CREAM Science Flight Computer

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***Abstract*. The balloon-borne Cosmic Ray Energetics and Mass (CREAM) instrument is comprised of several detector subsystems. The Science Flight Computer (SFC) combines the data from those subsystems into a single event record, and sends it to the University of Maryland via NASA's onboard Command Data Module (CDM), satellites tracking the flight, and mission support centers monitoring the flights. In order to perform this task successfully, the SFC must not only endure severe environmental conditions of low atmospheric pressure and temperature, but have a storage system not susceptible to vibrations or impacts from launch, flight and landing. We conducted the experiments under atmospheric pressure of 5 mbar and temperature range of between -10 °C and +50 °C. The excellent stability and robustness of the SFC have been verified by its successful operation in the CREAM-III/IV flights, which accumulated 48 days of exposure in Antarctica.**

***Keywords*: Corona discharge; Silicon CMOS device; Solid state disk (SSD)**

I. Introduction

The Cosmic Ray Energetics And Mass (CREAM) experiment is designed to measure the energy spectra and composition of cosmic rays through a series of long balloon flights in Antarctica [1][2]. The CREAM instrument comprised of several detector subsystems is monitored and controlled via the Science Flight Computer (SFC). The SFC builds data from different detector subsystems into a single event record, and sends it to the ground via the CDM and satellites. Since the CREAM experiment is conducted in the upper atmosphere over Antarctica, the SFC must endure severe environmental conditions of low atmospheric pressure and temperature to perform this task successfully. The SFC especially must have a robust storage system so that not only are stable read/write operations possible in the Antarctic atmosphere, but its installed software and collected scientific data should be protected against vibrations or impacts of launch, flight and landing.

This paper is organized as follows. Section 2 presents the effects of atmospheric environments in Antarctica on the SFC, and describes how the SFC has shown stable operations in those conditions and how the storage system of the SFC has been designed for robustness. In section 3, the experimental results conducted in laboratory are shown, and the stability and robustness of the SFC is verified by the CREAM-III/IV flights. The summary can be found in section 4.

II. Effects of experiment in Antarctica on the SFC and methods for improvement

Figure 1 shows the atmospheric temperature and pressure of Antarctica according to its altitude. Since the CREAM experiment has been conducted at the hatched region of from 30 Km to 37 Km, the effects of altitude on the SFC's operation must be considered.

First of all, low atmospheric pressure may lead to corona discharge in the SFC. Corona discharge is an electrical discharge brought on by the ionization of fluid surrounding a conductor. It usually occurs when a high electric potential difference is applied between two asymmetric electrodes; one with high curvature such as the tip of a needle and the other with low curvature such as a plate. This results in electrical damage by a momentary spark. It was reported that the atmospheric pressure has significant effects on the corona inception voltage (V_i) which tends to decrease linearly with a decrease in air density [5][6]. The relationship between V_i at standard pressure and that at low air pressure may be expressed as the following [6].

$$\frac{V}{V_o} = \left(\frac{P}{P_o}\right)^m$$

where V and V_o represent respectively the V_i at low air pressure P (high altitude) and that at the standard air pressure P_o (101.3 kPa = 1.013 bar); the exponent m is a constant whose value characterizes the influence of air pressure on V_i. In order to avoid corona discharge, it is necessary to eliminate electrodes with high curvature in the electrical system of the SFC. We can meet this requirement by soldering components on Printed Circuit Board (PCB) with round-shaped contacts.

Secondly, low atmospheric temperature can effect the operation of semiconductor devices in the SFC. The silicon CMOS device at low temperature not only performs better due to the increase of carrier mobility and switching speed, but it is more reliable due to

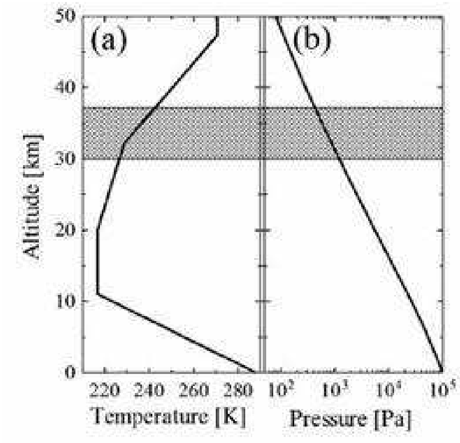

Fig. 1. Variation of atmospheric temperature and pressure according to altitude [3][4].

