THE UNIVERSITY OF SYDNEY

SCHOOL OF AEROSPACE MECHANICAL AND MECHATRONIC ENGINEERING

AERO3760: SPACE ENGINEERING 2

Group E: SnapSat

Data Package Document 1
Critical Design Review

21 AUGUST 2015

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Table 0.1: caption

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1 System Overview

The SnapSat is low budget (<$1000) 1U CubeSat designed by University of Sydney students. It's purpose is to be launched 30km into the atmosphere on a weather balloon as a proof of concept for CubeSats.

It utilises a 3D printed chassis, tested ..... blahblah structure stuff

Computationally, it consists of 5 major modules; the payload, attitude control and determination system (ADCS), location system, communications system.

2 Payload Design

The SnapSat payload is a single camera, used to take images of the earth throughout the flight. Due to the inherent size and power limitation of CubeSats, budget and ease of interface with the Iduino Due Pro, the 2MP ArduCAM Mini was selected.

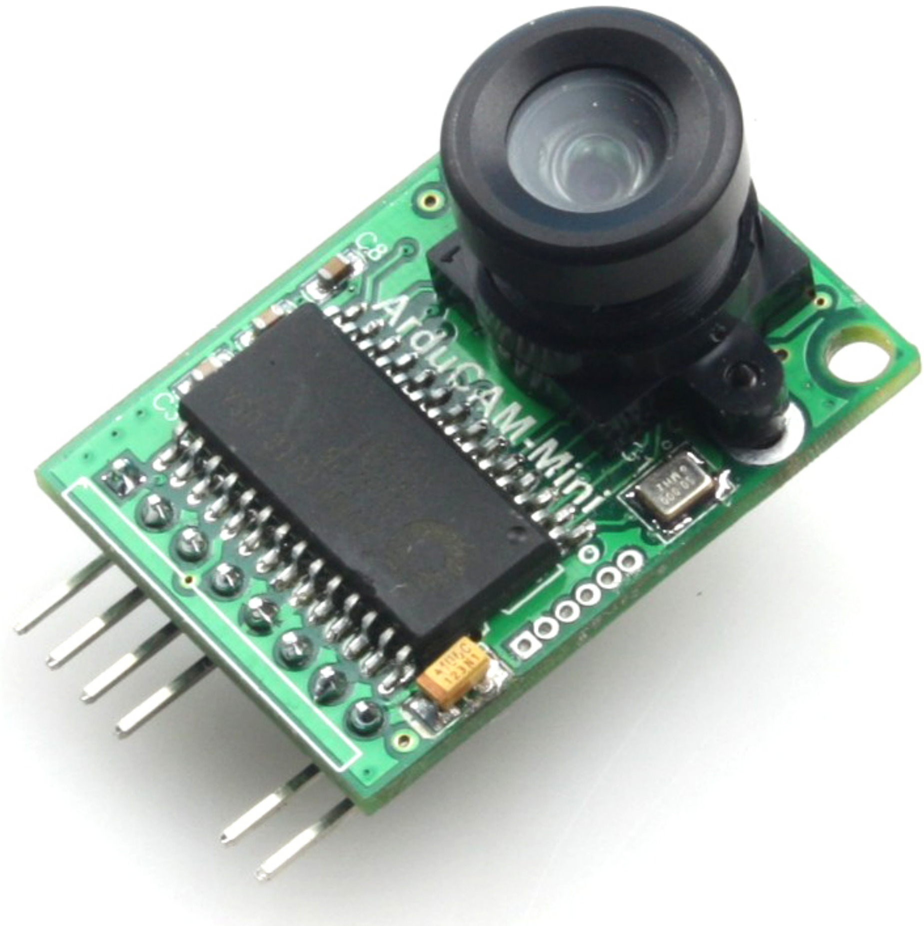

Figure 2.1: An image of the ArduCAM Mini. Note that there is no storage mechanism on this module, necessitating an external SD card.

Unlike the ArduCAM, on which this is based, the ArduCAM mini has no integrated SD Card to store photos. As such, the design includes an Adafruit SD Card which stores all pictures.

