PROPOSAL FOR A NEW HYPER SPECTRAL IMAGING MICRO SATELLITE: SVALBIRD

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Abstract. This document describes a proposal to construct and launch a new generation of polar orbiting microsatellites for Earth observation. The project is a joint venture with the Technical University of Berlin (TUB), University Centre on Svalbard (UNIS) and SVALSAT. The proposed microsatellite is designed for interactive Earth observation using a hyper spectral imager. The mission objective, the final configuration of the satellite, the ground segment, the operation, and the total cost of the project is presented.

1. INTRODUCTION

The development of microsatellites has during the last decades evolved to be a cost efficient alternative in remote sensing. Due to the advances in the fields of electronics and optics they can in many cases replace the large, heavy, and expensive commercial satellites. Microsatellites provide platforms that can be configured and launched for a very specific mission within a short time frame. The most advanced microsatellites are also attitude controlled. This enables the ground user to stabilize and point the satellite in any direction during flight. As a consequence, not only simple telecommunication devices, but more advanced payloads involving optical instruments have been installed onboard these satellites. The user interactive concept of the microsatellites are used to monitor processes which change fast (within one day), for search actions or to track any target at ground level. The microsatellites have become true platforms for remote Earth observation.

The Technical University of Berlin (TUB) has developed expertise in construction and launch of 6 microsatellites in polar orbit with special emphasise on attitude control and environmental / house keeping aspects (The TUBSAT series). TUB is currently working on the 7'th satellite called LAPAN-TUBSAT with the Indonesian National Institute for Aeronautics and Space (LAPAN). The attitude is controlled by using fibre optical gyros, re-action wheels, magnetic torque coils and a star sensor. Their most advanced satellite is capable of tracking a ground based object in real time at a resolution of 6 m at ground level for approximately 5 minutes (max.10 min). The payloads have so far been monochrome video cameras with rather limited use when it comes to number of possible applications.

The TUBSAT's ability to lock on a ground target and sweep slowly over the terrain, makes it ideal for a line scanning instrument such as a hyper spectral imager. The University Centre on Svalbard (UNIS) has developed small airborne hyper spectral imagers that image objects with both high spatial and spectral resolution. These instruments have proven to be a successful tool on a large number of applications in remote sensing. We therefore propose to go one step further by adding a spectral imager to the proposed satellite.

The partners of this proposal have already finished the ground segment including an installed and operative command station at the roof of UNIS and a data downlink from SVALSAT. In addition, the fibre cable to Norway has also proven to be useful for real-time acquisition of the TUBSAT satellites presently in orbit. It is therefore natural for us to continue the co-operation and progress by constructing a new satellite.

Norway has no research satellites in orbit as of today, and the present proposal shows a cost efficient way of designing and constructing a satellite platform and payload to our own specifications. The proposal includes everything needed to get the satellite into in-orbit operation. Despite the high technical level of expertise in space physics in Norway, no research group has so far been able to agree or to construct a remote-sensing research satellite. This proposal is therefore important in order to achieve goals that Norway should have been able to reach a long time ago.

2. THE GROUND SEGMENT

TUB, UNIS and SVALSAT started a joint project in 2002 called the "THE DLR-TUBSAT-SVALSAT-UNIS EXPERIMENT". The purpose of this project was to establish a control station and use SVALSAT to download data of high quality from the DLR-TUBSAT satellite. Fig. 1 shows an image gallery of the key elements of the ground segment.

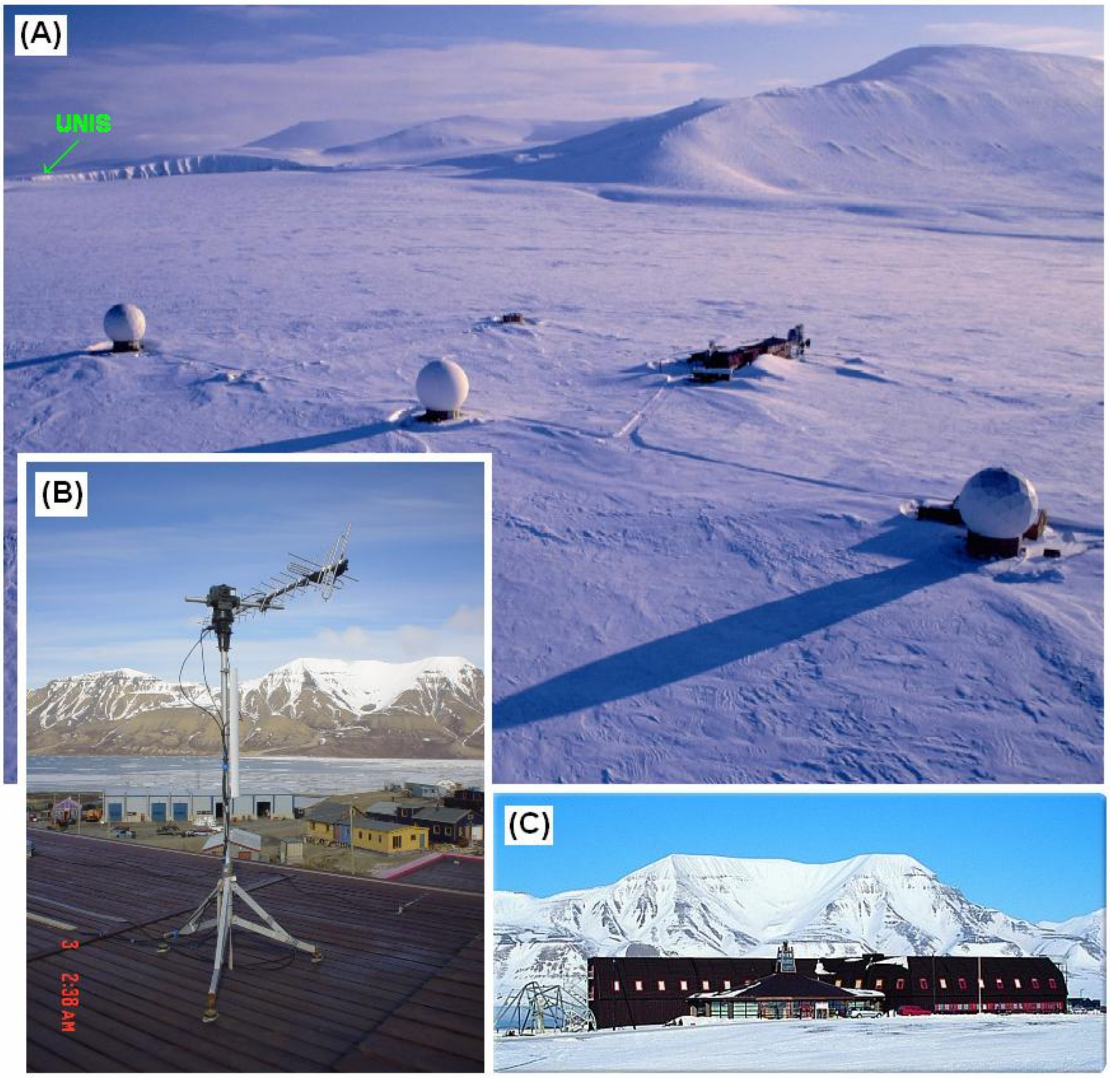


Figure 1. The Ground Segment. Panel (A): The SVALSAT ground station close to Longyearbyen, Svalbard (78N, 15 E). Panel (B): The tracking Yagi-antenna mounted at the roof of UNIS. Panel (C): The University Centre on Svalbard (UNIS).

DLR-TUBSAT is a co-operation with the Technical University in Berlin (TUB) and the German Aerospace Center (DLR). The satellite has successfully operated since it was launched as a piggy-back on 26 May 1999 from Shiharikota with the Indian Polar Spacecraft Launch Vehicle (PSLV).

Furthermore, one more satellite MAROC-TUBSAT have been launched in December 2001, a co-operation between TUB and the Royal Center for Remote Sensing in Morocco. The ground segment, command station at UNIS and the SVALSAT downlink, can also be used for this satellite. We plan to use the same ground segment for the new satellite described herein.

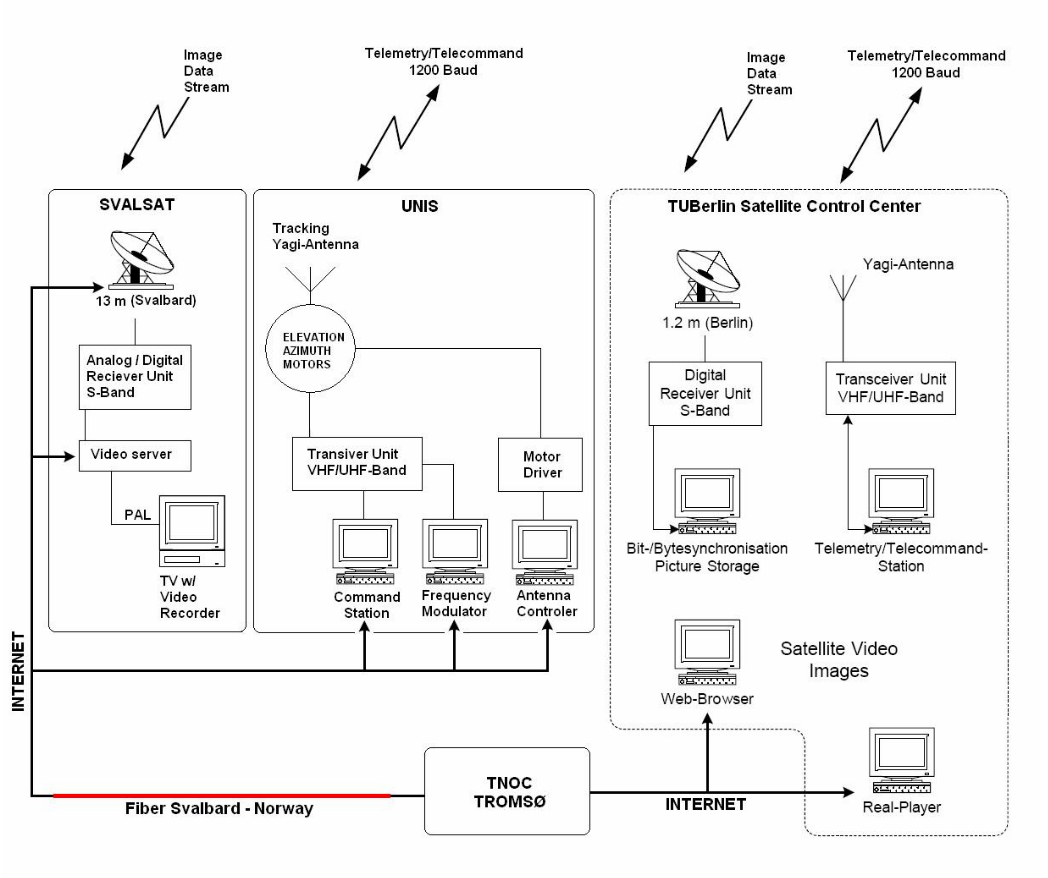


Figure 2. Ground station architecture

The ground segment consists of three parts and is shown in Fig.2 Two satellite control centres at UNIS and TUB are the main ground stations which are responsible for mission control and health monitoring of satellite. This is done by the transceiver units in the VHF/UHF-band and the Yagi-antennas. The tracking antenna at UNIS is also equipped with a frequency modulator in order to keep track of any Doppler shifts of the transmitted signals from the satellite.

The video stream or digital pictures of the payload are received via S-Band with the 13 m-antenna at SVALSAT. The data is then either grabbed by a video server and stored on video tapes, or send by FTP directly down to UNIS. All units at UNIS are controlled via INTERNET in real time from Berlin. The images can also be downloaded by a 3 m S-band antenna in Berlin.

In general, a request from UNIS and TUB is send by e-mail to the Tromsø Network Operations Centre (TNOC) to find out if the 13m antenna is available (free) to track a selected pass. The TNOC operator then programs the S-band antenna to track the satellite. TUB or UNIS can then prepare the satellite for its mission by sending commands in advance or in real time to the satellite. The high speed of the internet through the fibre optical connection between Svalbard and Norway makes these operations possible. The ground segment has been operating successfully since May 2003.

