniformity leads to ADC non-uniformity. Datasheet from the chip supplier shows our video processor has typical ±0.5 LSB DNL (Differential Non-Linearity) and ±1.3 LSB INL (Integral Non-Linearity) errors.

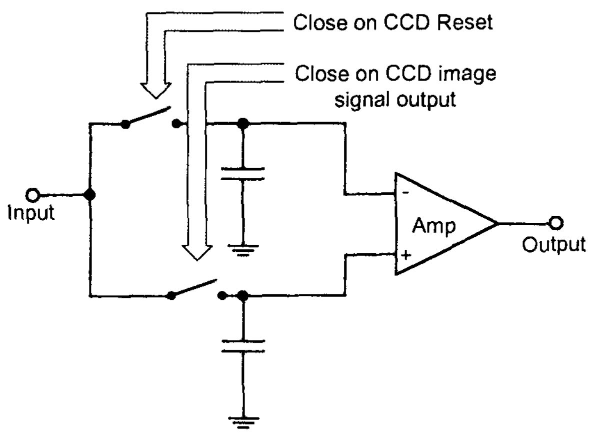

Fig. 5. CDS simplified circuit

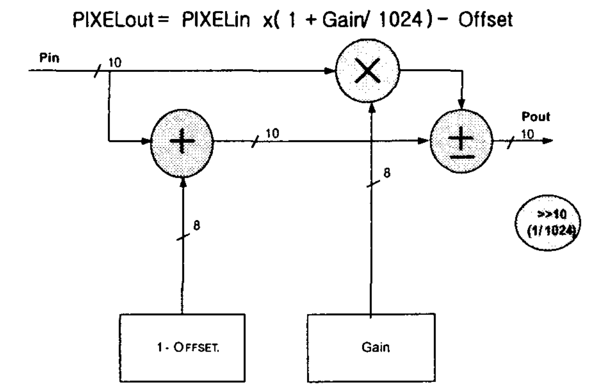

Fig. 6. NUC signal flow

3) NUC (Non-Uniformity Correction)

NUC module is a high throughput image processing unit that performs several tasks such as correcting non-uniformities in pixels of 8-video channels by gain and offset values stored in SRAM, re-arranging pixels especially from the MS channel, combining video data with uploaded headers, and receiving and adding ancillary data to imagery head data. It receives video data from FPE (Focal Plane Electronics) boards via HOTLink communication and performs corrections upon the pixels according to commands and relevant tables received from the SBC(Single Board Computer). 5 FPGAs are implemented inside NUC board in order to handle a total of 8 different video data channels, 6 for PAN and 2 for MS channels. Three FPGAs are for PAN-channel with each dedicated to the processing of two video channels and two FPGAs are for MS-channel with each dedicated to one video channel. The main role of NUC unit is to provide on orbit non-uniformity correction function. NUC unit has 8bit gain and 8bit offset table for the each pixel. By multiplying gain coefficient and adding offset, NUC is achieved. Gain adjustment range is 1~1.125 and offset range is ±62 gray level. Fig.6 shows internal signal flow of NUC unit.

3. Calibration

Now we have four variables in order to reduce non-uniformity error. The first and second one is video processor coefficients which are channel wise gain and offset. The third & forth is NUC table coefficients which are pixel wise gain and offset. Using those variables we must maximize SNR and minimize non-uniformity of the MSC system.

1) Test environment

The uniformity of radiometric response is verified by measuring the response of each pixel of the EOS (after applying the non-uniformity correction tables) while imaging a uniformly illuminate target at 5% and 95% of the sensor saturation, with nominal settings of gain and

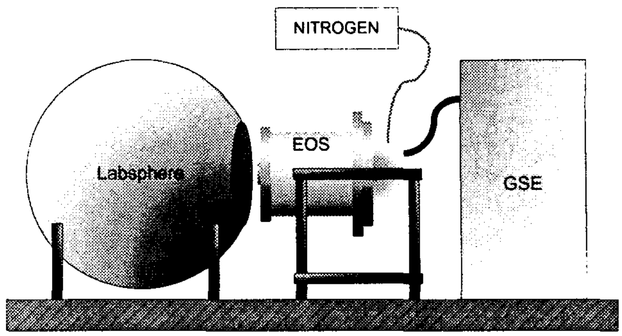

Fig. 7. EOS test environment

offset.

The output level of each pixel is recorded for a large number of lines (for averaging purpose), while illuminating with a uniform light source, though a collimator. The appropriate pre-calculated NUC table will be applied on the pixel data. The non-uniformity of the entire swath is analyzed.

