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ICU Closed loop bake out heater controller

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Applicable References (appears in [] in the following text):

1 – EIS Science requirements:	MSSL/SLB-EIS/SP007.07
2 – EIS Status:	MSSL/SLB-EIS/SP017.05
3 – EIS telecommanding structure:	MSSL/SLB-EIS/SP016.05
4 – Meeting with Berend Winter and Jason Tandy	11/10/04.
5 – FM CCD Bake out Heater Test Report:	MSSL/SLB-EIS/TR/005.02
6 – SOLAR-B EIS Mode definition:	MSSL/SLB-EIS/SP013.02
7 – EIS Health Monitor (auto safe):	MSSL/SLB-EIS/SP052.01
8 – EIS Structure requirements:	MSSL/SLB-EIS/SP006.3

Glossary and Convention:

ADC	Analogue to Digital Converter
BC	Block Command, Solar-B Command parameter
CAM	Camera
CCD	Charged Coupled Devices
EIS	Extreme ultraviolet Imaging Spectrometer
HM	Health Monitor
MHC	Mechanism and Heater controller
PSU	Power Supply Unit
OP/OG	Solar-B deferred command, Operation / Organised command store

1.0 Introduction

In order to operate EIS CAM, there is a need to decontaminate the CCDs by heating them to 35 °C (TBC). The contaminants are primarily iced water. This operation is called “CCD Bake Out” on EIS.

In order to perform this operation, two bake out heaters are embedded within the CCDs invar plate. Each CCD has its own heater and temperature sensor. The temperature sensors reading are reported in the PSU status [2].

2.0 EIS bake out requirements

There are three key requirements to perform bake-out operations:

1) EIS shall remain within its power budget. This necessitates that the CAM and MHC are turned OFF during this operation. A special EIS mode is implemented to perform this operation, Bake out mode [6].

2) The manufacturer recommends that the rate of temperature change should not exceed 2 °C per minute.

3) The CCDs and their heaters are qualified to 60 °C and this temperature shall not be exceeded.

3.0 Open loop vs. closed loop heater control

During the initial phases of the project, it was believed that a simple **open loop** control is required to perform the CCD bake out operation. The open loop bake out operation is performed as follows:

1- Command the instrument to bake out mode. This ensures that the MHC and CAM are turned OFF [6].
2- Turn the bake out heaters ON. It was hopped that the temperature will rise to a bake out level (30 to 40 °C).

The bake out operation was performed during the instrument calibration on the 3rd of July 2004 [5], under vacuum and the CCDs were cooled to operational temperature (-53 °C). The following results were observed:

1- The rate of temperature rise is an order of magnitude grater than that specified in requirement 2, section 2. An average of 10 °C per minute has been observed.

2 – The potential temperature rise is in access of the required level for bake out operations and that violates requirement 3, section 2.

In order to reduce the rate of temperature rise, an additional bake out test was undertaken by reducing the heater duty cycle to 20%. The test showed an improvement in that rate of temperature rise. However, the temperature could only reach +5 °C. A further increase to 40% in the heaters duty cycle was needed to reach +40 °C.

The tests performed in [5] led to the following conclusions:

1) A trade off between the heaters power (temperature rise rate) and reaching the target bake out temperature is needed.
2) No single power level could meet the above trade off. A gradual increase in the heater power is the only way to achieve this.
3) A software guard should be placed in such that the target temperature is not allowed to exceed the required level.

The only way to achieve the above three needs is to adopt a **closed loop** heater control that allows for gradual heater power increase as well as decreasing the heaters power level for the re-cooling. The latter is to soften the CCDs cooling rate back to operational temperature.

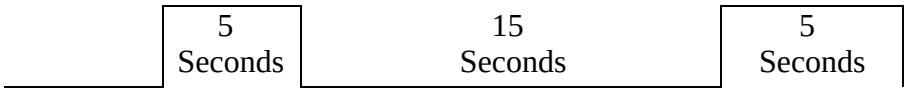
4.0 Bake out operational requirements

Based on the conclusions outlined in section 3.0, The bake out operational requirement has been modified as follows [4]:

1) The initial heater power (start up power) shall be a 5% duty cycle.
2) The heaters duty cycle shall be incremented or decremented in 5% steps.
3) The minimum time between changes in the heaters duty cycles shall be 5 Minutes. Failing to do this will result in the "duty cycle adjustment command" being rejected.
4) The default target temperature shall be +35 °C (TBC), allowing for orbital temperature swing of 3 °C [8, section 10.3]. The target temperature shall be specified in temperature sensor ADC units.
5) The target temperature shall be an up-linkable parameter. A change in the target temperature should be specified prior to invoking bake out mode.
6) The heaters cycle time shall be 20 seconds.

Duty Cycle definition:

A duty cycle defines the heaters ON time. For example, a 25% duty cycle and 20 second cycle time is as follows:



A 25% heater duty cycle (5 seconds ON and 15 seconds OFF)

5.0 Heater control task commanding and status reporting

To meet the requirements outlined above, the following new commands are required to be added to the EIS telecommanding structure document [3] in order to control the CCDs bake out operations:

CMD BC1 = 0x28 (set target temperature). This command requires one parameter (BC2) to specify the control temperature in ADC units. This command **must** be sent prior to invoking bake out mode, if the default target temperature needs changing.