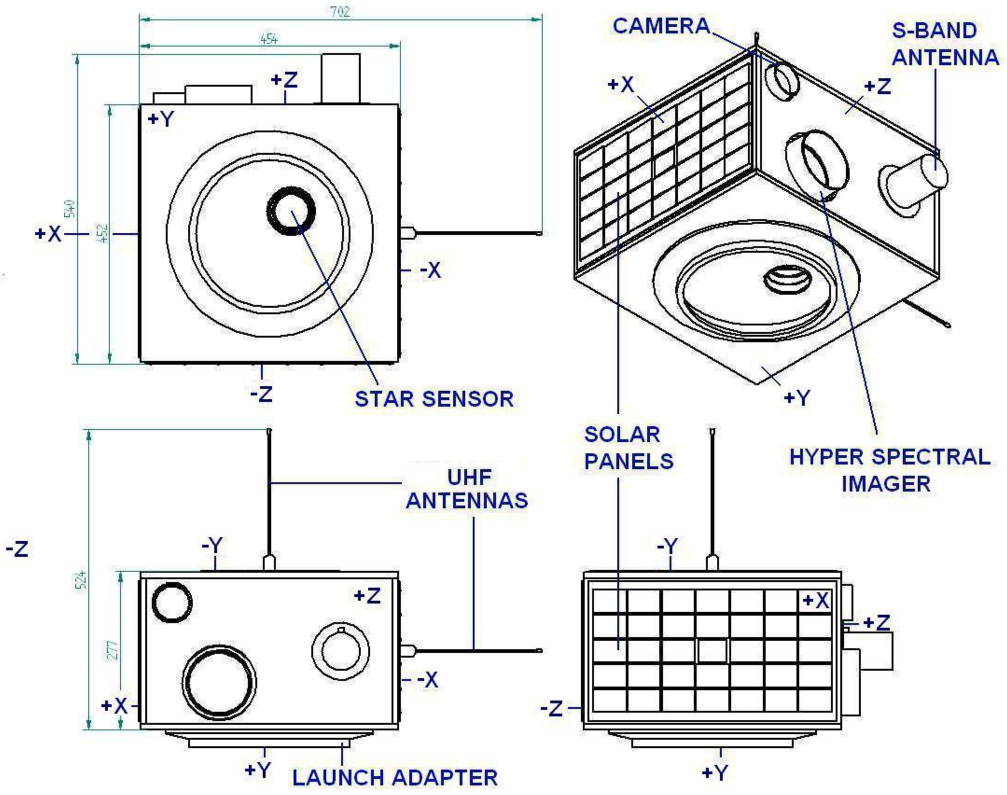


Figure 3. Overview of the new hyper spectral microsatellite (SVALBIRD). Each side is labelled according to axis configuration: z - yaw axis, x - flight direction (roll), and y - pitch axis, respectively.

3. THE SATELLITE BUS

This section consist of a system description of the satellite bus - the Housekeeping and the Attitude Control. The payload will be described in section 4. The system is based on the LAPAN-TUBSAT architecture.

3.1 - Housekeeping

The configuration of the space segment is shown in Fig. 3 and 4. The cube shaped satellite measures 45 x 45 x 28 cm^3 and weighs 50 kg. The cube is made out of 5 mm aluminium plates. This rather heavy solution is chosen to keep the inside temperature variations as small as possible and to protect the instruments from radiation. The S-band antenna is physically located on the same side as the front optics of the payload. It does not obstruct the field of view of the payload sensors. The S-band transmitter is located close to the antenna. Analog video transmission is performed within a bandwidth of 8 MHz, the transmission of single pictures occurs at 125 kbaud. The beam width of the antenna is 70 degree.

The house keeping system contains the batteries, the Power Control Data Handling unit (PCDH), the air coil and the two Telemetry Telecommand units (TTC's) in the UHF band, as well as the two antennae. Five duplex NiH_2 battery cells from Eagle-Picher each with a capacity of 12 Ah support an unregulated 10 V bus which is charged by four identical solar panels, each containing a single string of 34 silicon cells. The short circuit current of each panel is 980 mA. The PCDH contains the DC/DC-converter and the power distribution device. It is capable of switching different loads simultaneously, while constantly monitoring current levels and providing protection against short circuit. The UHF-TTC receives and transmits data via FFSK modulation at a rate of 1200 baud. Both transceivers nominally operate parallel in a listening mode. As long as no telecommand is received from the ground, the satellite is silent.

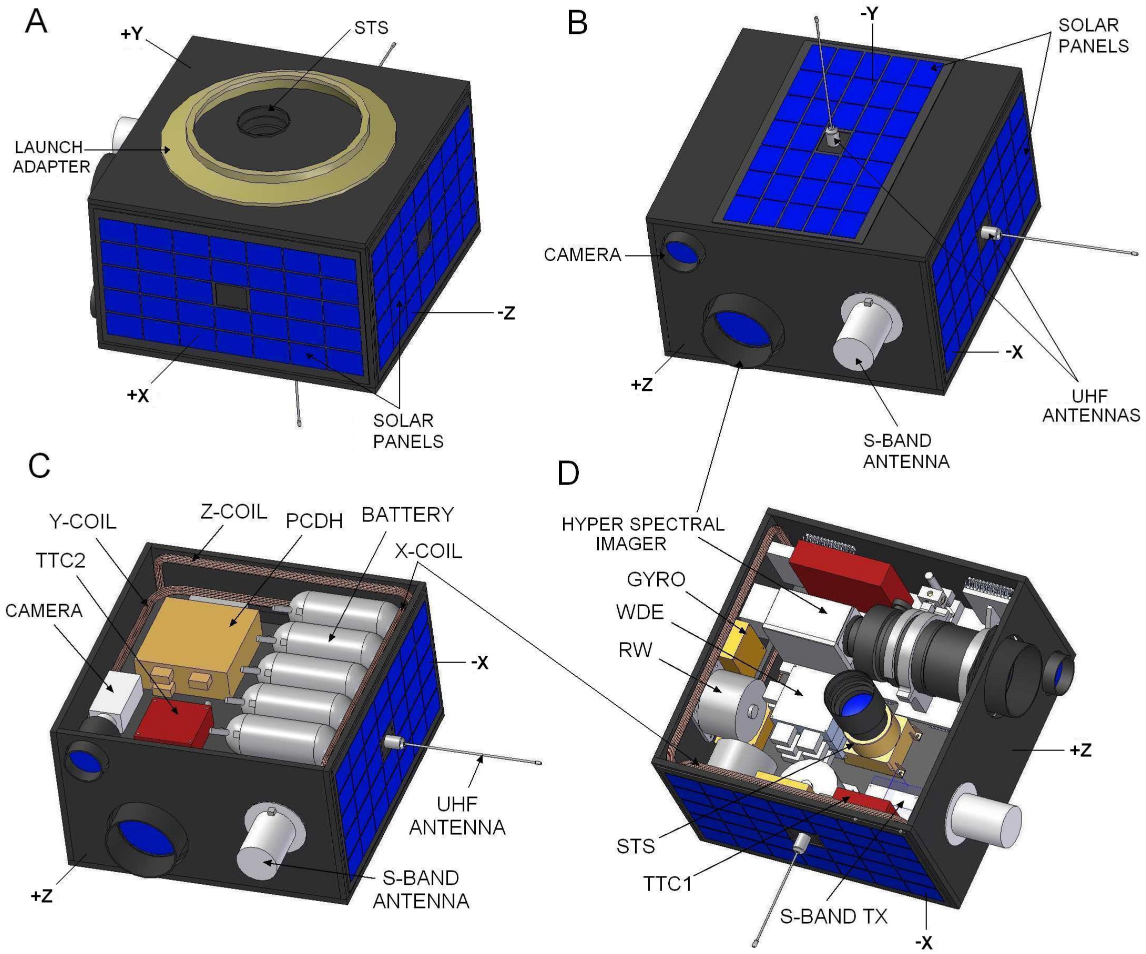
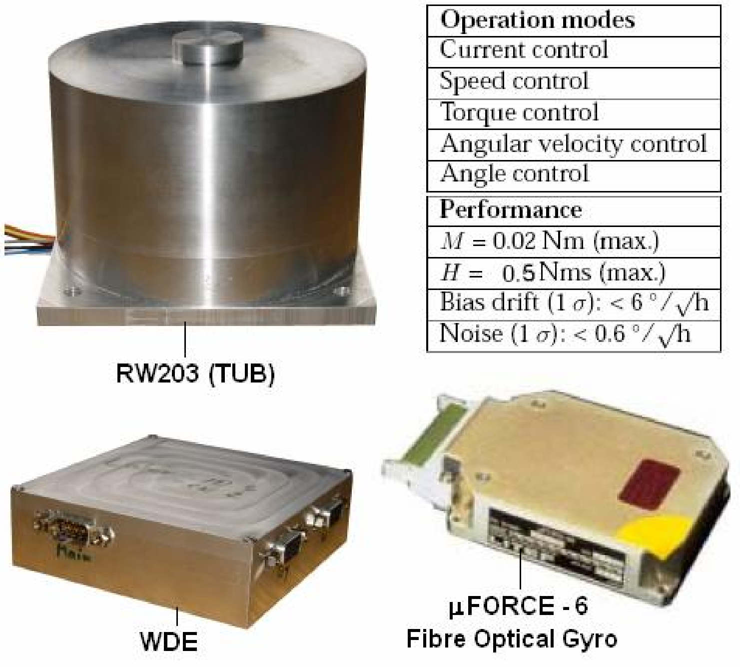


Figure 4. A 3D colour view of the satellite (SVALBIRD). Each side is labelled by numbers. STS is Star Tracker Sensor. XYZ-coils are the magnetic torque coils, RW - Reaction Wheels, TX - Transmitter (S-Band), TTC - Telemetry Telecommand Control units, PCDH - Power Control Data Handling, and WDE - Wheel Drive Electronics. Axis configuration: z - yaw axis, x - flight direction (roll), and y - pitch axis of satellite.

3.2 Attitude Control

Three Reaction Wheels (RW) are mounted orthogonal to each other on the inside walls of the satellite. They are in-turn controlled by three fibre optical gyros. The magnet torques are used for the reduction of the angular momentum of the satellite. The reaction wheels RW203, developed by TUB, have an external wheel drive electronic (WDE) with a micro controller to provide operation modes such as current control, wheel speed control and torque control. Furthermore, one fibre optic gyro µFORS – 6u, built by Litef, is connected to the WDE of one reaction wheel via serial communication interface and both are mounted in one body axis of the satellite. The micro controller of the WDE receives an angular increment from the gyro and calculates with this data an accumulated angle and an angular velocity. Each of the three wheel/gyro-unit ACS203 (see Fig. 5) provides operation modes which control the angular velocity or the angle in one axis of the satellite. With three of them in each body axis of the satellite the spacecraft is three axis stabilized. The highly integrated wheel/gyro-unit was designed especially for microsatellites with requirements in the field of low power consumption (wheel: 1 W steady state, gyro: 2 W), low mass (wheel: 1,2 kg, gyro: 0.15 kg), small volume (wheel: 808070 mm^3, gyro: 1006520 mm^3) and simple interfaces (electrical: 5 V & 12/15 V, data: 8 N 1). The operation modes and the main data of the performance are also shown in Fig. 5.



Operation modes
Current control
Speed control
Torque control
Angular velocity control
Angle control

Performance
M = 0.02 Nm (max.)
H = 0.5 Nms (max.)
Bias drift (1 σ): $< 6\,°/\sqrt{h}$
Noise (1 σ): $< 0.6\,°/\sqrt{h}$

Figure 5. SVALBIRD Wheel/WDE/Gyro-Unit ACS203.

The satellite is equipped with a CMOS star sensor STT03, as a inertial sensor. This sensor, the signals from the solar panels and the three ACS203 allows a high accurate attitude acquisition before the visible satellite pass starts. That means that nearly the complete visible time of the satellite (typically 12 to 15 min) is free for earth observation operations.