2) Video processor coefficient

In PAN channel, rare CCD output shows non-uniform response as Fig. 8. Video processor calibration is performed along the following steps. In low illumination environment, the major factor which contributes to the non-uniformity is channel offset difference. So we must get the adjustment offset level between each CCD output channel in low light first. To minimize effect of temporal noise, mean value of each CCD output channel is preferred. After that, adjust gain of each channel on high intensity light to have uniform response. Even small amount of effect, non uniform channel gain contribute to the low level uniformity. So we must repeat this adjustment procedure several times in low level and high level light condition. After channel gain and offset adjustment, system output has uniform response tendency as following Fig. 9.

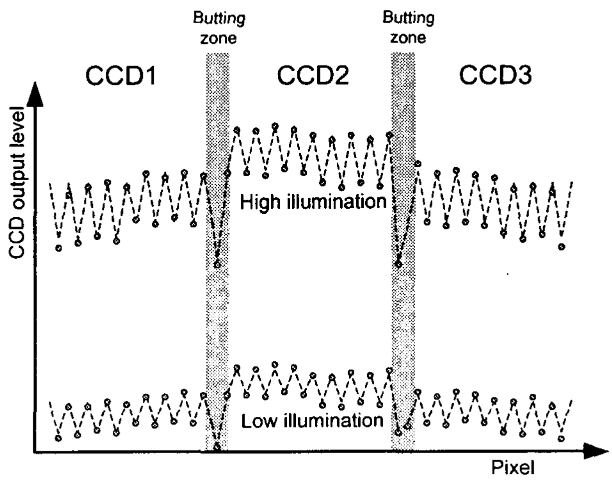

Fig. 8. Rare CCD output (PAN channel)

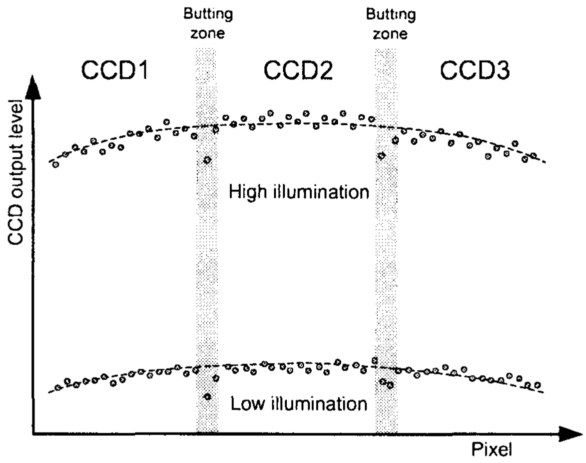

Fig. 9. Video processor output after a calibration (PAN channel)

3) NUC table generation

Current NUC operation concept is correct only high frequency component of the image so that it may not degrade image quality by lossy compression. If NUC covers wide range of non-uniformity including low frequency component, it must require wide width bit multiplication and addition to get current precision. It is heavy burden to the satellite system. NUC table generation is processed as follows. (1) Make temporal mean value of each pixel for several light condition (ex. 5%, 50%, 95%). (2) Make spatial low frequency curve of pixels (Fig.6 dashed line) (3) Using one dimensional regression algorithm, calculate gain and offset of each pixel close to the low frequency tendentious curve.

After all calibration, NUC output shows smooth uniform pixel response (Fig. 10). Low frequency non-uniformity is measured on the ground calibration phase and its full characteristic sheet will be provided to the ground station for a complete non-uniform correction.

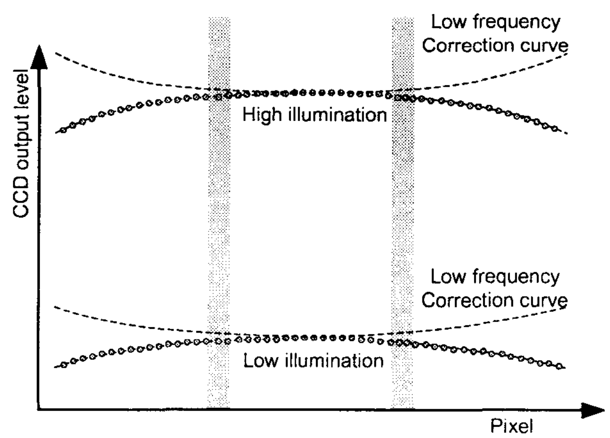

Fig. 8. NUC output after all calibration procedures (PAN channel)

4. Conclusions

PRNU is one of the most important specifications for the electrical optic payload. So, understanding of non-uniform characteristic of MSC system is very important. MSC system image chain consists of OM, CEU (which contains CCD and video processor), NUC and DCSU. OM and CEU make several non-uniformities due to the design and current process limits. Using video processor gain and offset control and dedicated digital signal unit, NUC, MSC reduces non-uniformity of the entire system.

References

[1] MSC EOS system requirement specification, ELOP
[2] MSC CEU hardware specification, ELOP
[3] MSC CCD requirement specification, ELOP
[4] MSC NUC system requirement specification, ELOP
[5] MSC EOS GSE software require specification, ELOP