A Review of EOS Thermal Control Logic for MSC on KOMPSAT-2

H.P.Heo, J.P.Kong, Y.S.Kim, J.E.Park, H.S.Youn, H.Y.Paik
Korea Aerospace Research Institute
45 Eun-dong Yusung-gu, Taejon 305-600, Korea
(hpyoung, kjp123, yskim1203, pje, youn, phy) @kari.re.kr

Abstract: MSC (Multi-Spectral Camera) system is a remote sensing instrument to obtain high resolution ground image. EOS (Electro-Optic System) for MSC mainly consists of PMA (Primary Mirror Assembly), SMA (Secondary Mirror Assembly), HSTS (High Stability Telescope Structure) and DFPA (Detector Focal Plane Assembly). High performance of EOS makes it possible for MSC system to provide high resolution and high quality ground images. Temperature of the EOS needs to be controlled to be in a specific range in order not to have any thermal distortion which can cause performance degradation. It is controlled by full redundant CPU based electronics. The validity of thermistor readings can be checked because a few thermistors are installed on each control point on EOS. Various kinds of thermal control logics are used to prevent 'Single Point Failure'. Control logic has a few set of database in order not to be corrupted by SEU (Single Event Upset). Even though the thermal control logic is working automatically, it can also be monitored and controlled by ground-station operator. In this paper, various ways of thermal control logic for EOS in MSC will be presented, which include thermal control mode and logic, redundancy design and status monitoring and reporting scheme.

Keywords: MSC, EOS, Heater, Thermistor

1. Introduction

MSC is a high resolution multi-spectral remote-sensing instrument. MSC will be installed on KOMPSAT-2 that will be launched in 2004. MSC will perform its mission with the GSD (Ground Sample Distance) of 1m, swath width of 15km and spectral range of 450nm ~ 900nm at the altitude of 685km.

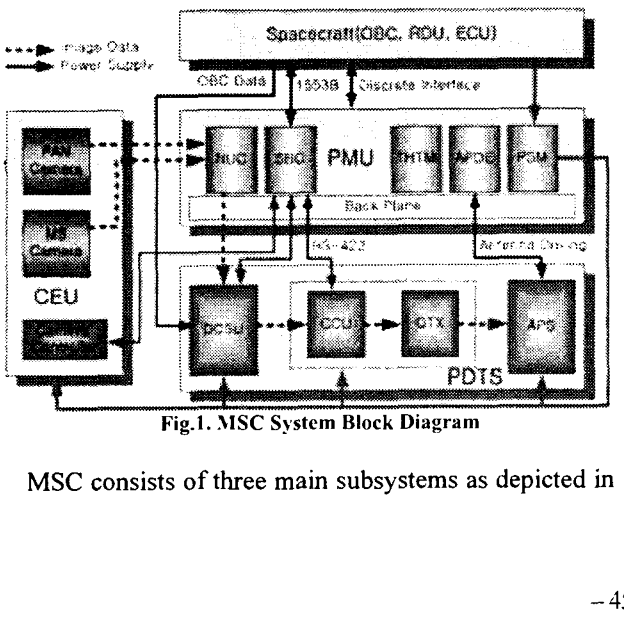

Fig.1. MSC System Block Diagram

MSC consists of three main subsystems as depicted in fig.1. One is EOS (Electro-Optics Subsystem), another is PMU (Payload Management Unit) and the other is PDTS (Payload Data Transmission Subsystem). EOS receives incident energy and converts them into digital electronic signal and PDTS stores these digital image data and transmits them to the ground station through X-band communication link. PMU performs the electrical and software interface between MSC and spacecraft, and controls all the MSC subsystem according to the ground station commands and reports all the state-of-health telemetry to the spacecraft. EOS consists of PAN (panchromatic) camera, MS (Multi-Spectral) camera and CC (Camera Controller). PMU consists of SBC (Single Board Computer), THTM (Thermal & Telemetry Module), NUC (Non-Uniformity Correction Board), APDE (Antenna Pointing & Deriving Electronics Board) and PSM (Power Supply Module). PDTS consists of DCSU (Data Compression & Storage Unit), CCU (Channel Coding Unit), QTX (QPSK Transmitter), ASU (Antenna Switching Unit) and APS (Antenna Pointing System). NUC is in charge of non-uniformity correction of image data. DCSU deals with image data compression and storage. APDE controls x-band antenna to look at the receiving antenna in the ground station. CC controls EOS to take pictures of ground target. CCU is in charge of encryption, CCSDS (Consultative Committee for Space Data Systems) encoding and randomization of incoming data stream from DCSU. THTM gathers the analog telemetry from all the units and sends them to SBC. THTM also controls the temperature of EOS structure, optic elements and detectors.