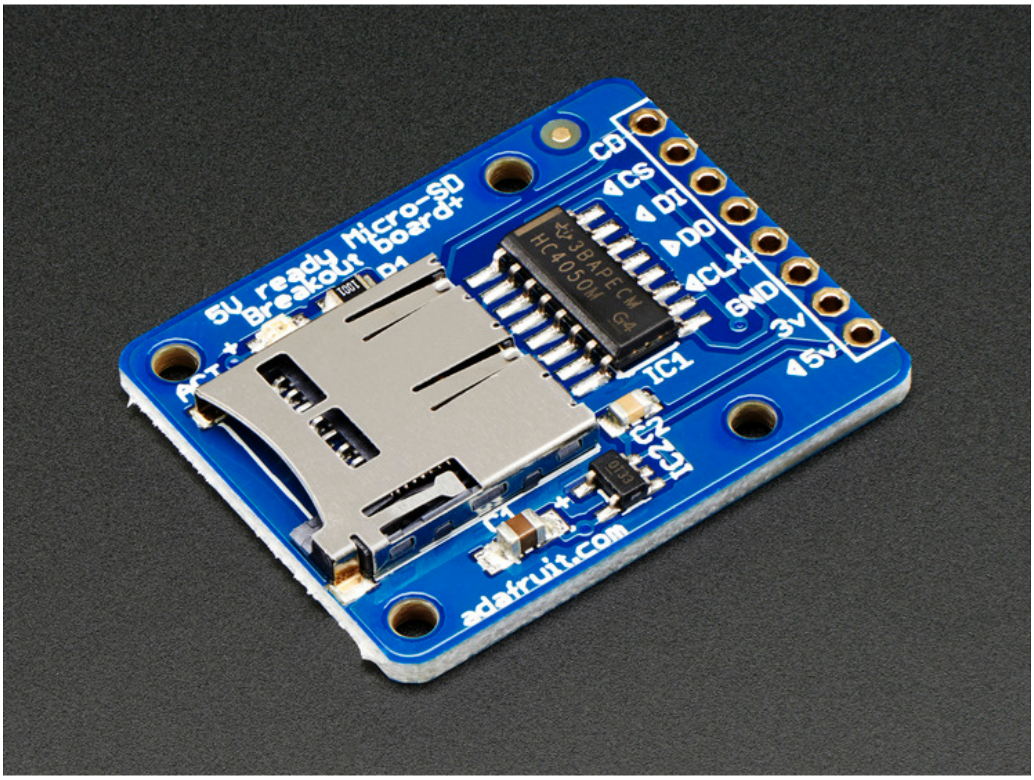

Figure 2.2: The SD card used in SnapSat

2.1 Integration

These two devices operate off the one SPI module and are physically located on the Bottom PCB. Additionally, the ArduCAM mini image sensor is controlled through I2C1 module. Both devices are powered by the 5V line, and use 3.3V CMOS logic levels, with no step up required.

STICK IN IMAGE OF BOTTOM PCB COMPLETED

Ultimately using a 16GB SD Card, assuming a size of 1MB per photo, and a balloon flight time of 4 hours this module is able to record 16000 photos or a photo every second.

3 Structural Subsystem

4 Attitude Determination and Control Subsystem

5 Electrical Power Subsystem

6 On-Board Computer and On-board Data Handling Subsystem

The SnapSat uses an Iduino Due Pro MCU to control the operation of the modules. It does not use an RTOS, instead using an infinite loop to log image and location data, but interrupt based control to priorities incoming messages of the communications subsystem.

FBD OF PROGRAM STRUCTURE

All data is logged on the SD Card

7 Communications Subsystem

8 Thermal Control Subsystem

The method of developing thermal control used for SnapSat considers the following simplified model of the satellite. The main body is idealised as a system dissipating heat (located at the centre of the CubeSat) to the boundary located on the face of the CubeSat. This boundary is exposed to the outer environment. Energy conservation laws require that in steady state, the heat dissipated by the internal electronics is equal to that transferred tot he boundary. Thus, the heat from internal dissipation added to the heat adsorbed from the outside is equal to the heat rejected to space. The general governing equation is

$$Q_{1\to 2} = K_{1\to 2}(T_a - T_2) \tag{8.1}$$

Where Q = heat exchange (Watts)
K = proportionality factor constant (Watts/Kelvin)
T = temperature of bodies (Kelvin)

between bodies 1 and 2. Additionally, the heat radiated from a blackbody surface of temperature T is given by

$$Q_r = KT^4 \tag{8.2}$$

Where the proportionality factor depends on physical constants, the material properties, surface conditions and geometry. A schematic of the incoming thermal radiation on the CubeSat in Low-Earth Orbit (LEO) is shown below.