There are two different operation modes for earth observation. First is a complete automatic mode, without any interference from ground, second is interactive control from the ground (see section 4). In both cases the attitude acquisition is pre-programmed some hours before and done automatically before the pass begins. After that a known target can be observed automatically, by using a rotation profile around one or two axes that is pre-programmed, or by an interactive control from a ground based operator.

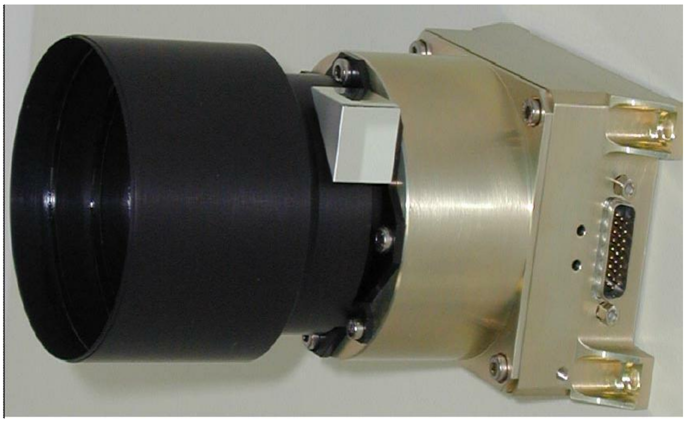


Figure 6. SVALBIRD CMOS Star Sensor STT03

A more detailed description of the data flow and the electrical system is found in the appendix. The above description [cf. Schulz/Roemer and Renner] is based on components that are well tested on the TUBSAT series.

4. INTERACTIVE EARTH OBSERVATION

Interactive earth observation means that an operator located at one of the control stations (UNIS or TUB) receives real-time video images from SVALSAT. The video server at SVALSAT and the optical fibre between Svalbard and Norway provides high speed data transmission through the internet. The operator is then able send commands to the satellite. He / She can steer the pointing direction of the camera platform, interactively via the command stations keyboard, to any interesting event on the ground. (see Fig. 7).

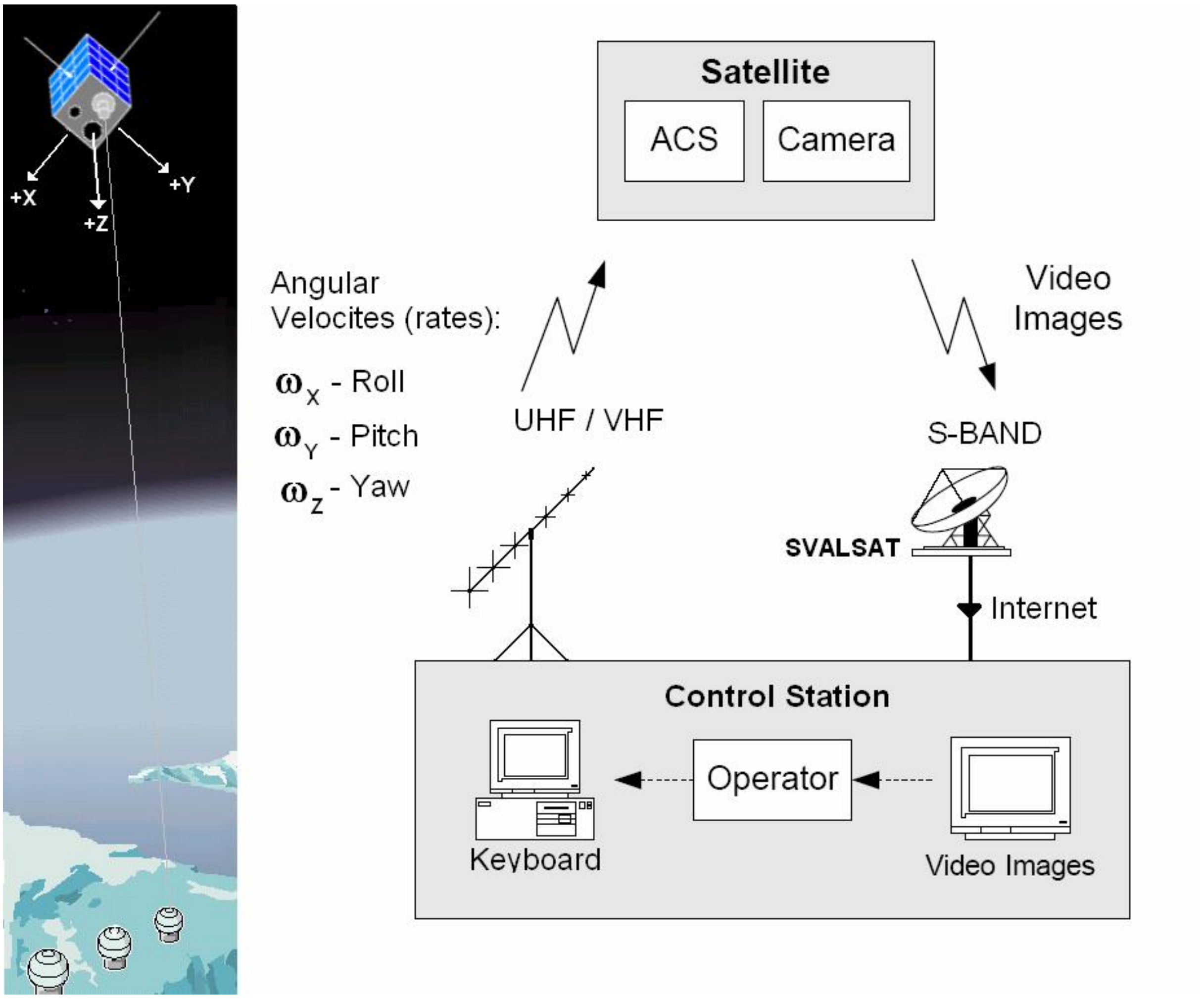


Figure 7. Interactive Earth observation configuration. ACS is the Attitude Control System. It response to the angular velocities issued by the operator at the control station. Rotations in the counter clockwise direction around the x-axis is roll. Correspondingly, around the y- and z-axis are pitch and yaw, respectively.

This is appreciated in applications where e.g. the target has not been identified clearly in advance, a search action is involved or a target has to be visually followed for a while.

The above principle is tested successfully. Fig. 8 shows how the DLR-TUBSAT can be used. A video camera with a 50 mm objective is first used to get an overview of the ground. The island Corsica is identified. Next a camera with a telescope lens is used to zoom in, and a more detailed scene can be studied. Note that the images in Fig. 8 are taken over a period of 1 second. They clearly demonstrates the high precision and speed of the Attitude Control System (ACS) on board the satellite. This type of interactive use is ideal for push broom hyper spectral imagers (see payload section below).

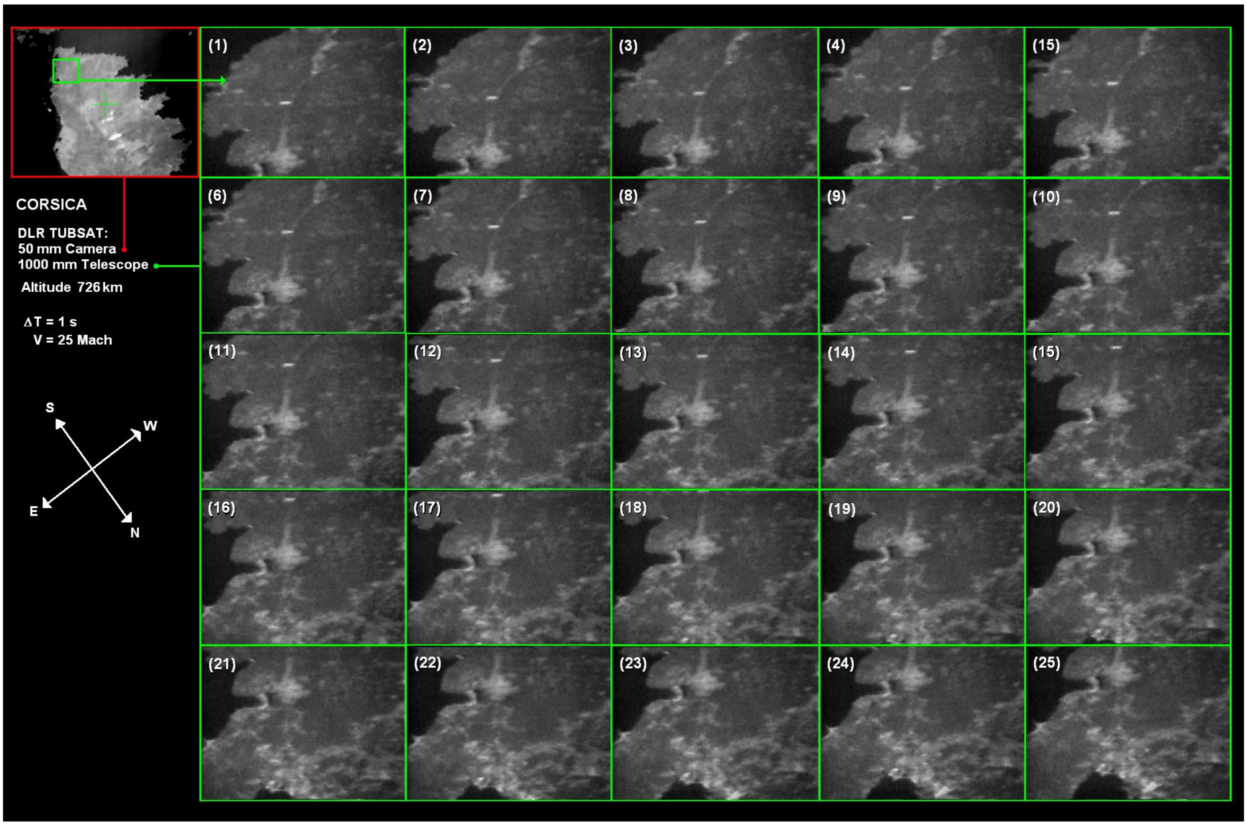


Figure 8. Image gallery from DLR-TUBSAT over Corsica. The red frame is taken with the camera using a 50 mm lens (120 m resolution). The green frames (1 - 25) are over a period of 1 second using the telescope lens (focal length 1000 mm; 6 m resolution).

The orbits of the TUBSAT family are typical sun synchronous with inclinations close to 90 degree (polar orbit), altitudes of approximately 700 km, and speeds up to 25 Mach (~100 minutes period of revolution around the Earth).

Another example of interactive use is shown in Fig. 9. The MAROC-TUBSAT satellite was in this case pre-programmed to take digital pictures. The satellite was configured and setup in advance by the control station in Berlin and at UNIS. During the next orbit SVALSAT recorded the data. The image sequence shows North-West of Svalbard, Norway. The images have a spatial resolution of approximately 250 m.

Our satellite will be programmed in a similar manner. First the target area will be selected with a request to TNOC about SVALSAT availability / down-link support. Secondly, the pre-programming of the satellite is performed making it ready for the selected orbit. During the pass, SVALSAT records the real time image sequence. If the hyper spectral imager is used, then the image sequence consists of spectrograms. Finally, post-processing of the spectrograms result in multi wavelength band images of the target.

5. THE PAYLOAD

The payload contains one fore field camera (50 mm focal length objective) with medium resolution (120 m resolution at ground level) and a high resolution telescope (6 m resolution) with a focal length of 1 m as front optics to the spectral imager. The detectors used on both instruments are Charge Couple Devices (CCD's). Each CCD-chip will be able to transmit video images in the CCIR-standard or digital pictures.