2. EOS Thermal Control Logic

The EOS is a combination of optical, mechanical and electronic components. The EOS consists of OM (Optical Module) and CEU (Camera Electronics Unit). OM is mainly consists of PMA (Primary Mirror Assemble), SMA (Secondary Mirror Assembly), HSTS (High Stability Telescope Structure) and CFA (Camera Focusing Assembly) as shown in fig.2. Each of them has several thermistors and heaters to be controlled properly. Heat from the CEU will be removed through cooling units while it is operating. The number of thermistor and location in the EOS are described in the table 1. THTM in the PMU collects all temperature information of EOS and controls the heaters to keep it in a specific temperature ranges.

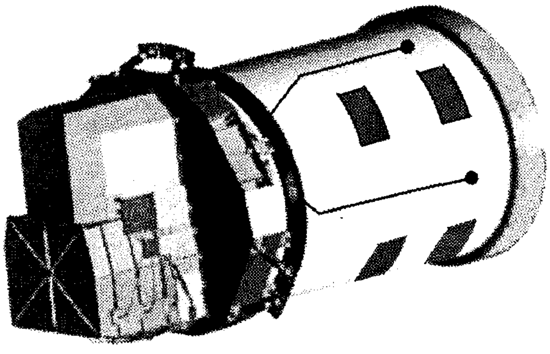

Fig.2. EOS in MSC System

Table 1. Thermistor Location in EOS

Units	Quantity	Range
PAN DFPA	4	-20℃ ~ 50℃
MS DFPA	2	-20℃ ~ 50℃
PMA	3	-40℃ ~ 80℃
SMA	3	-40℃ ~ 80℃
TUBE	3	-45℃ ~ 70℃

Because the resistance of the thermistor varies by the change of temperature, the temperature of each thermal control point can be calculated by measuring the voltage of the thermistor. The voltage on the thermistors is measured by ADC (Analog to Digital Converter) and it is converted into the resistance according to the following formula. The resistance is converted to temperature.

$$R_t = \frac{V_m * R_{ref}}{V_R - V_m} \Omega$$

Rref: Thermistor specific resistor value (Ω)
***V*r** : Sampled Reference voltage (V)
***V*m** : The measured voltage (V)
***R*t** : Computed resistance (Ω)

Even though the reference voltage for the thermistor is designed to be fixed, because it can be changed by the variation of the temperature, it will be measured through ADC and the measured value will be used for the calculation by the THTM.

After reading the ADC, it will be evaluated by the THTM software if the thermistor is neither shorted nor opened. If the ADC reading is smaller than 5 (short circuit) or bigger than 1018 (open circuit), the thermistor is considered as 'fail' because the output of ADC is 10 bit digital value. THTM software will keep the status of each thermistor if it is 'ok' or 'fail'. Each thermistor value will be read every 15 seconds and reevaluated repeatedly if it is 'ok' or 'fail'. These thermistor statuses are reported to the ground-station and it can be evaluated again by the ground-station operator because every thermistor readings are also reported to the ground-station. Ground-station operator can force the THTM to use or not to use a specific thermistor reading when calculating the average temperature using 'thermistor con figuration command'. THTM does not evaluate a thermistor reading afterward if it is forced to be fail by the 'thermistor configuration command'.

The calculated temperature value of each thermistor is used to get an average temperature of each thermal control point. For example, the average temperature of the PAN DFPA is computed from four thermistor readings. If a thermistor is marked as 'fail' status, it will not be used to calculate the average temperature. Only the rest of the valid thermistor readings will be used for thermal control.

This average temperature is compared with thermal control set point described in the table 2 in order to decide the status of the heater switches. For example, in case of PAN DFPA, the heater for the PAN DFPA will be on if the average temperature is below 5℃ and it will be off if the average temperature is above 8℃.

