The Overview of CEU Development for a Payload

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Abstract: The Electro-optical camera subsystem as a payload of a satellite system consists of OM (optical module) and CEU(camera electronics unit), and most performances of the camera subsystem depend a lot on the CEU in which TDI CCDs(Time Delayed Integration Charge Coupled Device) take the main role of imaging by converting the light intensity into measurable voltage signal. Therefore it is required to specify and design the CEU very carefully at the early stage of development with overall specifications, design considerations, calibration definition, test methods for key performance parameters. This paper describes the overview of CEU development. It lists key requirement characteristics of CEU hardware and design considerations. It also describes what kinds of calibration are required for the CEU and defines the test and evaluation conditions in verifying requirement specifications of the CEU, which are used during acceptance test, considering the fact that CEU performance results change a lot depending on test and evaluation conditions such as operational line rate, TDI level, and light intensity level, so on.

Keywords: Electro-Optical Payload, satellite bus, TDI CCD, Camera Electronics Unit

1 Introduction

Remote sensing using a satellite like KOMPSAT(Korean Multi-Purpose SATellite) implies that the instrument used to gather information is located on a platform of the satellite consisting of spacecraft bus and a payload. As shown in Figure 1, the payload comprises a EOS(electro-optical payload subsystem) and PDTS(Payload Data Transmit subsystem). The PDTS stores and transmits these digital image data which were generated in the EOS to the ground station through X band antenna. The EOS, which is used for imaging in a satellite system as an instrument has a general configuration of OM and CEU.

The system performance of the satellite as a remote sensing system depends largely on the performance of EOS together with the stability performance of the satellite, and the EOS performance is mostly affected by the CEU performance. In other words, most specifications of the EOS are defined by CEU performance except some mechanical aspect and MTF specifications, etc. And it also has been known that CEU performance changes depending on test and evaluation conditions, so it is important to set specifications with the definition of test and evaluation conditions especially for the CEU which uses linear TDI CCDs because of its various operational modes. This paper describes about it. We'll describe what is generally required for a CEU design, and the some key requirements with test condition and then about the calibration in CEU development phase instead of EOS level.

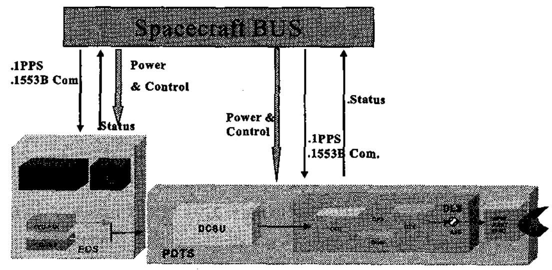

Figure 1. Payload System Configuration

2 The Requirement and Design Consideration for CEU

2.1 Functional Requirement

The CEU requirement is generally classified into life time related requirement, redundancy requirement, functional requirement, environmental requirement, electrical and mechanical interface requirement, operational requirement and performance requirement. Each requirement can be understandable easily by its name due to its general implication. But, we need to describe more details about the functional and performance requirement because they have special meanings in the CEU development.

Functional requirement includes, in general; programmable gain/offset control, line rate control, CCD timing adjustment control, power on initialization time, CEU image output control, DSNU(Dark Signal Non-Uniformity) and PRNU(Photo-Response Non-Uniformity) correction and focusing control, etc. The CCD timing adjustment control requirement means CEU functionality being able to do fine tuning of CCD control for a best performance in terms of noise and image quality. Line rate control in a space camera system using TDI CCD is critical because imaging should be done with synchronization between satellite velocity and line rate. Otherwise, it causes performance, especially MTF, degradation. And functionality of DSNU and PRNU correction is also considered to be important for an optimal performance in a satellite camera system where image compression is used for a data size reduction. The focusing control is also requested in a high resolution space camera to compensate the defocusing which can be happened during launch time, and be caused by thermal effects on the telescope. Programmable gain/offset control is requested for finding a best imaging conditions for the target being imaged.

