The Cubesat payload: A cameraunit.

Description: The purpose of this document is to describe the payload of the Cubesat. The payload has been chosen to be a cameraunit. The document will describe the purpose of the payload, the design of a suitable lens, the camera unit and the interfaces to it. It will also try to cover some of the considerations and suggestions that were conceived during the design of this unit.

Responsible group: OBC 732, **01gr732@control.auc.dk**
Subsystem: On Board Computer & Camera Unit.
Date: 12.11.01
Rev.: 1.0
File name: cameraunit−251001−rev1−0−pdf
Path: **ftp://??????.auc.dk/documentation**

Literature:
[1] Light Measurement Handbook, Alex Ryer, pdf−document from International Light.

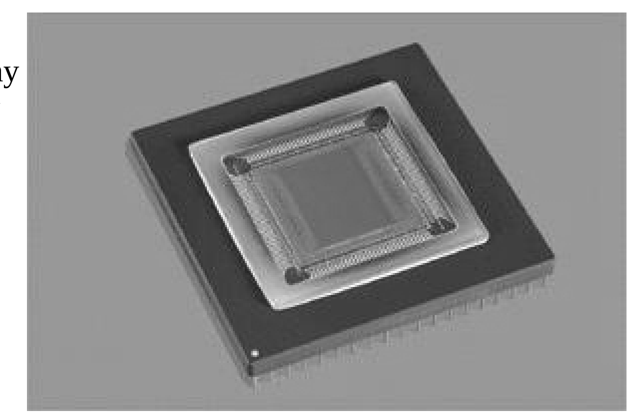
1.0 Introduction

During the preliminary Cubesat meetings in the summer of 2001 the mission of the satellite was discussed. Among the many mission objectives were e.g. the testing of components for space feasibility and the measurement of the space environment regarding radiation and temperature. The missions were though very limited since the necessary payload for the mission should be small in weight, measure and powerconsumption. Later on it was decided that a camera would be a realistic payload. The primary mission was decided as: Letting companies, research institutes and the general public take pictures of Denmark via the Internet. The purpose of this is to provide free scientific information and increasing the general interest for space technology and natural science altogether.
Later the CubeSat project was contacted by Århus University. They were interested in using the camera to measure star light intensity. It will not be needed to change the satellite or modify current designs to carry out this secondary mission.

2.0 The preliminary research

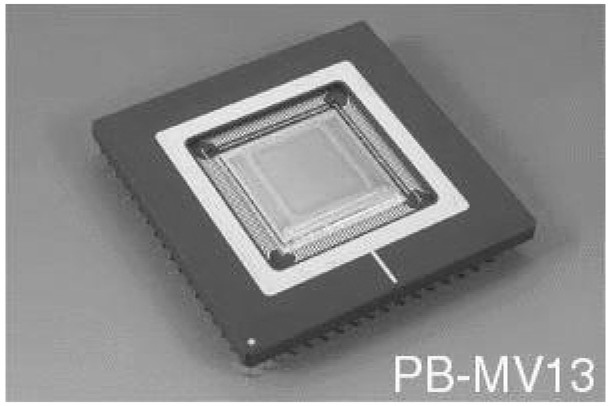
At one of the Cubesat meetings it was decided that we should make some preliminary research in what kind of camera would be realistic to implement into the satellite. Four different cameras were looked upon:

- The PC67XC/2. A complete CCD camera solution from the company supercircuits. The company advertises on their website that this camera has been used by NASA for a spaceflight. The resolution is 251.904pixel. If taking a 100km x 100km picture of earth the resolution would be 195m x 203m. The good thing about the camera is that it is a complete solution incl. a standard lens mount (C−mount). The solution is also fairly cheap and is available for 130$. On the other hand the camera comes with an analogue interface and has a 10 − 16V interface consuming 3 − 4.8W.