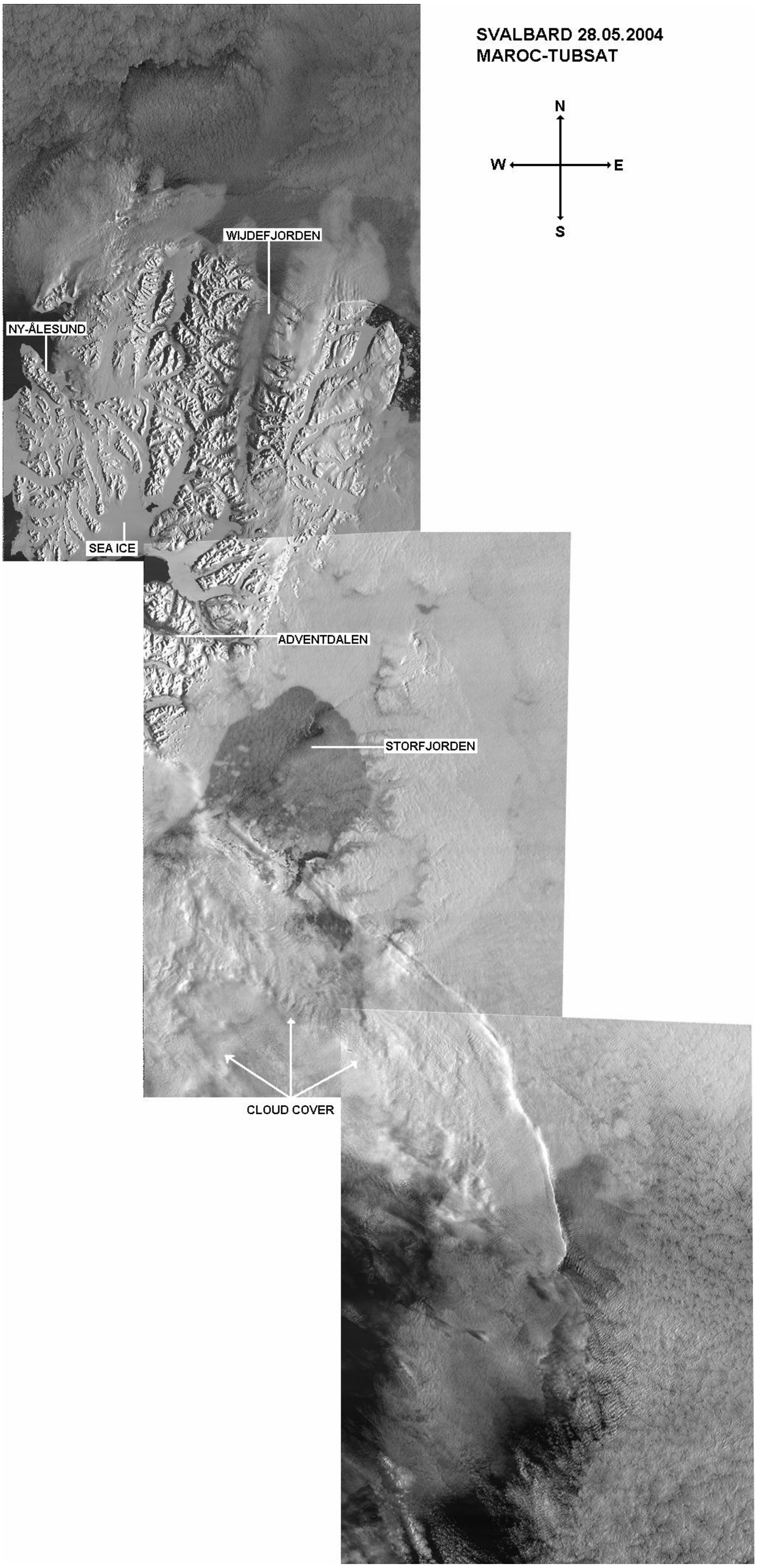


Figure 9. MAROC-TUBSAT image sequence of Svalbard, Norway, 28.05.2004.

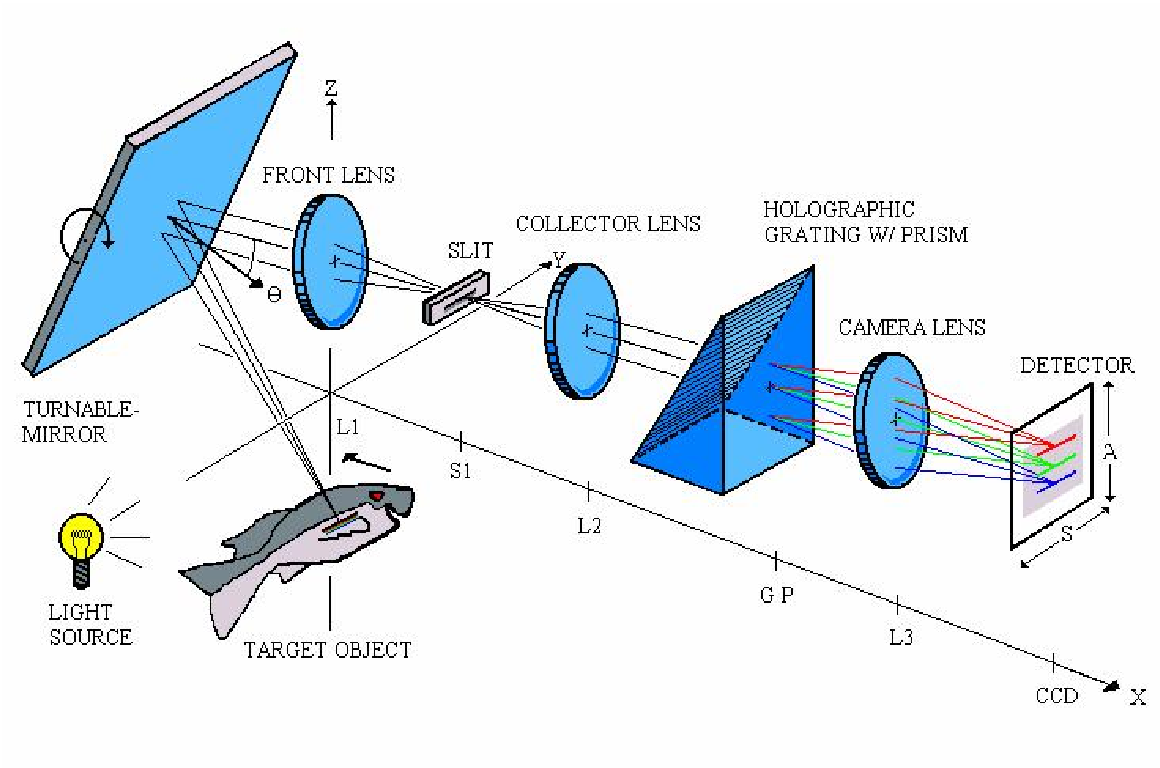


Figure 10. A 3 dimensional optical diagram illustrating the main principle of hyper spectral imaging. L1 is front lens, S1 entrance slit, L2 collector lens, G grating, P prism, L3 camera lens and CCD imaging detector. The optical axis is parallel with the X-axis of the XYZ-coordinate system. The slit is located parallel to the Y-axis. θ is the angle between the mirror's normal and the optical axis. The detector is located in the λS - plane which is parallel to the ZY- plane (Note: static object setup).

We aim to use a colour CCD on the 50 mm camera. As seen above, the use of monochrome (black and white) CCD detectors have been operating well on both DLR- and MAROC-TUBSAT. In order to be safe, we could use the same detectors (SONY 1/2" CCD with liquid capacitors replaced with solid ones). However, we will first see how the new 3-chip colour CCD performs on the LAPAN-TUBSAT before a final decision is made. The LAPAN-TUBSAT will be launched next year. Nevertheless, the technology and the know-how of the fore field camera is well established.

The challenge will be the spectral imager. Below is a description of the principle behind spectral imaging, the design of the proto-type instrument and samples from airborne campaigns conducted by the Geophysical department at UNIS.

5.1 Main principle of spectral imaging

The main idea behind spectral imaging of objects may be described as follows: Firstly, light from the object must be focused by a lens or mirror to form an image at the spectrographs entrance slit plane. The resulting spectrogram is the intensity distribution as a function of wavelength and position along the slit. The diffracted slit image contains both spectral and spatial information along a thin track of the object (See Fig. 10).

Secondly, in order to obtain the object's full spatial extent, it is necessary to sample the whole object. This requires the use of a high resolution rotary element. The whole idea is to record spectrograms for each track of the object as the image at the entrance plane is moved across the slit. A front surface mirror in front of the focusing element may be used in connection to a high resolution stepper motor.

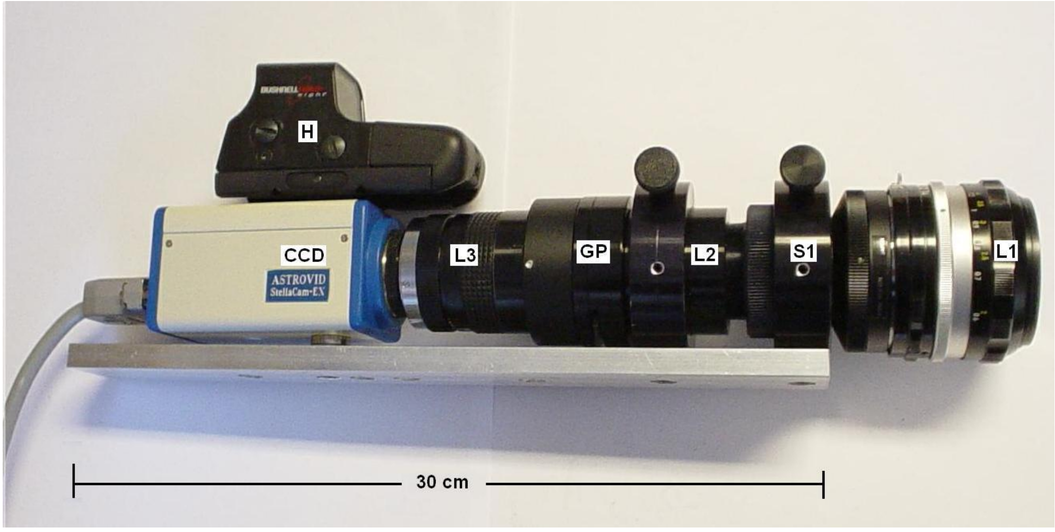


Figure 11. Airborne spectral imager generation VI (Airspex VI). H is a Holographic aim point. L1 is front lens, S1 entrance slit house, L2 collector lens, GP Grating/Prism holder, L3 camera lens and CCD imaging detector (video). The labels are according to Fig. 10. The spectral range for this instrument is 450 - 830 nm and the bandpass is 5 nm.

Another approach would simply be to rotate/move the whole instrument itself or the object on a conveyor belt etc. In fact, the use of a mirror enables us to sample target objects that are static or moving relatively to the instrument by rotating or keeping the mirror fixed, respectively. In our case the scanning mirror will be removed since the satellite is able to scan in any desired pointing direction due to its high precision attitude control system.

Fig. 10 shows a typical choice of experimental design. Please note that the use of lenses instead of mirrors is no limitation in implementation of the above principle. The use of a transmitting grating combined with a prism increases the resolution especially in the blue part of the spectrum. In addition, each optical element is aligned along the optical axis. Consequently, the imager is easy to assemble.