CMD BC1 = 0x29. This command increases the heater duty cycle by 5%. This command **must** be sent from bake out mode.

CMD BC1 = 0x2A. This command decreases the heater duty cycle by 5%. This command **must** be sent from bake out mode.

Also the following status type 1 parameters [2] are required:

Heater controller status, heater controller target temperature and heater controller current duty cycle.

6.0 Heater control operational procedure

In order to operate the closed loop heater controller, the following procedure shall be followed:

1) Command the instrument to bake out mode [3]. At this point the bake out heaters are enabled, via the PSU relays. It is recommended that this command be issued while EIS is in ground contact.

2) The heater controller task starts and then **idles** for **30 seconds** before applying the start up 5% heater power. The **idle time** is to allow the ground to disable one of the heater relays, in the unlikely event of a bake out heater fault.

3) After the 30 seconds idle time has elapsed, the controller starts acquiring the CCD temperatures and applying the initial 5% heater power. Also at this point an ICU elapsed time timer is started for power updates.

4) Increase the heater power level by issuing CMD BC1 = 0x29. While this command can be sent from the ground, however, its primary use is from Solar-B OP/OG store. It is anticipated that the maximum power level required to reach the required temperature is around 40% (7 increments of 5%).

5) When the bake out period has elapsed, decrease the power level by issuing CMD BC1 = 0x2A. Power shall be decreased in a controlled manner using a similar algorithm to that used for incrementing power. When the heater power reaches 0%, the controlling task shall switch the heaters OFF and terminate its operations. The bake-out heater operations shall only restart by invoking bake out mode again. Changing EIS mod from bake out mode to Standby or Emergency modes would result in switching the heater power to 0 and terminate the control task operations. However, if the duty cycle not equal 0, then this is considered as an abrupt termination, i.e. abort.

In order to gain observing time, it is possible to command the instrument to Standby Mode then Manual Mode to power the MHC ON. Then from Auto Mode, a sequence

to configure the MHC can be run so that normal structure heating operations can be resumed and if possible start science observing following the next ground contact. The latter should be undertaken following the commissioning phase and as the instrument behaviour in orbit is characterised and understood.

6.1 Heater control example

It is envisaged that the bake out heater control operation is performed as follows:

From the ground invoke the bake out mode. From Solar-B OP/OG store perform the following operations (as an example):

OP/OG TIME	CMD	DESCRIPTION
+ 10 Minutes	BC1 = 0x29	Set Duty cycle = 10%
+ 10 Minutes	BC1 = 0x29	Set Duty cycle = 15%
+ 10 Minutes	BC1 = 0x29	Set Duty cycle = 20%
+ 10 Minutes	BC1 = 0x29	Set Duty cycle = 25%
+ 10 Minutes	BC1 = 0x29	Set Duty cycle = 30%
+ 10 Minutes	BC1 = 0x29	Set Duty cycle = 35%
+ 10 Minutes	BC1 = 0x29	Set Duty cycle = 40%
Bake out temperature target reached at some point		
+ 12 Hour	BC1 = 0x2A	Set Duty cycle = 35%
+ 10 Minutes	BC1 = 0x2A	Set Duty cycle = 30%
+ 10 Minutes	BC1 = 0x2A	Set Duty cycle = 25%
+ 10 Minutes	BC1 = 0x2A	Set Duty cycle = 20%
+ 10 Minutes	BC1 = 0x2A	Set Duty cycle = 15%
+ 10 Minutes	BC1 = 0x2A	Set Duty cycle = 10%
+ 10 Minutes	BC1 = 0x2A	Set Duty cycle = 5%
+ 10 Minutes	BC1 = 0x2A	Set Duty cycle = 0% Heater controller task terminate its operations. Heaters are **OFF.** Bake out operations **can only re-start** from re-entering bake out mode
Normal mode transitions and MHC configuration may be resumed		

6.2 Additional notes

1) A change in the default bake-out temperature should be undertaken prior to bake out mode being invoked.

2) Separate to the bake out target temperature, there is a health monitor limit set for the CCDs temperature [7]. If the health monitor limit is reached, EIS emergency mode is invoked. To avoid unnecessary trips, a sufficient margin should be set between the health monitor limit and the bake out target temperature, to account for temperature over-shoot, sensor noise and orbital temperature swing. A margin of 15 °C is not unreasonable.

3) The elapsed timer returns time ticks in between two calls. A minimum time lapse of 5 Minutes in between two consecutive power updates must occur before the new

power level is accepted. For example, requesting power updates at 2 and 3 minutes intervals will result in rejecting both.

Also note that there is an uncertainty of 20 seconds (heater cycle time) of when the last power update was received by the controlling task, compared with when it was sent from the OP/OG store (asynchronous operation). The controlling task checks whether a power update was received prior to starting a new heater cycle. To ensure correct operation, the 5 Minutes limits will be set internally within the ICU software to (5 minutes – 25 seconds) (20 seconds heater cycle time plus 5 seconds margin). This will guarantee the acceptance of all power updates spacing of 5 minutes from the OP/OG command store.

4) The 5 minutes restriction on increasing the duty cycle has removed the need to restrict the maximum heater power applied. The temperature rise rate would be most vulnerable to high heating power at low temperatures. However, the ground testing has shown that applying 40% duty cycle is capable of reaching the required bake out target temperature [5].