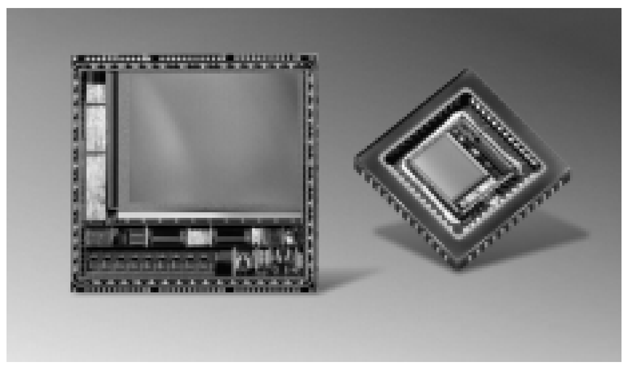
- PB−MV40. This is a HighSpeed CMOS photochip from the company photobit. This means that is simply the chip that converts optical light into a digital signal and places it onto its ports. The chip needs a structure to hold a lens and some interfacing before it can be implemented as a camera. The resolution of this camera is 4mill pixel. If again we were to take a picture of earth it would give a resolution of 50m x 50m. The good thing is that the chip has a very high resolution, a low powerconsumption (700mW @ 250 frames pr. second) and is fast. On the other hand one chip cost about 2000$ and need work before it can be implemented.

- PB−MV13. This HighSpeed CMOS photochip is also from photobit. This version has a 1.3mill. pixel resolution. This gives a resolution when taking a 100km x 100km picture of 78m x 98m. The chip also has a freeze−frame function, which means that it takes the picture in a single shot. Other camerachips read the value of each pixel one at the time. This camera reads all pixels at a time − making it extremely fast.

  The good thing is that it is fast and has a low powerconsumption (150mW @ 60 frames pr. second). On the other hand it costs about 1700$ and need work before it can be implemented.

- MCM20027. This chip is manufactured by the well−known firm Kodak. It has a resolution of 1.3mill pixel, which as above gives a resolution of 78m x 98m. It comes for about 22$ when buying 10.000 units. The price for one unit is not known but it is expected to be much cheaper than the Photobit chips above.

Pro and cons

Each camera has been rated regarding different criteria. The rating is from −−− as the worst rating to +++ as the best. The criterias have also been weighted after their importance to the project.

Camera	**Weight**	**PB−MV40**	**PB−MV13**	**MCM20027**	**PC67XC/2**
Power consumption	5	++	+++	++	−−−
Resolution	3	+++	+	+	−−
Price	1	−−	+	++	++
Interface	4	−	−	+	−−
Size	4	+	+	+	++
Weight	5	+	+	+	++
Type of shutter	2	++	+++	++	+
Temperaturerang e	5	++	++	+	0
Additional work before implementation	4	−−−	−−−	−−	−
Availability	2	+	+	+++	+
Voltagelevel	4	+++	+++	++	−−−
Result		**38**	**42**	**43**	**−13**

This means that the best choice of camera is a camera based on the MCM20027.

3.0 Construction of the camera

The camerachip will need some additional implementation before it can be used. Since we have no prior experience in this kind of technology and we are under a tight schedule to finish the on board computer the group decided that it could not spare the manpower to develop a cameraunit itself. Instead it contacted the Danish company Devitech currently resided in Nørresundby. Devitech is a company that produces dedicated camera solutions for specific assignments. After a short meeting with Niels Heeser Nielsen, the managing director and Peter Jüergensen project engineer it was decided to initiate collaboration in the making of a dedicated camera for the CubeSat. Devitech are currently working on a camera prototype based on the MCM20027 camera chip as described above. The prototype is scheduled to be finished 1. December. Devitech has decided to sponsor this prototype free of charge to the project. They have furthermore agreed to use both engineering manpower and money in making a specific version that will suit the project.

3.1 Interfacing the cameraunit.

The cameraunit will need some interfacing before we can use it on board the satellite.

3.1.1 I2C

First of all it will be needed to set up different registers in the camera such as gain and shutter mode. This initialization can be done via the I2C bus already decided to connect the different units in the satellite. The camera from Devitech is I2C programmable as standard.