The intensity at each pixel of the spectrogram, the output image of the CCD, can be defined as

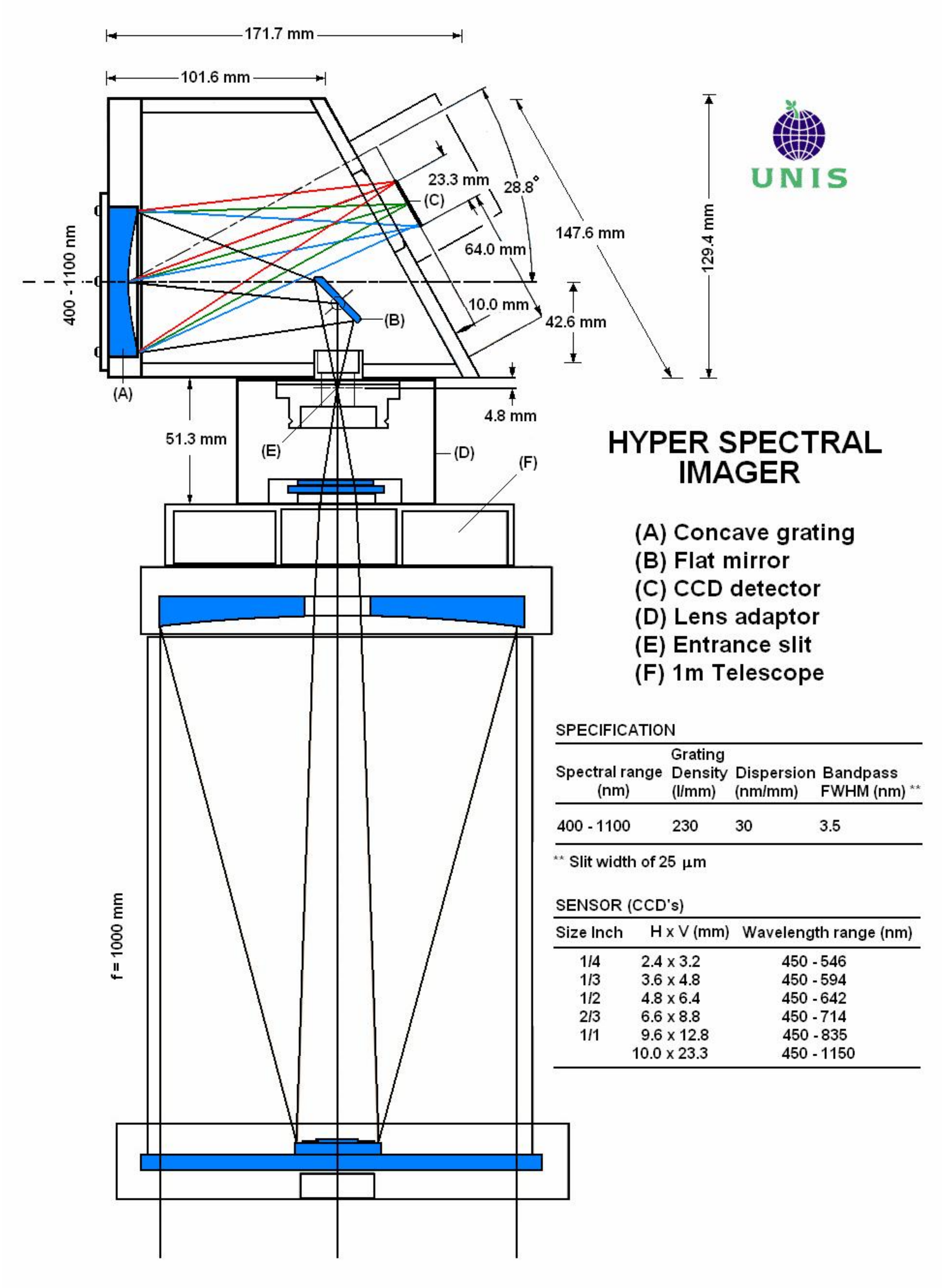
$$J_\theta = J_\theta(\lambda, h), \quad [\mathrm{mW/m^2Å}] \quad (1)$$

where λ is the wavelength and h represents the slit height at the detector surface. Both slit S1 and the CCD detector are positioned parallel to the YZ plane with surface normal along the X-axis, Subscript θ denotes the angle between the mirror normal and the optical axis, which is parallel to the X-axis of Fig. 10. On the satellite, θ is the angle that the satellite rotate by to lock on a target on the surface of the Earth (interactive process to reduce the relative speed between the sensors and the ground level as it moves over the target).

The object or target image (one row of the image matrix) is constructed by integrating over the desired wavelength region:

$$I_{\lambda c}(\theta, h) = \Sigma\ J_\theta(\lambda, h)\,\Delta\lambda, \quad [\mathrm{mW/m^2}] \ (2)$$

where the integration occurs in the wavelength interval $\Delta\lambda = \lambda_1 - \lambda_2$. λ_c is then defined as the centre of the wavelength region from λ_1 to λ_2.



SPECIFICATION

Spectral range (nm)	Grating Density (l/mm)	Dispersion (nm/mm)	Bandpass FWHM (nm) **
400 - 1100	230	30	3.5

** Slit width of 25 µm

SENSOR (CCD's)

Size Inch	H x V (mm)	Wavelength range (nm)
1/4	2.4 x 3.2	450 - 546
1/3	3.6 x 4.8	450 - 594
1/2	4.8 x 6.4	450 - 642
2/3	6.6 x 8.8	450 - 714
1/1	9.6 x 12.8	450 - 835
	10.0 x 23.3	450 - 1150

Figure 12. Payload: Optical diagram for the proposed hyper spectral imager on board SVALBIRD.

The next step is to obtain the spatial resolution as the satellite rotates. Frozen in time, the field of view of the imager across the slit width, w, is given by

$$\Delta\theta = 2 \tan^{-1} [\, 0.5\, w\, (f^{-1} - p^{-1}) \,] . \quad \text{[deg]} \quad (3)$$

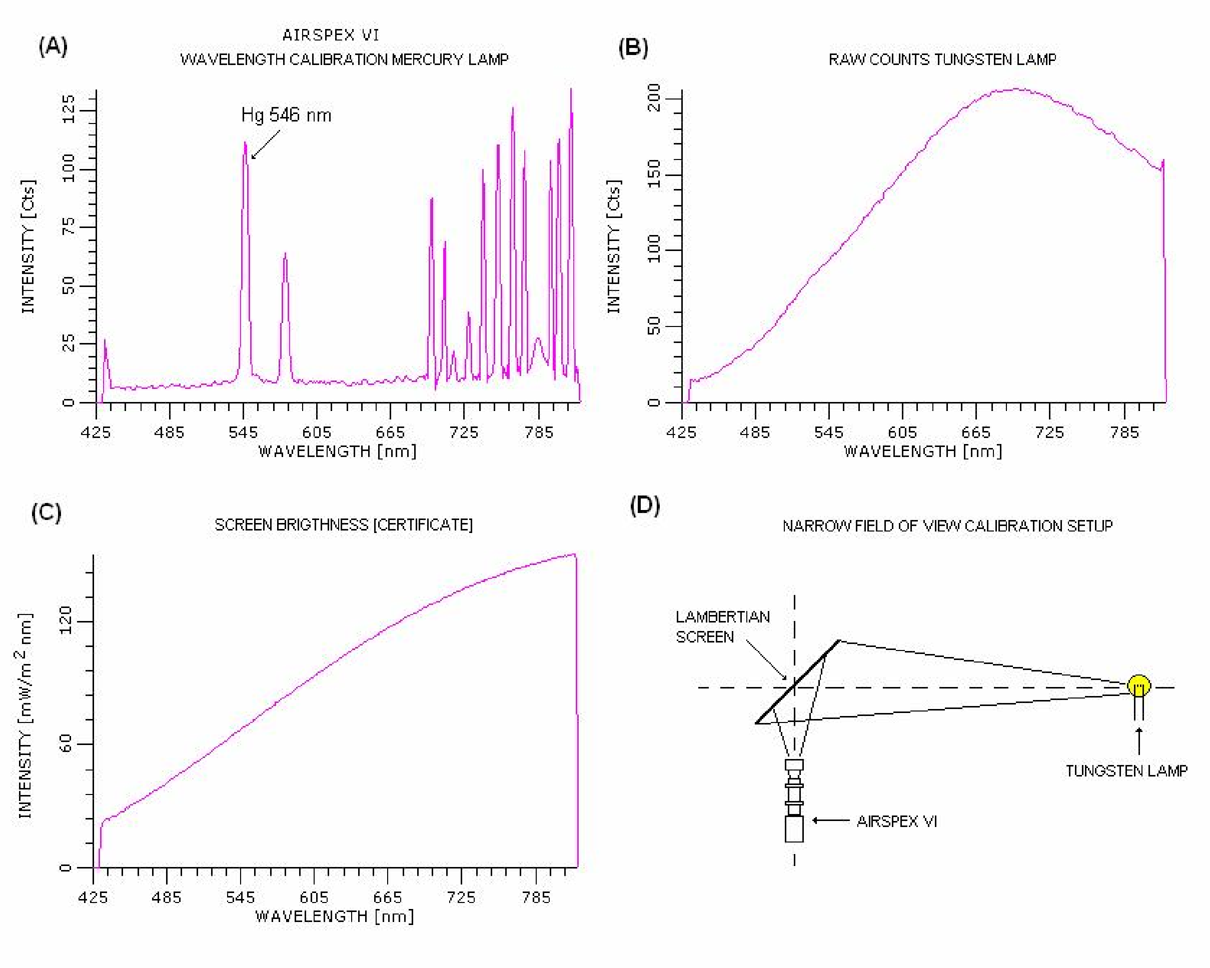


Figure 13. Results of both wavelength- and absolute calibration for Airspex VI. The wavelength calibration was obtained by the use of a Mercury vapour gas lamp (Panel A). The green Mercury emission line at 546 nm is marked. Panel B shows the spectrum of the diffuse re-emitting screen illuminated by the absolute calibration lamp. Note that the average slit response given in raw counts [Cts]. Panel C represents the absolute certificate spectrum for the 1000 W Tungsten lamp in units [mW/m^2 nm]. The calibration setup is sketched in Panel D.

f is the focal length of lens LI (front lens) and *p* is the distance to the target. The corresponding spatial resolution can then be defined as

$$\Delta x = 2\, p \tan [\, 0.5\, \Delta\theta \,]. \quad [m] \qquad (4)$$

For objects located at $p = 700\ km$, by use of a slit width of $w = 25\ \mu m$ and a focal length $f = 1m$, $\Delta\theta = 0.0014$ degrees and $\Delta x = 17.5\ m$. This means that if we are using a 1/2" CCD (6.4 x 4.8 mm^2) with pixel size of 8μm, the corresponding resolution along the slit is approximately $\Delta y = 5.6\ m$. Using a spectral bandpass of 5 nm over the 450 - 830 nm wavelength range, gives us a number of pixel per spectral bin close to 10. The ground swath becomes 3.360 km. This procedure must be optimized according to instrumental design.

5.2 Hyper spectral design

There are many designs that could be used, depending mainly on the type of dispersive / diffractive optical element used. Fig. 11 shows an assembled instrument according to the optical design shown in Fig. 10. This instrument, Airspex VI, is the latest version of the spectral imagers at UNIS. Examples of airborne data from this instrument will be shown in the next section.