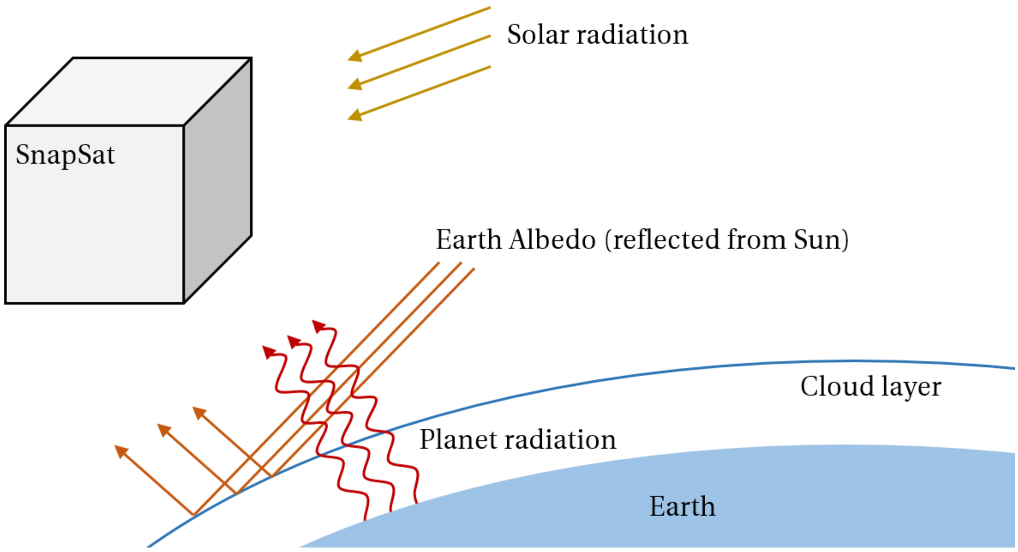

Figure 8.1: Incoming thermal radiation on the satellite

8.1 The Three Modes of Heat Transfer

The first law of thermodynamics states that the internal energy change on a system is equal to the amount of heat added subtracted by the amount of work done. The work done by the satellite on its environment is zero in out case, so the change in energy becomes

$$\frac{dU}{dt} = Q = A\rho c_p \frac{dT}{dt} dx$$

$$\begin{aligned} \text{Where}\quad Q &= \text{heat added (Watts)} \\ A &= \text{cross-sectional area (m}^2\text{)} \\ \rho &= \text{density of material (kg/m}^3\text{)} \\ c_p &= \text{specific heat capacity (J/kg K)} \\ T &= \text{temperature (K)} \\ dx &= \text{incremental length (m)} \end{aligned}$$

Is is dependent on the physical and geometric properties of the satellite and the change in temperature. The total heat balance for the satellite is then given by the heat flux entering the system minus the flux leaving the system. These are characterised by the modes of heat transfer below.

8.1.1 Convection

Convection is the heat transfer between a solid surface and flowing fluid. This is of importance during mission launch, however does not apply in a space environment. Convection considerations were ignored for this design.

8.1.2 Conduction

Thermal energy transfer within a material due to vibrating atoms - for example if the material is heated in one location, conduction is the method by which it spreads to the rest of the material. This is most important for on-board electronics, the rate of heat transfer is given by

$$Q_{conduction} = \frac{kA}{\Delta x}(T_1 - T_2)$$

which is the same as equation 8.1. The heat transfer depends on the area of the satellite normal to the direction of heat transfer A, the thermal conductivity k and the temperature differential T.

8.1.3 Radiation

Perhaps the most complex form of heat transfer is radiation, where all bodies above 0K emit and absorb electromagnetic energy. We consider each body as a perfect emitter (black body) and integrate the emitted energy across all wavelengths, this gives

$$E_{bb} = \epsilon\sigma T^4 \tag{8.3}$$

measured in Watts/m^2. This is the same as equation 8.2, where σ is the Stefan-Boltzmann constant. In this case, the emissivity ϵ has been added to account for the fact that the surfaces are not perfect black bodies.

8.2 Total Incoming Radiation

The total radiation incoming onto the satellite as it orbits is defined in figure 8.2 below. This assumes that the satellite is in full view of the sun 65% of the time in each orbit.