3.1.2 The port configuration of the camera

When the camera is taking a picture it will lower the voltage on a dedicated TRIGGER−port on the unit. This will signal the OBC that there is picture data from the camera. The camera works by integrating the value of each pixel one by one. The 10−bit value will be read out on a 10−bit dataport. When data is ready on the dataport the HCLOCK−port will go low. The camera will be set to integrate the pixels in vertical lines. This is done to prevent data loss when switching between the different 256kbyte memory modules. When a line has been finished the cameraunit will raise the voltage on a VCLOCK−port for a short period to indicate that it is beginning on a new line. The exposure time (integration time) is controlled by a pixelclock supplied from external logic. The external logic / Camera−OBC interface is described the OBC designdocument.

3.1.3 power interface.

The camera is based on a 5V powerbus as supplied by the satellites powersupply. The camera consumes up to 400mW but only 300mW at 13.5Mhz which is a little above the frequency we are planning to use. The camera can go into a stand−by mode where it consumes 50mW.

3.2 Exposure

It is important to ensure that the camera will have the right exposure when taking the picture. The camera has two different programmable gain functions. This means that you can set a gain factor of the value of each pixel. The first gain function can set the gain between 0.483 and 7.488. The second function (raw gain mode) can set the gain between 0.0695 and 1.36925. If the gain is set above 1 the signal−to−noise ratio (SNR) will increase significantly hence making the picture quality decrease. It is therefore better to expose the camerachip too much instead of too little. To make sure that this is the case the following estimate of the light intensity from earth has been made:

Light reflected from earth (albedo): 30%
(Source)

Variation in reflection: Max 20%
(Source)

Light intensity from the sun outside the atmosphere: $1370 Wm^{-2}$
Light intensity from the sun at the surface of the earth: $1000 Wm^{-2}$ (clear day at noon, source)

Intensity loss in the atmosphere: $(1370 - 1000)/1370 =$ 27%
Light intensity seen from CubeSat: $(0.3 \cdot 1000 Wm^{-2}) \cdot (1-0.27) = 219\ Wm^{-2}$
$= 16425 lux$

Normal light intensity indoor: 200 - 500lux
(Source)

According to Devitech the cameras light sensitivity is good enough to take pictures indoor. The diameter of lens in front of the camera will affect the amount of light that will illuminate the camerachip. This will be described later in detail. It is though weighted that the illumination from earth is so strong that this factor will have a limited saying. Hence comparing the estimated amount of light with the normal indoor light intensity it is estimated that there will be enough light intensity to exposure the camerachip. The light intensity will be adjusted later by turning down the gain on the camera. This will be made by additional experiments on the cameraunit.

3.3 Robustness of camera.
The camera components have no protection against radiation. This means that the camera can be disturbed by radiation and the taking of the picture may be corrupted. Since the camera will only be active for a very short period of time it is weighted that rate of errors will be fairly small.
The temperature range of the camera is according to Devitech limited to the temperature range of the camerachip. According to the datasheet of the kac−1310 camera chip the operating temperature of the chip is $0^{o}C - 40^{o}C$. This means that either a passive or active thermal control of the camera is needed. A passive thermal control is recommended since the active control will require some sort of heating device, which will add to the list of hardware needed and the power consumption. The passive thermal control could be implemented by leaving the cameraunit in stand−by mode. The power consumed will then heat the camera. Also due to the needed length from lens to camera (46.5mm) the camera will be placed in the middle of the satellite. Here the temperature deviations aren't as big as in the regional areas. The camera unit will also be fitted with a temperature sensor so that we can monitor the camera and abort the taking of a picture if the temperature is to low.

4.0 Diagram of cameraunit.
This is the camera design as Devitech defines it.

5.0 Structure budget of camera.
The camera will be up to 50mm x 50mm. It will be a Printed Circuit Board (PCB) with components on both sides. On one side the camerachip will be placed. This chip is 5mm thick. The total depth of the unit will probably be about 15mm. The total weight of the cameraunit will be under 30g.