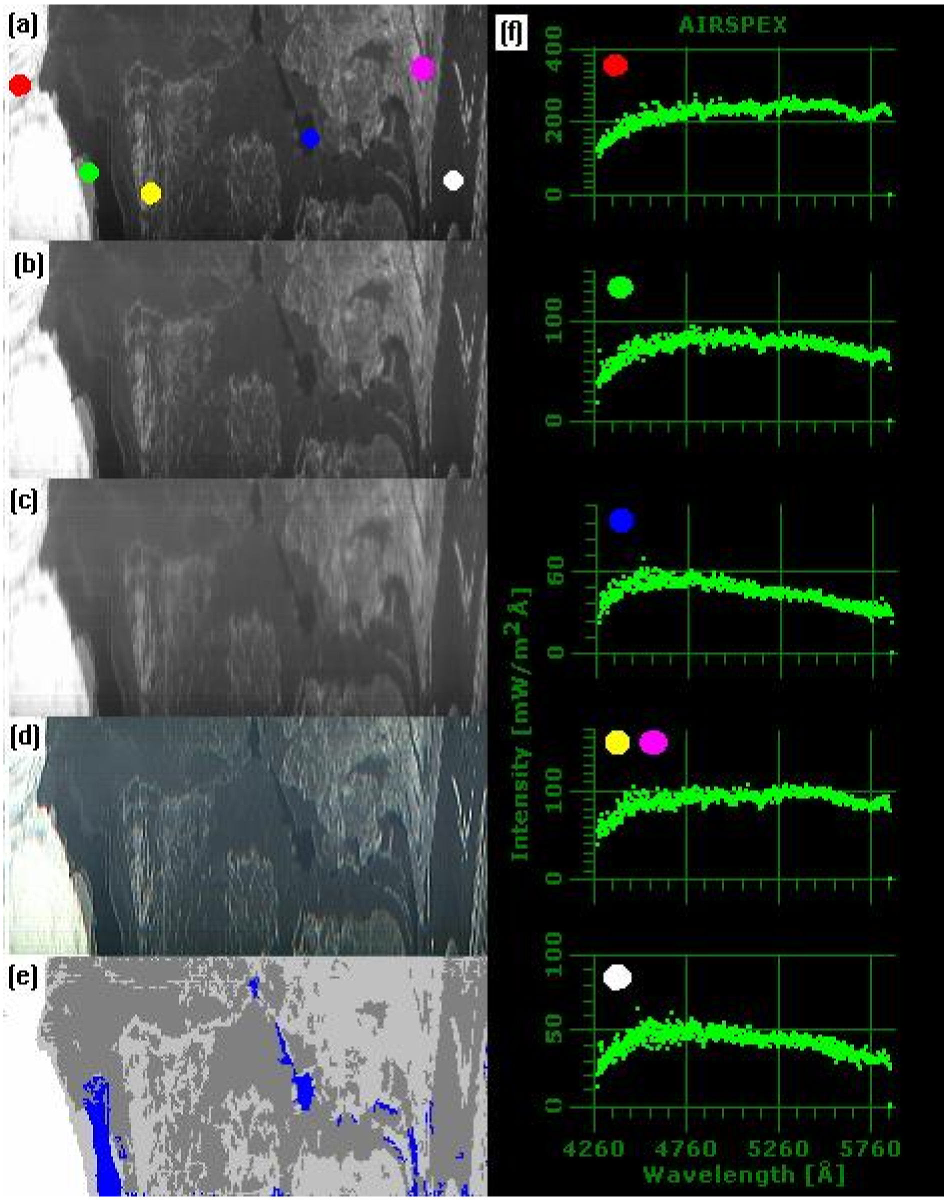


Figure 14. Airborne images from Vestpynten close to Longyearbyen airport, Norway, 11:15 UT 15 April, 1999. The three monochromatic images (a), (b), and (c) have centre wavelengths 581.9, 529.4 and 487.3 nm, respectively. Each individual image is obtained by summing an incremental wavelength region of 10.5 nm. The exposure time was 60 msec. The false colour image (d) is obtained by making a composite RGB image from (a), (b) and (c). Image (e) is the result of the classification applying the Bayes method. Panel (f) shows a range of spectra according to the selected positions in image (a). Colour tags (circles) mark the selected positions to the corresponding spectra. The spectra represent the reflected light from snow cover onshore (red tag), leads (blue tag) and different types of sea ice (white, green, yellow and pink tags). Flight altitude is 3000 m. View angle is 45 degrees to nadir. Resolution is 7 m.

The Airspex VI is physically a rather long construction, and there are many optical parts. Also, if we use the telescope lens as front optics instead of the normal objective (50 mm), the instrument would not fit inside the satellite. As a consequence, we aim to construct a more compact instrument. A concave ion edged holographic reflective grating would reduce the amount of optical components. Fig. 12 shows the optical diagram of the new spectral imager for our satellite. The design is based on an instrument that was tested in spring 2001 at UNIS. It can be further optimized according to size by matching the f/value of the telescope to the concave grating (f/value = 2.0).

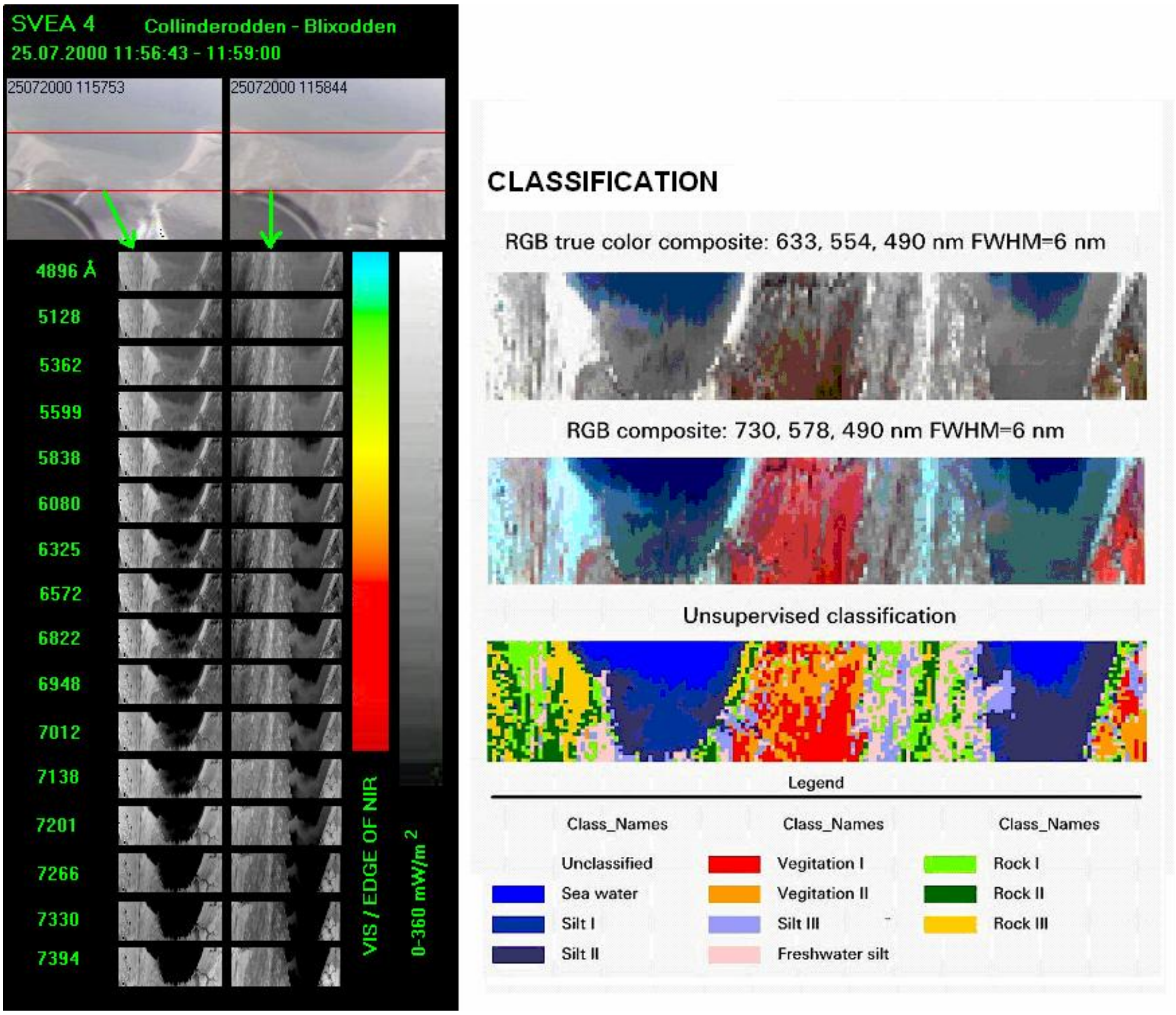


Figure 15. Black Panel (top) shows two colour images from Collinderodden and Blixodden, close to Svea on Svalbard, Norway. Date is 25.07.2000. Time: 11:56 - 11:59 UT. Below the images are the spectral sequence of images from 489.6 - 739.4 nm. The bars to the right represents colour in the visible spectrum and the calibrated intensity in mW per square meter, respectively. To the right side is the result of an unsupervised classification. The instrument is capable of mapping different types of vegetation, rocks and 4 types of silt in the water (also freshwater silt). The data was taken with an instrument which is close in design to the one shown in Fig. 12 (the proposed imager). Flight altitude is 3000 m. View angle is 45 degrees to nadir. Resolution is ~20 m.

A typical 1024 x 512 pixels CCD (ex. Hamamatsu S7019-1009) with 24 μm sized pixels (active area 12.288 x 24.576 mm^2) will give us a wavelength range of 400 - 1138 nm and 5 pixels per spectral bin (FWHM=3.5 nm). The ground resolution will be $\Delta x = 17.5\ m$ and $\Delta y = 16.8\ m$. The swath width will be *8.6 km*.

The above example requires that 8-bit images must be transferred through the S-Band at a rate of 104 Mbits per second. In practice, the signal must be compressed down to about 2 Mbits per second for S-Band. We need to investigate available technology before we decide on which detector to use. Worst case scenario is to use a 1 inch CCD with video output. The same technique that the fore field camera uses (S-Band BPSK demodulated and veterbi coded according to ESA standards). The spectral range will then be reduced to 450 - 830 nm. The design of the instrument is in other words very important in the upcoming discussion, if this project becomes founded. Nevertheless, the above instrument will fit as it is into the satellite bus. A more detailed description of hyper spectral imagers is found in Sigernes et al. (2000).

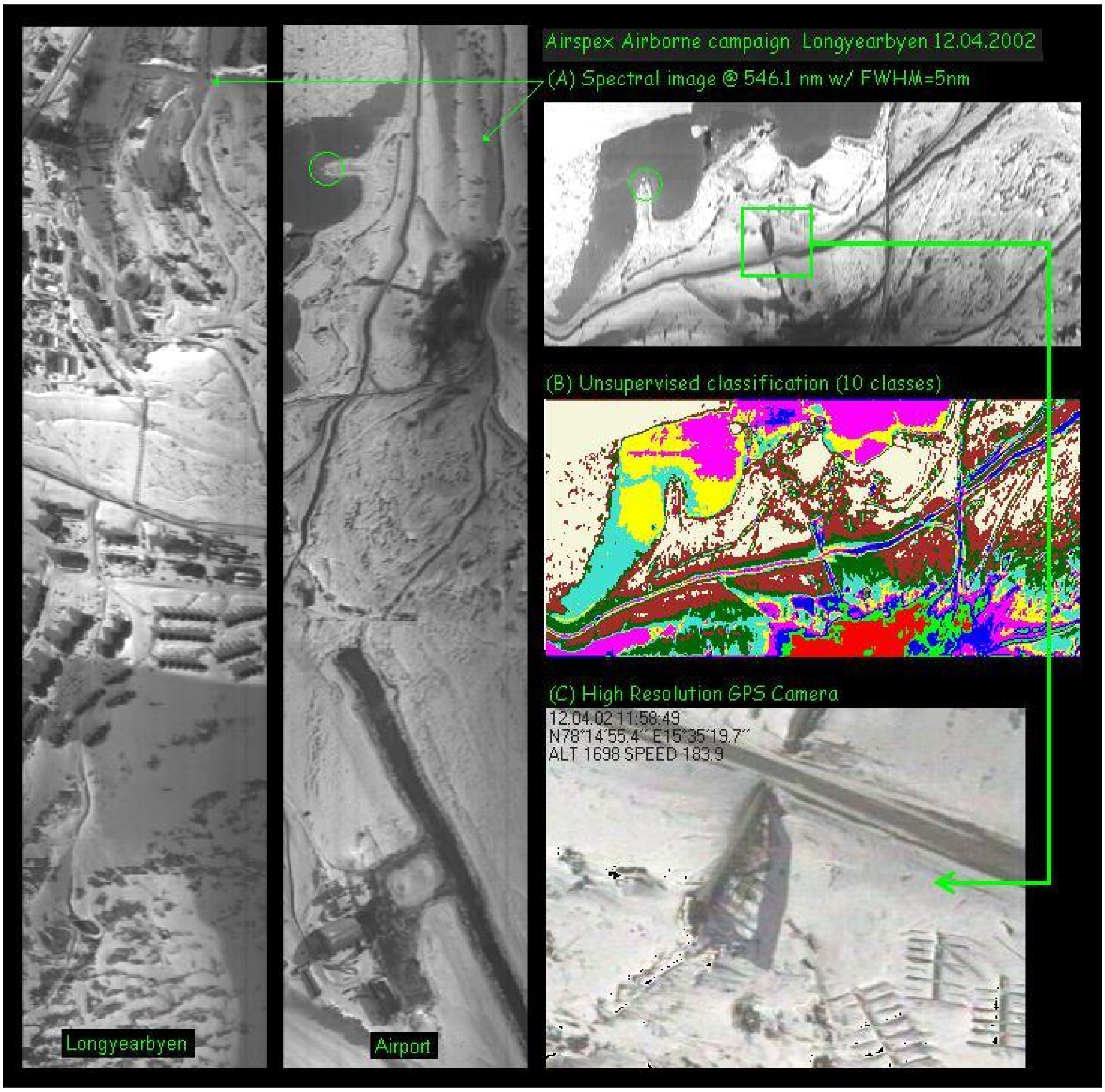


Figure 16. Hyper spectral imaging of Longyearbyen, 12.04.2002. The two Gray scaled image strips to the left are generated with a centre wavelength of 546.1 nm. The bandpass is 5 nm. The altitude is 2000 m and the view angle is 30 degrees to nadir. The resolution is close to 2 m. Panel A shows the 546.1 nm image of the cleaning facility for coal (Renseverket) owned by the company Store Norske Kullkompani AS. An unsupervised classification with 10 classes is presented in panel B. The GPS position of the plane is found in the upper left corner of the high resolution camera image in panel C.