Table 2. Default Thermal Control Set Point

Units	Low Limit	High Limit
PAN DFPA	5 ℃	8 ℃
MS DFPA	5 ℃	8 ℃
PMA	-20 ℃	-17 ℃
SMA	-5 ℃	-2 ℃
TUBE	-20 ℃	-15 ℃

THTM software keeps the default thermal control set point and these are able to be updated by the ground-station command if necessary. It will be updated for out-gassing mode just after satellite launch or during normal in-orbit operation. During the out-gassing mode following table 3 will be uploaded to THTM and it will be used for thermal control of EOS.

Table 3. Out-Gassing Mode Thermal Control Set Point

Units	Low Limit	High Limit
PAN DFPA	5 ℃	8 ℃
MS DFPA	5 ℃	8 ℃
PMA	54 ℃	56 ℃
SMA	54 ℃	56 ℃
TUBE	-20 ℃	-15 ℃

3. Fault Detection & Recovery

Only when the EOS thermal control is working properly, the best performance of the MSC system can be guaranteed. Due to the fact that the thermal distortion of the EOS can directly cause the degradation of the image data, EOS thermal control logic has much redundancy concept and failure detection and recovery scheme.

1) Recovering SEU (Single Event Upset)

In MSC system, the thermal control logic is based on THTM which is the microprocessor based board and a lot of system information for thermal control logic is saved in the memory. In the THTM, all these information in the memory have more than one copy in order not to be damaged by SEU. THTM software examines those data periodically to check if there was an SEU. If some of the data has been spoiled by the SEU, it will be recovered using another copy.

2) Validating New Thermal Set Point

As described in the previous chapter, thermal control set point can be changed by the ground-station command. When SBC receives the command for updating the thermal control set point from the ground-station, the new table will be evaluated by SBC software to check if it contains only reasonable range. If not, the command will be rejected. Table 4 shows the checking limits.

Table 4. Acceptable Range for Thermal Control Set Point

Units	Normal Mode	Out-gassing Mode
PAN DFPA	0 ℃ ~ 30 ℃	0 ℃ ~ 30 ℃
MS DFPA	0 ℃ ~ 30 ℃	0 ℃ ~ 30 ℃
PMA	-20 ℃ ~ 45 ℃	30 ℃ ~ 58 ℃
SMA	-10 ℃ ~ 45 ℃	30 ℃ ~ 58 ℃
TUBE	-20 ℃ ~ 40 ℃	-20 ℃ ~ 40 ℃

3) Checking THTM Internal Failure

There are two THTM (primary and redundant) in the system and both THTM are identical. During the normal operation, SBC enables only primary THTM and it is in charge of controlling the temperature of the EOS. Because SBC is continuously monitoring the status of THTM, like voltage status, RAM check results, ROM check results and ADC status, if there is some problems in the primary THTM, SBC will switch active THTM from primary to redundant. If it happens, ground-station operator can know the exact situation by the related telemetry and some action may be taken. Before some action is taken by the ground-station operator, if another problem is occurred to the redundant THTM, SBC enables both primary and redundant THTM instead of switching THTM repeatedly. In this case, both THTM will perform the thermal control simultaneously.

4) Duty Cycle Mode

As explained in the previous chapter, each thermal control point has more than one thermistor and the average temperature of valid (which is marked as 'ok') thermistor reading is used for controlling the status of heater. If all thermistors in the same control point are evaluated as 'fail', it will be controlled in the 'duty cycle mode'. In the duty cycle mode, the thermistors are not used any more to decide the status of heater. The status of the heater is controlled only by the 'on off duty cycle table'. In the duty cycle mode, the PAN DFPA and MS DFPA heaters will be off whenever the respective camera is active in order to prevent overheating the camera detectors. Default duty cycle table which is kept by THTM software is described in the table 5. This duty cycle table can also be updated by a ground-station command.

Table 5. Default Duty Cycle Table

Units	On Time	Off Time
PAN DFPA	60 seconds	60 seconds
MS DFPA	60 seconds	60 seconds
PMA	120 seconds	120 seconds
SMA	60 seconds	60 seconds
TUBE	60 seconds	180 seconds

5) Using Redundant Switch for Heater

In order to protect the system from failure of the switches for heaters, the switches are configured as 'I-bridge' which uses two serially connected FET (Field Effect Transistor) switches. Even though one of two switches is failed and it is closed all the time (short fail), the control logic will work properly using the other switch.