2.2 Performance Requirements

The performance requirements include spectral band, ground sampling distance, SNR, saturation level, dynamic range, linearity, swath, dark signal and dark signal noise, MTF, PRNU and DSUN, etc. As described already, these requirements should be defined with the test and evaluation conditions.

2.3 Design Consideration

The CEU for an optical payload, as a main component of EOS, is required to support one panchromatic band and 4 multi-spectral imaging bands based on the requirement of a satellite when we take KOMSAP-2 as an example. In a development of the electronic box of a satellite system, fault isolation and redundancy concept is considered as critical. And one of the restrictions in a CEU development is that FPA is not able to include full primary and redundant CCDs together on a focal plane due to its area limitation of focal plane, so FPA designer should consider how to overcome this issue. One method is to protect imaging from failure of the full swath of certain imaging band by separating the one image band into more than two modules which are controlled independently taking account of fact that full-swath imaging of one imaging band is usually implemented using more than two CCDs. It more or less replaces the primary and redundant design concept which usually is used against single point failure in a satellite system. And for the fault isolation, the electronics should be designed to have the modular concept by which any failure in a module does not propagate into other modules.

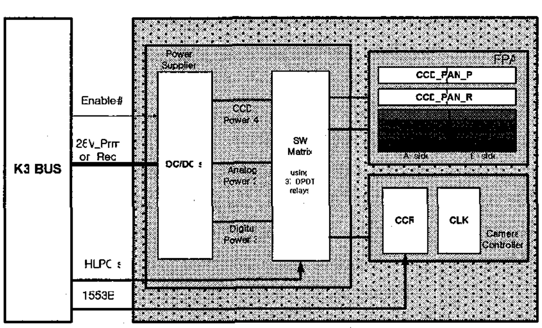

Figure 2. CEU Configuration

2.4 CEU Configuration

As shown in Figure 2, CEU consists of 3 blocks; Power supply block, CC(Camera Controller) block and FPA(Focal Plane Assembly). FPA, which comprises one band of panchromatic CCDs and 4 bands of multi-spectral CCDs, is assembled directly to the OM platform to be aligned opto-mechanically. Each imaging bands are implemented independently and isolated each other electrically so that any failure in the one band does not propagate to other bands. And each band's imaging data includes its own header information that is used for interpreting the image data correctly. The CC(Camera Controller), as the name implies, controls the imaging operation by handling the command and telemetry from/to BUS spacecraft. It controls the starting/stopping of imaging, the imaging modes and imaging parameters. The FMC(Focus Mechanism Control) that is also located in CC provides focusing control to the EOS when user decide to compensate the de-focus which might be caused by the launch shock or thermal expansion of the telescope during the normal operation, etc. The Power supply block functions to supply secondary powers to the each box mentioned above. Its main modules are DC/DC converter modules, and a switching matrix. DC/DC modules generates the 9 kinds of secondary power for the CEU's internal electronics, and the switching matrix, by the control of high level pulse command from the BUS spacecraft according to the imaging mode, selects the image sensor module.

3. CEU Calibration

It is general to do calibration in the EOS level when a contractor develops EOS including CEU. However, when a CEU is developed by a third party it is required to do calibration in the CEU level. This section describes calibration in the CEU level.

The purpose of the calibration is to derive relevant physical or object information from the measured data. On the phase of CEU development the design, measurement and analysis for the CEU-only calibration without OM are required. The differences in calibration between CEU and camera-system exist and come form the telescope alone. The calibration procedure refers to the following topics; geometric, radiometric and image quality. The geometric calibration or determination of interior orientation is a map between image pixel of the TDI CCD matrix and the coordinates in the focal plane or camera coordinate system. It can be calculated by an affine transform. The radiometric calibration establishes the link between sensor output signal measured in voltage and expressed in digital number and absolute physical radiation values in front of the sensor, which can be described by a transfer function. Image quality is the last requirement of calibration. The blur of the system is caused by the atmosphere, motion of the object or the system, finite size of the aperture, the detector and so on.