6.0 Lens
To comply with the specifications on taking a 100km x 100km picture of earth (footprint) we need a lens in front of the camerachip. The lens also has affect on the amount of light exposed on the camerachip. To design the lens the following calculations where needed.

6.1 Designing the lens
In this section the optical design is going to be analysed. At first it is important to know

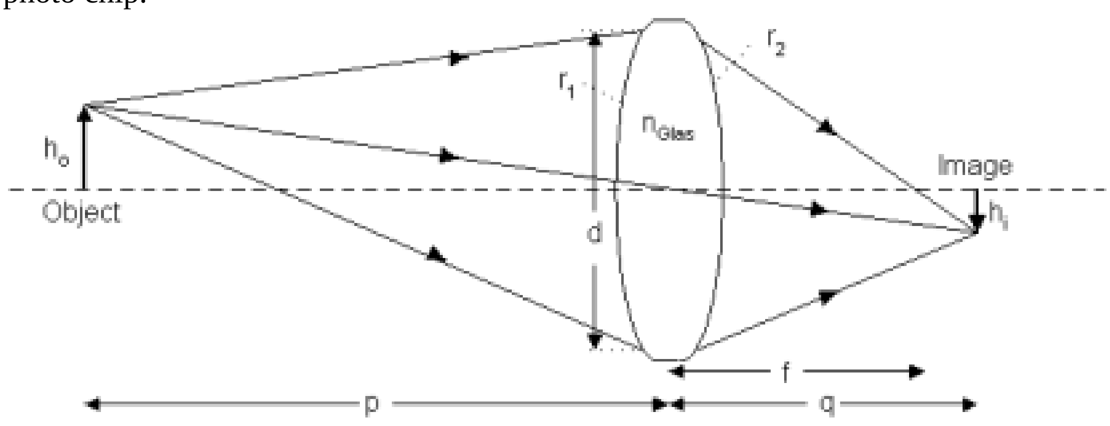
how far from the CMOS−chip the lens should be placed. If this distance is more than 100mm, which is the length of the CubeSat, then it is not possible to use only one lens. Second is to discuss what kind of lens is the optimal for this specific purpose. Maybe it is possible to use a low−price lens that has a certain amount of distortion which will not effect the quality of the picture because the resolution on the CMOS−chip is lower than the distortion of the lens. Another possible aspect is to get the lens which is optimal for the CubeSat and within a reasonable price limmit. In the end of this paper it will be discussed what should be the next step in order to get a lens which is suitable for he AAU CubeSat.

6.2 Placing the lens in focus

To get the best picture of Denmark it is important to place the lens in the right distance from the camera. This lens distance vary according to the distance to and the high of the object the camera is looking at. In the CubeSat's lifetime this lens distance will remain the same because the camera has the same object, the same orbit and approximately the same height. The change in the satellite altitude has all together no influence on the picture quality because it is very small in proportion to the distance from the earth to the CubeSat.

The area the camera is going to take the pictures of is decided to be about 100x100 km and the area on the camera chip where it is optical sensitive is 7.68x6.14mm. In order to get the best result the entire sensitive area of the chip ought to be used when taking the picture. The chip it rectangular and therefore the picture of earth will be so too.

The model below illustrates the travelling of light from the object through the lens to the photo chip.



Figur 1: Light from object to image.

h_o: Height of object.
h_i : Height of image.
p : Distance from object to lens.
q : Distance from lens to image.

In the CubeSat project the height of the object (h_o) is 100km and the distance (p) is 600km. To calculate the distance from the lens to the chip (q) the magnification equation is very useful:

$$m = \frac{h_i}{h_o} = -\frac{q}{p}$$

In order to get the entire chip to take the picture, the longest side of the chip is used to calculate the distance q:

$$q = -\frac{h_i}{h_o} p = -\frac{7{,}68mm}{100km} \cdot 600km = \underline{\underline{-4{,}608cm}}$$

The distance from the lens to the camera is −4,608cm[1] which means it is possible to use only one lens inside the CubeSat.