5.3 Calibration

Ideally each photon entering the spectrograph will be transformed to an electronic count by the detector, but some loss will always occur. The throughput can be considered as an equivalent for the sensitivity or wavelength dependent calibration curve of the instrument, giving the ratio of electronic counts out to the number of photons passing through the instrument. It is necessary to calibrate the instrument against a known light source to obtain the spectral intensity in absolute units. In addition, a diffuse reflective surface (Lambertian) is needed to make sure that the instrument's field of view is uniformly illuminated. The source for the calibration then becomes the screen not the lamp. Wavelength calibration using spectral gas tube lamps with known emission lines must be carried out before any sensitivity calibration.

The spectral imager will be calibrated in the optical lab at UNIS. The Lambertian screen is a Spectralon screen from the Company Labsphere (SRT-99-180) and the calibration lamp (1000W

Tungsten; SN7-1275) is traceable through NIST (National Institute of Standards, US). The screen to lamp distance is 2 m. The screen is tilted 45 degrees facing the lamp. The procedure is called narrow field of view calibration. Fig. 13 shows the calibration for Airspex VI.

6. POSSIBLE APPLICATIONS

The data presented in this section is obtained by the airborne spectral imagers constructed by the Geophysical Department at UNIS. A total of 30 hours flight time have been spent since 1998. A local twin motor airplane, a Dornier 228 owned by the company Lufttransport have been used. The instruments have been pointed at angle of 30 degrees to the vertical (side view). The costs of these campaigns have been covered through the course AGF-331 "Remote Sensing and Spectroscopy".

Figs 14, 15,16 and 17 show typical example data from our airborne campaigns in the arctic. Provided funding, we aim to make observations covering a number of applications including (but not limited to):

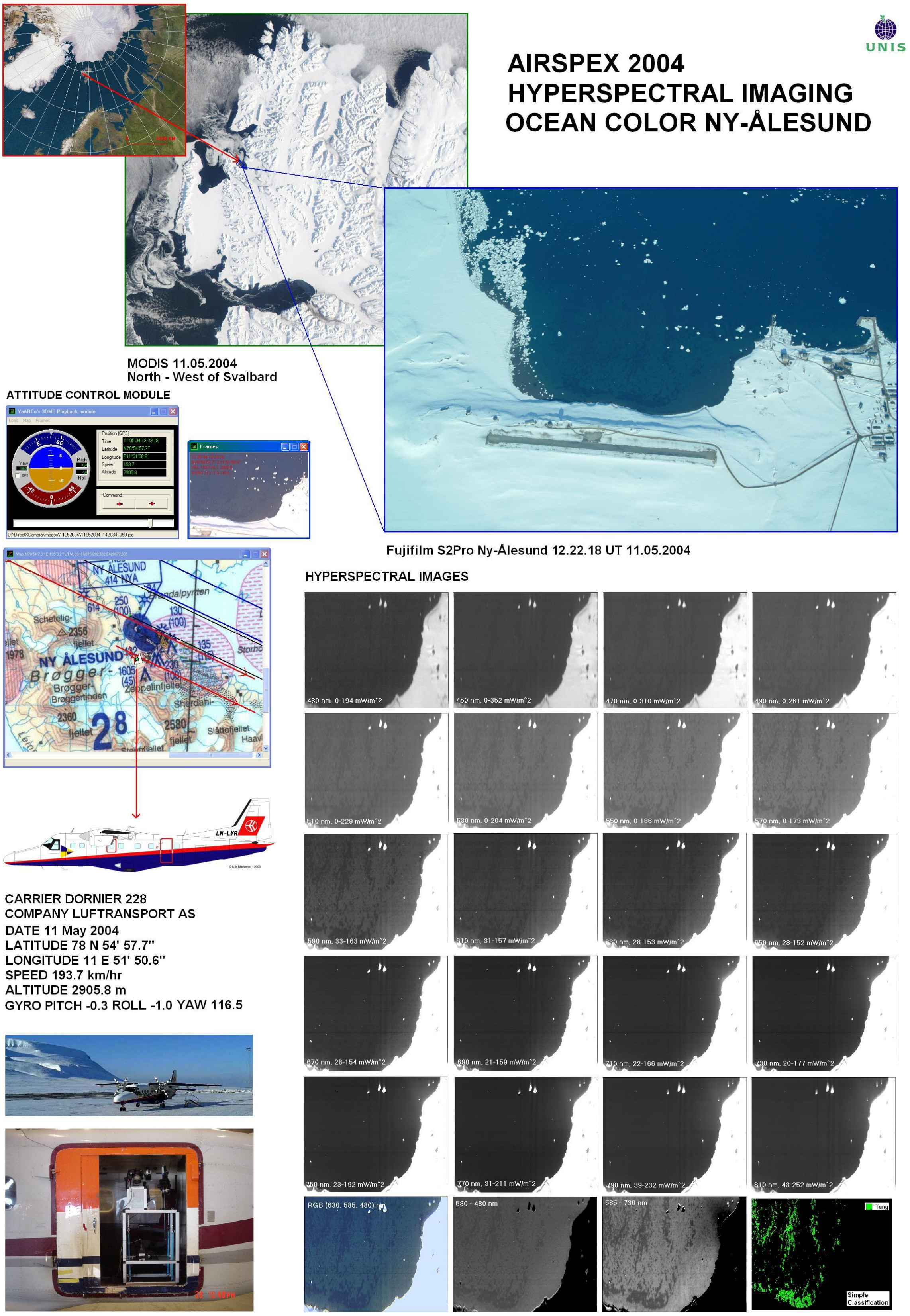
1. Ocean Colour, Algae blooming surveillance
2. Vegetation mapping
3. Sea Ice Mapping and Sea Ice Dynamics
4. Snow covered area mapping
5. Natural resource management
6. Glacial Mass Balance
7. Weather data for forecast modelling (clouds versus snow cover)
8. Cloud liquid content, aerosols, trace gases, cloud transmission
9. Polar Search and Rescue studies

7. TEACHING STUDENTS

During construction and use of the satellite, we aim to actively involve students. The course AGF-331 "Remote Sensing and Spectroscopy" at UNIS already contain lectures about the TUBSAT project and spectral imaging in general. A new course is now under planning and will deal with satellite construction from scratch. See appendix for course description. We plan to invite guest lectures to cover topics including attitude control, payload construction and operation with special focus on the proposed satellite. We aim to promote the project in order to recruit new students at Master and PhD level - needed by the fast growing space industry in Norway.

8. BUDGET WITH TIME SCHEDULE

The construction of the SVALBIRD can start as early as January 1, 2005. It should then be ready for launch as a piggy back in July, 2006. The current launch adapter (see Fig 4) is designed to be used on the Indian Polar Spacecraft Launch Vehicle (PSLV). Table 1 gives an estimate of the total costs of labour and parts.



Position (GPS)
Time 11.05.04 12:22:18
Latitude N78°54'57.7"
Longitude E11°51'50.6"
Speed 193.7
Altitude 2905.8
D:\DirectXCamera\images\11052004\11052004_142034_050.jpg
Map: N78°54'7.9" E11°35'9.2" UTM: 33 X N8761202,532 E426677,385

CARRIER DORNIER 228
COMPANY LUFTRANSPORT AS
DATE 11 May 2004
LATITUDE 78 N 54' 57.7"
LONGITUDE 11 E 51' 50.6"
SPEED 193.7 km/hr
ALTITUDE 2905.8 m
GYRO PITCH -0.3 ROLL -1.0 YAW 116.5

Figure 17. Airspex 2004. Hyper spectral images of Ny-Ålesund, 11.05.2004. A satellite image from MODIS (taken simultaneously with the airborne data) is shown at the top together with a high resolution colour image (Fujifilm S2Pro digital camera with 28 mm objective). Attitude and position tracks are shown to the left. The view angle is 30 degrees to nadir. The sequence of Gray scaled images are from 430 nm up to 810 nm with a bandpass of 5 nm. The composite RGB

is made using the 480 nm (Blue), 585 nm (Green) and 630 nm (Red) , respectively. From the difference between the images at 585 nm and 730 nm, structure on the bottom of the bay is seen. A simple classification (Bayes) reveals a map of the brown algae population (mostly *Laminae* sp.).

Tabel 1 Part #	Time period [months]	Description	Estimated costs [kilo Euro]
1	1-6	Procurements	
2a	6-12	Satellite Bus construction	1000 *
2b	6-12	Payload construction	125
3	12-18	Testing and launch delivery	**
4	18 -	Ready for launch as piggy back	1000 ***
5	1-12	Teaching and Transfer of Technology program	100

Tabel 1. SVALBIRD's total costs of labour and parts. * Includes satellite bus construction with fore field cameras, testing and delivery to launch site. ** Equipment tests includes: incoming inspection, vacum testing, thermal testing and performance testing. On satellite level: end-to-end performance, near-field to far-field communication tests, close loop attitude on air bearing facility, and vibration tests. *** Negotiable price, depending on main launch vehicle and organization.

In addition we apply for 10 years of salary for two associate Prof. physics (~ 73k Euro per year, including overhead) and 2 PhD. students to UNIS (387k Euro for 6 years) to secure the after use of the satellite in orbit (negotiable). Part 5 in the above table is intended for the Norwegian participants of this project. We will stay in Berlin one year during construction of the satellite bus and learn the whole process of building and handling the SVALBIRD in orbit.

Total budget becomes 4072k Euro (4.072 million Euro).

9. SUMMARY

A proposal to construct and launch a micro satellite for hyper spectral imaging of the Earth's surface in polar orbit is given. We apply for 34 million Norwegian kroner (1 Euro = 8.3 kr) to implement and execute the above plans. We have the *know how* - we just need funds to realize it.

RELEVANT REFERENCES

Bleif, J.-H., Roemer, S. and Renner, U., The TUBSAT Attitude Control System: Flight Experience with DLR-TUBSAT and MAROC-TUBSAT, IAA-B4-1201, Technical University of Berlin, Institute of Aerospace, Marchstr. 12, D-10587 Berlin, Germany, 2003.

Bleif, J.-H., Earth Observation at Night with the Micro-Satellite DLR-TUBSAT, Technical University of Berlin, Institute of Aerospace, Marchstr. 12, D-10587 Berlin, Germany, 2004.

Roemer, S. and Renner, U., Flight Experiences with DLR-TUBSAT, IAA-B3-0304, Technical University of Berlin, Institute of Aerospace, Marchstr. 12, D-10587 Berlin, Germany, 2001.