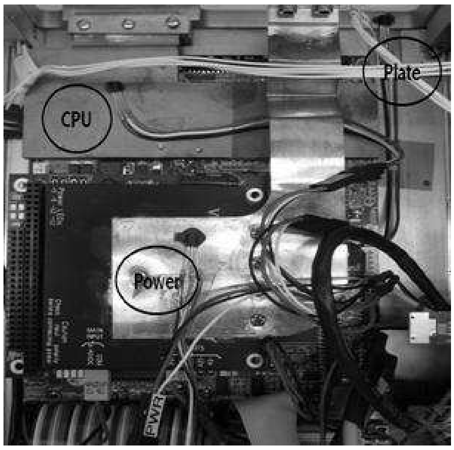

Fig. 3. Science Flight Computer (SFC). Notice three temperature sensors attached on plate, CPU and power module.

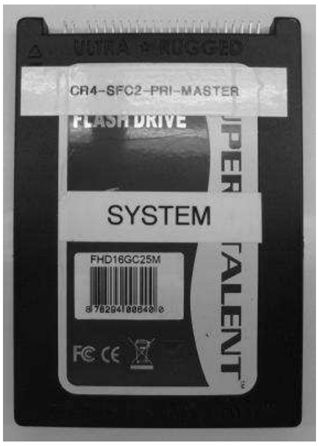

Fig. 2. Solid State Disk (SSD) used as storage system of SFC.

latch-up immunity and reduced thermal noise [7]. The electron mobility increases linearly as the temperature decreases from the room temperature to about 100 K [9]. However, the bipolar device poorly performs at the low temperature as a consequence of strongly reduced current gain [8]. Since the digital systems are mainly composed of silicon CMOS devices, it is expected that the SFC will show better performance in the Antarctic environment. As described in the following sections, however, the temperature of the SFC during flights remains near the room temperature because of the effect of heat dissipation from its electrical system. Consequently, the positive effect of low atmospheric temperature on the SFC is nullified.

Finally, we have to consider the reliability and robustness of the storage system in the SFC. The SFC must have a storage system able to support stable read/write operations in the Antarctic atmosphere, and its installed software and collected scientific data must not be damaged from vibrations or impacts resulting from launch, flight and landing. The common variant of hard disk drives (HDD) mainly used in mass storage is susceptible to vibration and shock damage. The potentially huge impact from the landing of the instrument especially compels protection of the drive, such as vibration isolators [10] to suppress vibration. However, this additive apparatus makes the heat dissipation of HDD worse because the drive using mechanical movements to access encoded data generates much more heat than solid-state electronic devices. A solid state disk (SSD) is not susceptible to vibration, and also shows much less heat dissipation. Besides, SSD capacity and affordability has advanced significantly in the past few years. Figure 2 shows the SSD used as the storage system of the CREAM SFC, which operates stably at low atmospheric pressure and temperature.

III. Experiment and verification

This section deals with the SFC vacuum and thermal tests conducted in the laboratory. The tested SFC is different from the CREAM-III/IV SFC, with respect to CPU type and number of thermal sensors. However, they have very similar hardware configurations. For the experiment, the SFC was first put into a chamber and then the air pressure and temperature of chamber were set to desired conditions. As the SFC is given conditions or commands, such as instructing it to access storage, the status of the SFC is monitored in real-time and recorded in log file simultaneously. The experimental result was a success, and it was verified during the CREAM-III/IV flights. Figure 3 shows the SFC used in the test, and three thermal sensors are attached on the machine to measure the temperatures, respectively, of base plate, microprocessor and power module. Table 1 shows the hardware specification of the SFC tested.

TABLE I
Hardware specification of tested SFC.

Mother Board	WinSystems EBC-855
Microprocessor	Intel Celeron 1GHz
Main Memory	DDR333 256MB
Storage	SuperTalent SSD 16GB

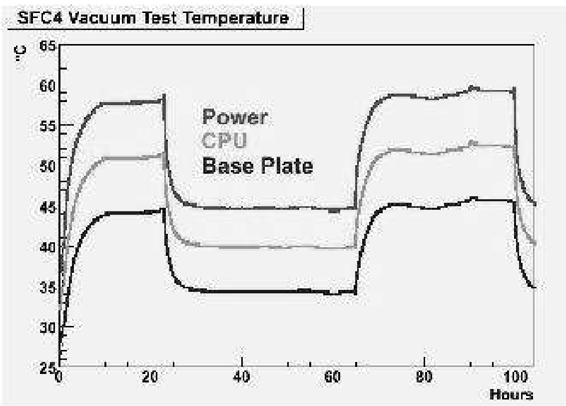

Fig. 4. Temperature variation of SFC in vacuum test.