When looking for a lens it is important to know how long the focal length (f) is. The focal length can be calculated by means of the lens' equation :

Lens' equation : $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

$$f = \frac{p \cdot q}{p+q} = \frac{600km \cdot 46{,}08mm}{600km + 46{,}08mm} \approx \underline{\underline{4{,}608cm}}$$

In the CubeSat's case the focal length almost equals the distance q because the distance to the object is so large. The next step is to use the lens maker's equation and to find a lens which has the three parameters that approximately matches the focal length.

Lens Maker's equation : $\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$
n : Refraction index of the material.
r_1 : Outside radius of the lens.
r_2 : Inside radius of the lens.

In the following, different lenses will be taken into consideration and in the end one selected.

6.3 Different lenses

When deciding what kind of lens that should be use in the AAU CubeSat, the environment has to be taken into account. The lens is placed in a vacuum environment and the lens will be exposed to at lot of radiation. Therefore the following demands must be fulfiled :

- The lens may not have any closed airspaces which can erupt in vacuum.
- The lens glass may not deteriorate during the first year in space (radiation).
- If more than one lens is cemented together, the binding material may not deteriorate during the first year in space (radiation).
- Rapid changes in the temperatur may not damage the lens glass.

[1] The negative sign means that the light travels through the lens to the object on the other side.

There are several kinds of lens types, but the best to use when looking at an object at an infinite distance, is an Acromat−lens or a Triplet−lens. The Acromat is cheaper and lighter than the triplet because the Acromat is a composite of only to lenses where the triplet is a composite of three lenses. The triplet on the other hand has in most cases the advantage of less optical distortion (a less blurred image).
The crucial part is to get the optical distortion smaller than then the size of one pixel on the CMOS−chip in our case the pixel is 6x6μm.

With the help of Carl−Erik Sølberg[2], the two lenses have been simulated in order to find out how big the distortion would be for each lens type. The problem is that not even the best lens would be able to focus all colours from on specific point in the object to the same specific point in the image. The problem is negligible if the lens would be able to focus all colours within on pixel and that is why we are able to judge whether to use an Acromat or a Triplet lens on the AAU−Cubesat.

The simulation results were :

	In the middle of the image	**In the corner of the image**
Acromat−lens	A spot of 5x5μm	An elliptical spot of 100x50μm
Triplet−lens	A spot of 7x7μm	An elliptical spot of 15x8μm

The simulation reveals that it is impossible to avoid blur when using the two lenses with a pixel size of 6x6μm. Therefore to get best possible picture with minimum blur in the corner, it is advisable to use a Triplet−lens.

Another calculation Carl−Erik Sølberg made, is how large the diameter of the diaphragm should be. Without lens−error the diffraction of the light makes a spot on 10μm with a diaphragm of 6mm. Because of that the diaphragm in the CubeSat has to be at least 12mm to keep the spots smaller than the pixel size.

6.4 Structure budget of lens
The physical dimensions of the lens is as given above. The total mass of the lens is approximately 20g.

6.5 Lens suggestion
In the search for a lens the requirements listed above will be taken into consituration.
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We are at the moment working with several different lenses and wil suggest one as sone as possible.

The lens specifikations !!!

[2] Engineer lic.techn. institute 13 at Aalborg University.

When we have a lens suggestion we are gowing to present it to Carl−Erik Sølberg. If he do not see any trouble in using this lens, it will then be presented to %%ham fra Århus%% which is working on the Rømer satellite telescope. Further more it will be declared on an optic newsgroup where it is possible for any one to comment our choice.

7.0 Structure between camera and lens.

The cameraunit needs to be mounted very precise in front of the lens. This is to ensure that the light hits the camera chip in the precise distance of the lens. Otherwise we can risk that the picture will be blurred. To ensure this there should be mounted some sort of structure between the lens and camera PCB. The diameter of the structure should equal the diameter of the lens and the length should equal the focal length calculated above. The structure is defined by the structuregroup.