Roemer, S. and Renner, U., Flight Experiences with the Micro-Satellite MAROC-TUBSAT, IAC-03-IAA.11.2.07, Technical University of Berlin, Institute of Aerospace, Marchstr. 12, D-10587 Berlin, Germany, 2004.

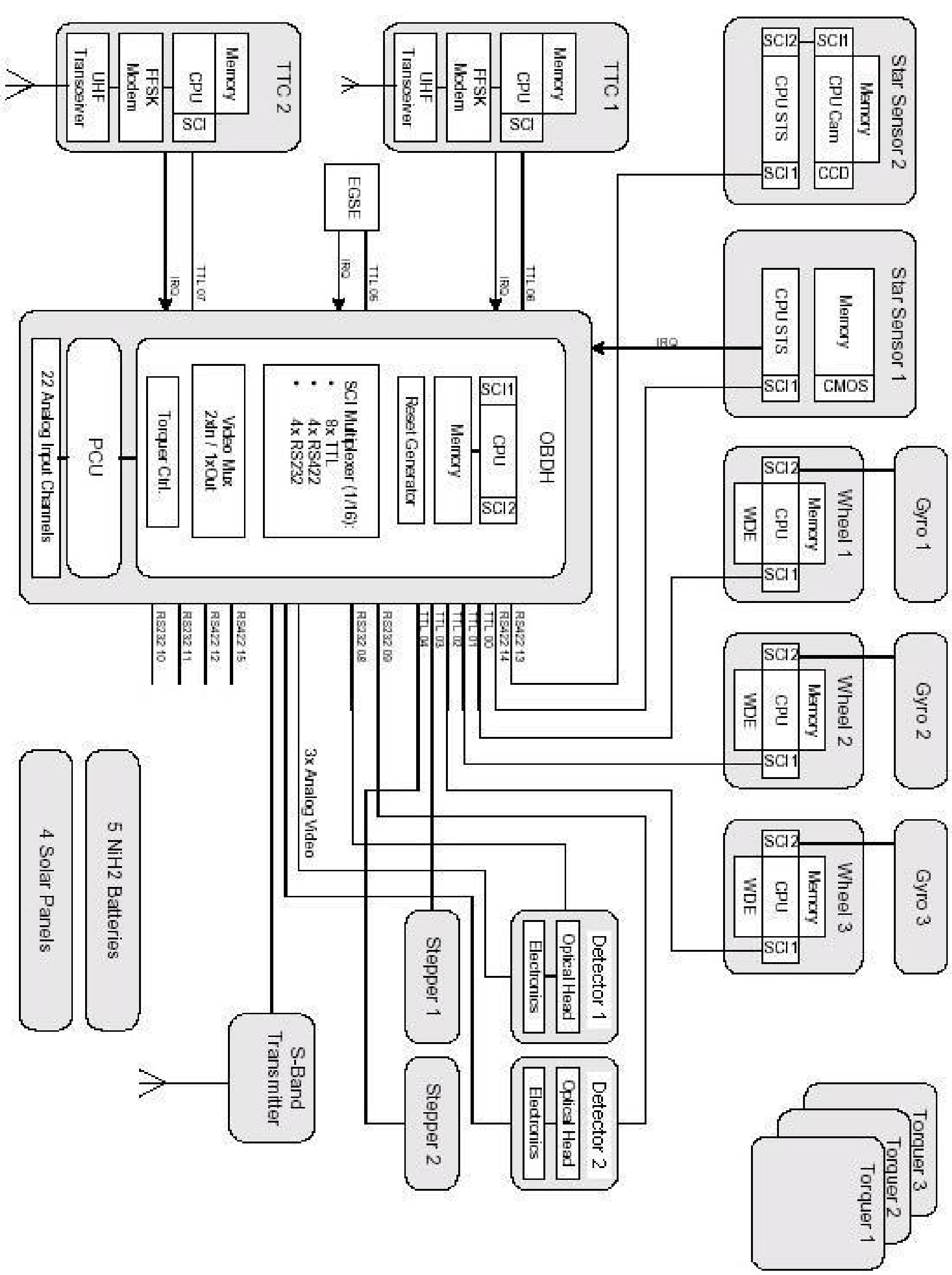
Schulz, S. and Renner, U., DLR-TUBSAT: A Microsatellite for Interactive Earth Observation, Technical University of Berlin, Institute of Aerospace, Marchstr. 12, D-10587 Berlin, Germany.

Schulz, S., Interactive Attitude Control for Earth Observation with Micro-Satellites, Technical University of Berlin, Institute of Aerospace, Marchstr. 12, D-10587 Berlin, Germany, 2001.

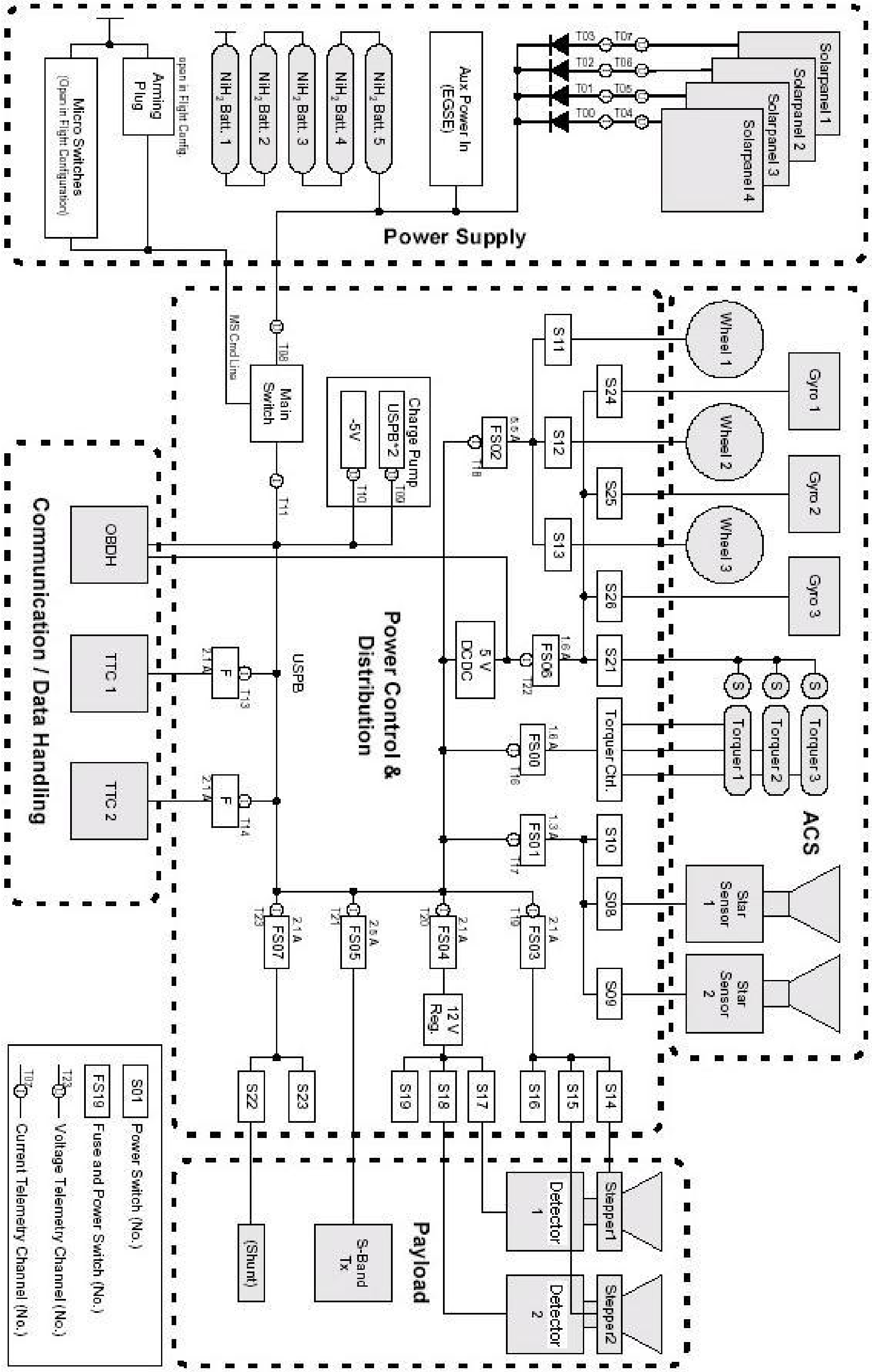
Sigernes, F., Lorentzen, D.A., Heia, K., and Svenøe, T., A multi-purpose spectral imager, **39**, N0. 18, 3143, (Front cover issue), *Applied Optics*, 2000.

APPENDIX

Internal Communication Block Diagram



Power Supply Block Diagram



AGF-331 REMOTE SENSING AND SPECTROSCOPY

Objective: This course will give a fundamental and experimental basis for advanced spectroscopy in order to be able to conduct and develop experiments in the frontier of atmospheric studies and remote sensing. This will give a unique understanding of the specific light qualities on Svalbard and an understanding of geophysical data obtained by remote sensing. Imaging techniques will be emphasised.

Content: The first part of this course deals with design of spectrometers and evaluation of elements based on geometrical optics, dispersion and interference, bandpass, resolution, sensitivity, stability, spectral range, and response time, as fundamentals of a complete description of the instrument function. With the basic theory established, concepts like photoelectric detection, detectors and photon counting, wavelength and intensity calibration, will be explained and conducted for both scanning and imaging instruments. The facilities at *Nordlysstasjonen* in Adventdalen will be used, since it contains an array of up-to-date spectrometers used in studies of dayside and night side aurora. A practical exercise will be given to obtain and quantify the emission features of the night-sky throughout the wavelength range from 300 to 900 *nm*

The rest of the course introduces imaging spectroscopy both theoretically and practically. Image processing, satellite orbits, radiative transfer and spectral properties of ground targets will be included in order to compare with imagers on satellites. In daylight, the reflective properties of ground targets will be measured from 400 to 700 *nm* with a spectral resolution of 0.5-3.5 *nm* and a spatial resolution of 0.014-30 *m*. These ground-based measurements will be conducted in order to prepare for an airborne experiment. Finally, the data collected during the flight will be evaluated and summarised in a report.

Credits:	5vt/15 ECTS
Builds on:	Basic knowledge of physics and calculus.
Duration:	One term; spring.
Teaching:	50 hours lectures, 50 hours exercises / field work
Evaluation:	Oral examination, graded.
Literature:	Compendia and selected literature.
Contact person:	Fred Sigernes, fred@unis.no .
Schedule 2004/2005	Spring 2005

AGF-33X SATELLITE CONSTRUCTION FOR EARTH OBSERVATION

Objective: This course will give a fundamental and experimental basis in satellite design and satellite operation. This will give a unique understanding of the space conditions, orbital dynamics and requirements for space based earth observation satellites and the actual technology that is used for it.

Content: The first part of the course describes the space conditions and orbital dynamics of earth orbiting satellites. The design of a earth observation satellite will be shown from the scratch with all needed subsystems and typical system technologies for them. Based on this the course will show the technical requirements for the sub systems earth observation satellites, special design philosophies (e.g. design to the needs) With the exercises the students should get a feeling for space based system and it needs.

The second part will introduce the students into the TUBSAT earth observation satellites and the SVALBIRD satellite project, a hyper spectral earth observation satellite. The student shall understand the decisions behind the used technical concepts and strategies.

In the last part the students are instructed to operate a satellite and its payload by using a low cost ground station for satellite operation and payload download with SVALSAT. Finally, the students will operate with the TUBSAT satellites and will collect in time data from Svalbard and surrounded areas with the UNIS based UHF satellite ground station and the SVALSAT station.

Credits:	10 ECTS
Builds on:	Basic knowledge of physics and calculus.
Duration:	5 weeks
Teaching:	40 hours lectures, 8 hours exercises / field work.
Evaluation:	Oral examination, graded.
Literature:	Compendia and selected literature.
Responsible for the course : **UNIS Contact person:**	Stephan Roemer, Stephan.Roemer@ilr.tu-berlin.de Fred Sigernes, fred@unis.no .
Schedule 2004/2005	Spring 2005