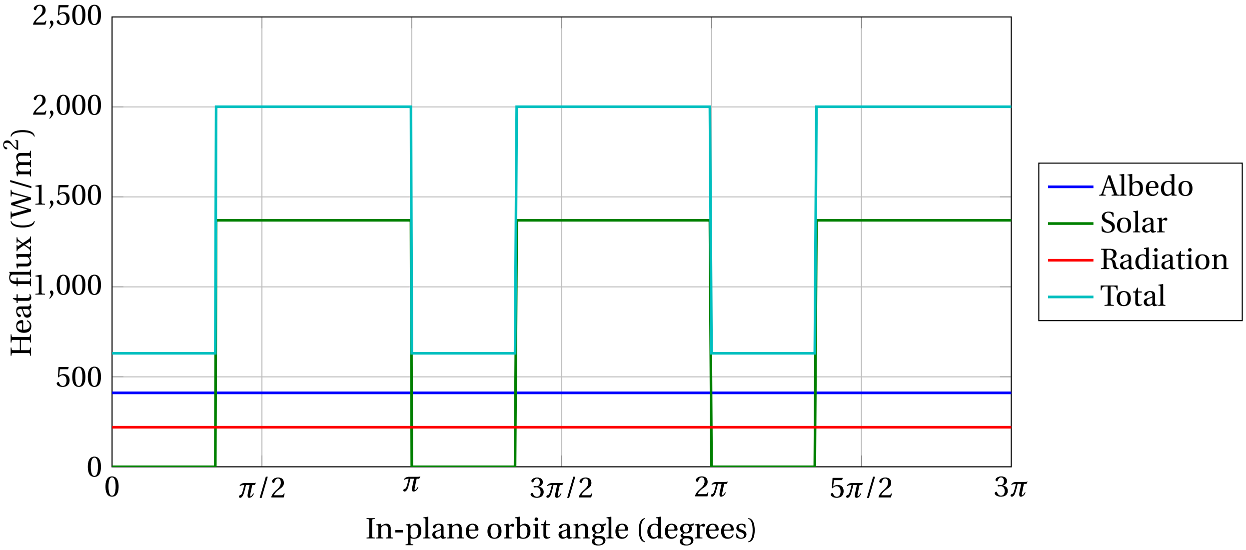

Figure 8.2: Radiation incoming onto the satellite as it orbits

Whilst this is the incoming radiation on the satellite as a whole, it is not indicative of the amount of radiation received by each side of the satellite. As the spacecraft is attitude controlled, the lower side will be facing the Earth always and only receive solar radiation for a short period of time. The amount of solar radiation (and even Earth IR radiation) received depends on the projected area that the radiation falls upon. Corrections are found using the view factor of each side of the satellite.

8.2.1 View Factors

The view factor of each side of the satellite allows for the calculation of the effect of the incoming radiation. The calculation takes into account the projected amount of heat flux on each side. The view factor is of importance when considering the radiation effect of Earth's infrared and albedo. The view factor indicates the area of the panel that radiation falls upon. Naturally, the view factor fo the panel facing the Earth is 1, whilst that of the panel facing away from the Earth is 0. The other panels lie between these values, they are listed below.

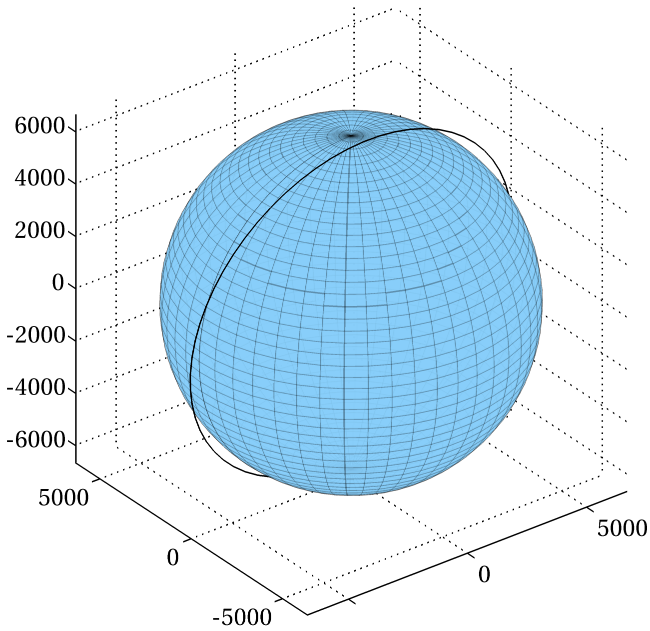

Figure 8.3: Representation of Satellite Orbit

8.3 Spacecraft Thermal Environment

As shown in figure 8.1, the spacecraft is subject to the following heating mediums: solar radiation, Earth infra-red and Earth albedo. The amount of radiation falling upon each panel is a function of the surface absorptivity and the view factor of the panel. The panel naming convention for this section is shown below.

8.3.1 Solar Radiation

The incoming solar radiation on the satellite is given by

$$Q_{solar} = Q_{sun}\,\alpha \cos\phi \tag{8.4}$$

Where Q_{sun} = solar heat flux (Watts)
α = panel surface absorptivity
ϕ = angle between the normal of the panel to the sun (rad)

For each of the panels, the solar radiation intensity is shown in the figure below. The skew in four of the panels is due to the 45°rotation of the orbit along the z Earth frame.