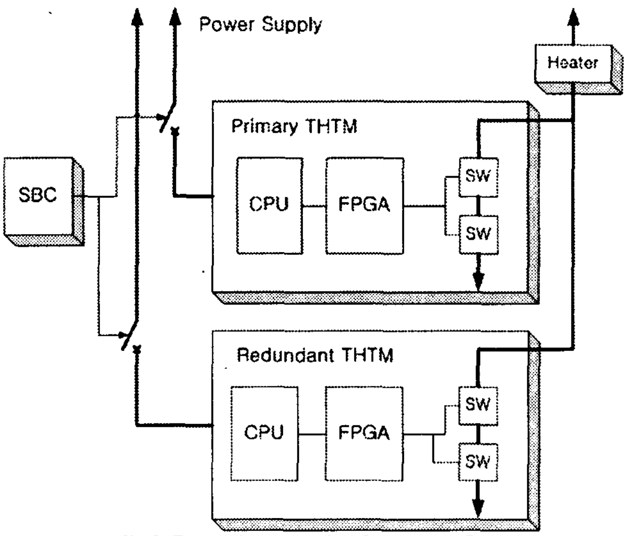

Fig.3. Redundancy Design for Heater Control

However, if one of the switches is fail and it is open all the time (open fail), the other switch is not enough to turn on the heater. In this case, the temperature of the control point will be decreased under the low limit of the set point. Especially, PAN & MS DFPA can be easily damaged if the temperatures of them are below the low limit. In order to cope with this failure, SBC always monitors the temperature of the DFPA which are to be sampled and transferred to SBC by THTM. If the temperature is lower than the predefined temperature limit, SBC will automatically switch active THTM from primary to redundant. From that moment, redundant THTM will do the thermal control. If the temperature of the DFPA is still below the limit, SBC will activate the primary THTM again. Therefore, both primary and redundant THTM will do the thermal control simultaneously. Additional failures which normally cause the THTM switch will not cause the THTM switch any more.

Therefore, automatic switching THTM will occur only once before the system receives manual command from the ground-station to select active THTM. Even though this recovery logic will work automatically, everything about logic can be controlled by the ground-station operator using related command. The temperature limit which causes the THTM switch can be changed by command. The time duration from the moment SBC detects the low temperature to the moment SBC do the THTM switch, can also be changed by command. The ground-station command can make SBC not perform the THTM switch even though the temperature is below the limit.

6) Validating Thermistor Reading

THTM reads the value of the thermistors periodically and performs the validation check if it is neither open circuit nor short circuit. However, there is a possibility, even though it is extremely little, that the thermistor reading may indicate wrong temperature compared with actual temperature. Accordingly, the average temperature results in different temperature from actual one. This kind of failure can not be handled by THTM, therefore part of the EOS may be overheated or overcooled, which may cause permanent damages to them. In order to overcome this situation, SBC always checks the thermistor reading if they are within reasonable range according to the predefined range. If some of the thermistor readings are out of this boundary, SBC declare that they are 'fail' and send 'thermistor configuration command' to force THTM not to use these thermistors for thermal control. The detail operation of the validity check can be controlled by ground-station command. Valid temperature range for the thermistor is initialized by the SBC software and it can be updated by the ground-station command. Validity checking operation can be disabled at all by the ground-station command. Default validation ranges are described in the table 6.

Table 6. Thermistor Validation Boundary

Units	Normal Mode	Out-gassing Mode
PAN DFPA	0 ℃	40 ℃
MS DFPA	0 ℃	40 ℃
PMA	-20 ℃	40 ℃
SMA	-10 ℃	45 ℃
TUBE	-25 ℃	40 ℃

4. Conclusions

Keeping the temperature of the EOS within a specific range is very much important in order not to cause the thermal distortion and deformation which may result in overall performance degradation. In MSC system, two microprocessor based controller, THTM, provides reliable control on the temperature of the EOS. Failure detection and recovery concepts are implemented in the THTM and SBC. The system will keep multiple copy of database for thermal control in order to be recovered from SEU. Thermistor readings are to be checked if it is within reasonable range. The average temperature is calculated only with the validated thermistors. Backup duty cycle mode will recover the failure of the thermistors.

References

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