In general, the radiometric calibration of the TDI-CCD without the telescope optics is essential to characterize CEU's spectro-radiometric performance with respect to the following items:

- -Determination of the Dark Signal Non-Uniformity (DSNU)
- -Determination of the Photo Response Non-Uniformity (PRNU)
- -Measurement of the spectral response function
- -measurement of the radiometric sensitivity and determination of the corresponding calibration coefficients
- -Temperature dependence of the calibration coefficients
- -Determination of the dynamic range
- -Measurement of the linearity of the detector signal response through the whole dynamic range
- -Determination of the Signal to Noise Ratio (SNR)
- -Measurement of the polarization sensitivity

4. Test and Evaluation Conditions

The CEU, after manufacturing, goes through the validation test in terms of electronic functions, electro-optical performance as well as the proof of the compatibility of the design regarding the mission loads such as environmental stresses. This section suggests the test and evaluation conditions for some key parameters which are crucial to EOS performance as well as CEU based on the rational decision. Because test results depend on the test conditions considerably, it is requested that for each test items optimal conditions should be discussed and decided according to the mission of the project. Among various conditions are line-rate, TDI stage and input radiance. Following are the descriptions and test conditions for some key requirement specification.

SNR

The SNR specification should be met under the customer-defined input radiance, and the line rate is set to normal value with normal TDI stage. That is, the SNR shall be tested by using an adequate light source that simulates the effective earth radiance values or an extended target and analyzed based on the measured values of responsivity and system noise. The output level for each pixel (of the PAN and all MS bands) shall be recorded for a large number of lines (for statistical noise calculation), while illuminated by a predefined illumination level.

PRNU/DSNU

The PRNU/DSNU test should be done for all TDI stage because its correction parameters for all stage are stored on-board for application on a nominal line rate. The uniformity of radiometric response shall be verified by measuring the response of each pixel after applying the non-uniformity correction tables(PRNU/DSNU tables) which are generated while imaging a uniformly illuminated target at 5% and 95% of the sensor saturation, with nominal settings of gain and offset. The output level of each pixel (of the PAN and all MS bands) shall be recorded for a large number of lines for averaging purposes, while illuminating the entire DFPAs with the Large Apperture Integrating Sphere (LAIS), a uniform light source. The appropriate pre-calculated NUC table will be applied on each pixel data and then the Non-Uniformity of the entire swath will be analysed. The measurement will be carried out at 10%, 30% 50% 70% and 95% of the Saturation level.

Radiometric Response Linearity

This specification should be met at the input radiance level between 10~90% of saturation level with nominal TDI stage at nominal line rate. The calculation is done with respective to the reference line which is generated by least square method using measured data at input level of 10, 30, 50, 70 and 90 % of saturation level.

Dark Signal/Dark Signal Noise

This specification should be met at the darkness with nominal TDI stage at nominal line rate too. For Dark Signal test, more than 100 successive-line readings of a pixel are averaged for each pixel and then maximum value of them is selected as Dark Signal. For Dark Signal Noise, the standard deviation of the more than 100 successive-lines of pixel readings is calculated for selecting a maximum as Dark Signal Noise.

MTF

The static MTF is tested and verified at the nominal line rate. In terms of TDI stage, nominal operational TDI for the cross-track MTF, and no-TDI stage for the along-track MTF test due to the un-synchronization of integration between along track charge transfer and slit target movement shall be selected. The MTF test on CEU level shall be done using performance-known OM.

4. Conclusions

We described the overview of the CEU development process in terms of requirement specifications, design considerations, calibration and test, which are necessarily defined in the early stage of CEU development. And we defined the test conditions taking account of the fact that performance results of the CEU and EOS depend on these conditions such as line rate, TDI stage and input radiance which is set according to the mission or presumed imaging target of a satellite program.

References

[1] Fairchild, DATA sheet CCD10121

[2] MSC operational Handbook