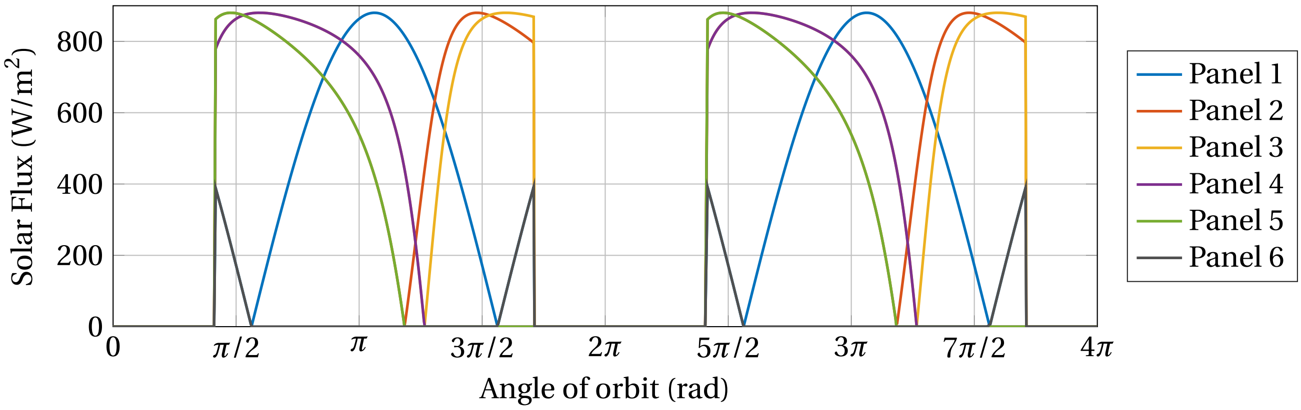

Figure 8.4: Solar radiation falling on each panel

8.3.2 Earth Infrared Radiation

The incoming radiation from the Earth is in the infrared band. This radiation is due to the effective temperature of the Earth and is a constant value for each panel. For this reason, the values will not be displayed on a graph. The incoming radiation varies from panel to panel depending only on the view factors as described in section 8.2.1. The value is given by

$$Q_{Earth-IR} = \sigma T^4_{Earth} \alpha VF \tag{8.5}$$

Where $\sigma = 1.381 \times 10^{-23}\ \mathrm{m^2\ kg\ s^{-2}\ K^{-1}}$ (Boltmann constant)

T = effective temperature of the Earth

α = panel surface absorptivity

VF = panel view factor

8.3.3 Earth Albedo

8.3.4 Total Incoming Radiation Per Panel

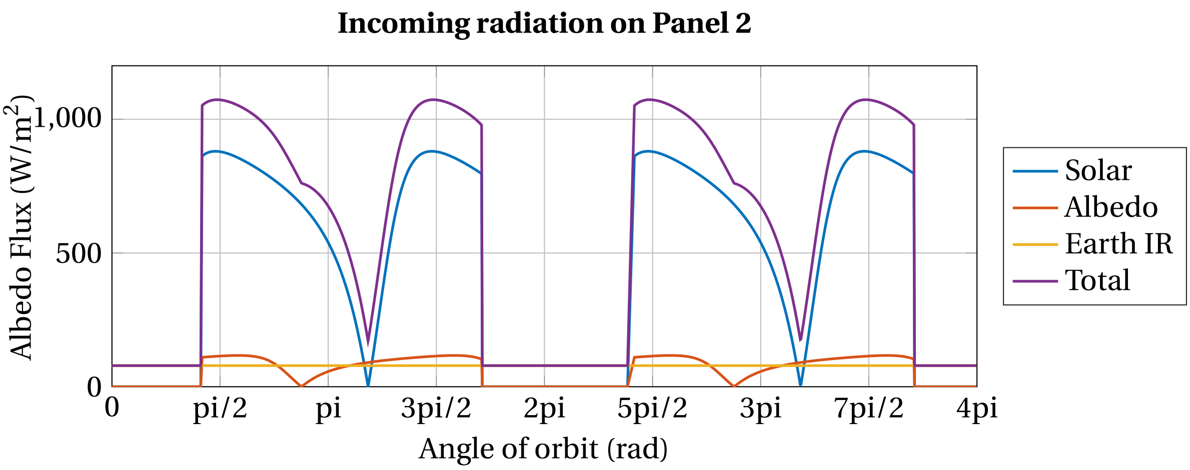

Figure 8.5: Total radiation falling upon panel 2