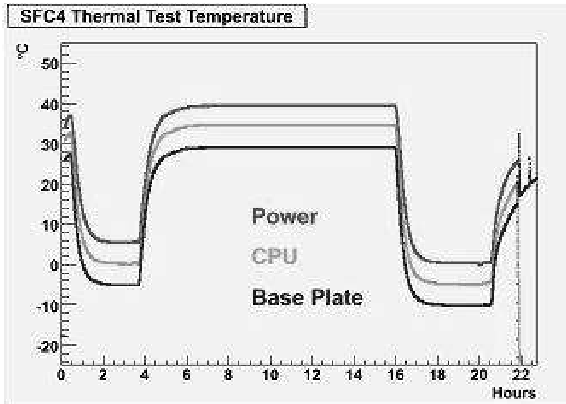

Fig. 5. Temperature variation of SFC in thermal test.

A. Vacuum test

Figure 4 shows the temperature variation of the SFC obtained from the vacuum test. The chamber was in a vacuum state (∼ 5 mbar) during two time intervals (0 ∼ 23 hours, 65 ∼ 100 hours), and it had atmospheric pressure 1.013 bar during the remaining time interval. The SFC operated stably during the entire test. As visible in figure, there is a temperature difference of about 13 °C between the two different chamber conditions. This is because the heat dissipation by convection in vacuum cannot occur.

B. Thermal test

Figure 5 shows the temperature variation of the SFC obtained from the thermal test. The chamber temperature was set to -10 °C at 0.4 hour and to +25 °C between 4 and 16 hours. Through additional experiments, the SFC has been qualified for stable operation at the temperature range of at least -10 ∼ +50 °C in the atmosphere of 1.013 bar.

C. Solid State Disk (SSD) test

Table 2 shows the result of SSD tests conducted under some different conditions. We verified the stability of the SSD via write operations and file system checks. The writing test evaluated the performance by measuring the time to write one SSD and multiple SSDs respectively. We investigated whether or not the file system had an error in the file system checking. All the SSDs were evaluated under normal conditions, as well as in vacuum and thermal environments. Note that the SSD was connected with a USB 2.0 interface during the thermal test. As shown in the table, all the SSDs tested operated well under the given environments without an error.

D. Verification from CREAM-III/IV flights

Figure 6 shows the temperature of the SFC during the CREAM-IV flight. Note that this data was taken during the last day of the mission, and the SFC remained within the temperature range of +10 °C to +35 °C. The excellent stability and robustness of the SFC has been verified by its successful operation in the CREAM-III/IV flights, which accumulated 48 days of exposure in Antarctica.

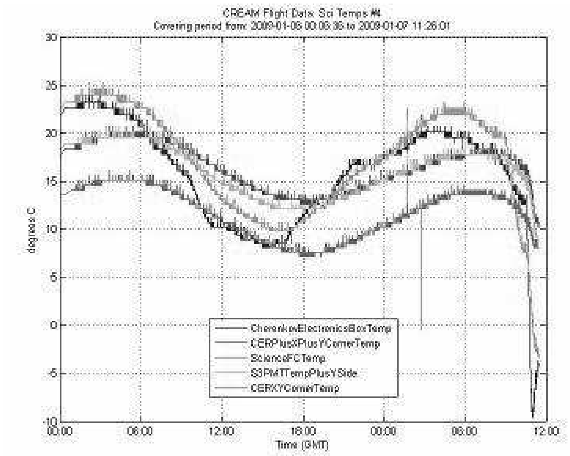

Fig. 6. Temperature (°C) of SFC in flight [11].

IV. Summary

The effects of severe atmospheric conditions in Antarctica on the CREAM SFC have been discussed and the methods to decrease negative effects have been presented. The SFC must have a robust storage system to endure low atmospheric pressure and temperature as well as vibrations and impacts. Through experiments in the laboratory the SFC shows a stable and robust operation and this has been verified by the successful CREAM-III/IV flights.

References

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TABLE II
TEST RESULTS OF SSD AT VARIOUS CONDITIONS ($msec$/4MB)

Condition	Test	SSD1	SSD2	SSD3	SSD4	SSD5	SSD6
Normal	WTS[1]	172	173	172	172	174	173
	WTM[2]	645	605	583	533	587	594
	FSE[3]	OK	OK	OK	OK	OK	OK
Vacuum	WTS[1]	171	172	171	172	173	172
	WTM[2]	528	485	282	532	482	278
	FSE[3]	OK	OK	OK	OK	OK	OK
-20 °C	WTS[4]	223	230	227	203	220	210
	WTM[5]	333	362	366	234	287	263
	FSE[3]	OK	OK	OK	OK	OK	OK
+50 °C	WTS[4]	233	235	238	214	228	221
	WTM[5]	332	364	363	339	387	333
	FSE[3]	OK	OK	OK	OK	OK	OK

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[1]WTS: time to write data to single drive on IDE bus.
[2]WTM: time to write data to 2-4 drives simultaneously on IDE bus.
[3]FSE: check file system error with fsck.
[4]WTS: time to write data to single drive on USB.
[5]WTM: time to write data to 2-4 drives simultaneously on USB.