DLR-TUBSAT: A MICROSATELLITE FOR INTERACTIVE EARTH OBSERVATION

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ABSTRACT - *DLR-TUBSAT is a joint project of the Institute of Aerospace at the Technical University of Berlin (TUB) and the German Aerospace Center (DLR). The microsatellite was launched on 26 May 1999 with the Indian Polar Spacecraft Launch Vehicle (PSLV) together with KITSAT-3 and the primary payload IRS-P4. The test satellite was designed for interactive earth observation where the target is not clearly identified in advance, a search action is involved or a target has to be visually followed for a while. This paper will describe the mission objective, the final configuration of the satellite, the ground segment and the operations. Finally the achievements of the first year in orbit and the lessons learned will be presented.*

1 – INTRODUCTION

Satellite remote sensing is very useful in areas such as forestry, agriculture, geology, hydrology and mapping in any way. Since 1970 a lot of remote sensing systems have been launched for imaging the earth, e.g. projects like LANDSAT, SPOT and IRS. Due to the size and costs of these projects remote sensing was limited to governmental organizations which were interested in weather services, military observations and mapping. The attitude of these satellites has to be nadir pointing in order to scan the earth face with linear CCD sensors and the repeat cycle is from 3 to 26 days. They need a high volume of data storage and data transmission. Remote sensing with a resolution in the range of 30 m is good for monitoring environmental processes that change within a period of more than 5 days.

Earth observation is going to be a commercial market more and more. With the launch of IKONOS a new era in the field of earth observation began. IKONOS provides panchromatic imaging data with a resolution of 1 m and mulitsprectral of 4 m. These images are radiometrically and geometrically corrected, map projected and will be offered via internet. The satellite has a repeat cycle of one to three days and is capable of delivering more up to date information.

What role do microsatellites have in this business ?

1. Provide a cheap platform that can be configured and launched for a very specific mission within a short time.

2. Take advantage in their mobility of monitoring processes which change fast (within one day), for search actions or for following a target.

Microsatellites have a high mobility due to their compactness and small mass which is essential for observing the following category of events: weather phenomena like hurricanes, lightning or polar lights, spectacular fires, volcano eruptions, floods, earth quakes, ship, plane or railway accidents or any other events of this type which e.g. a news agency would like to present in the news. This interesting area is typically only a few square kilometers large and the resolution requirement is of course as high as possible.

In this case interactive earth observation means that the user in the ground station receives video images from the satellite and is able to steer the pointing direction of the camera platform interactively via mouse control to the interesting event on the ground (see figure 1). This is appreciated in applications where 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.

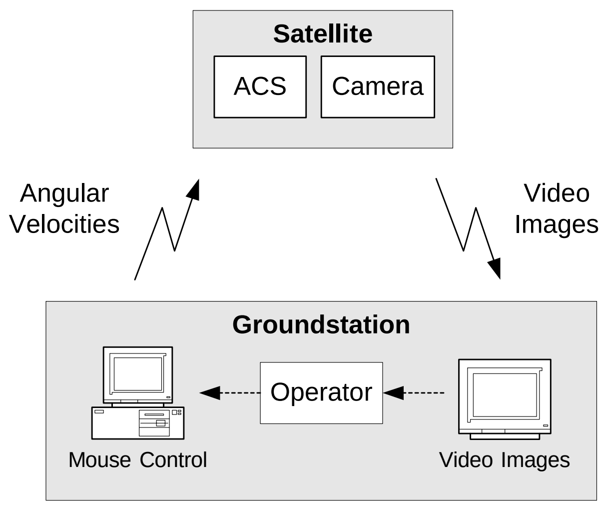

Figure 1: Interactive earth observation

The test satellite DLR-TUBSAT has been designed especially for this purpose and was launched on 26 May 1999 with the Indian rocket PSLV (Polar Spacecraft Launch Vehicle) from the launch site Sriharikota together with KITSAT-3 and the primary payload IRS-P4 (OCEANSAT). The satellite was attached with a ball-lock type separation system to the vehicle equipment bay (VEB) of the upper stage and was separated about 19 min after launch with one meter per second. The final orbit parameters are listed in table 1.

Type	sun synchronous
Altitude	726 km
Descending node	12:00 am
Eccentricity	0.0017
Inclination	98.3811 °
Period	99.344 min

Table 1: Orbital characteristics

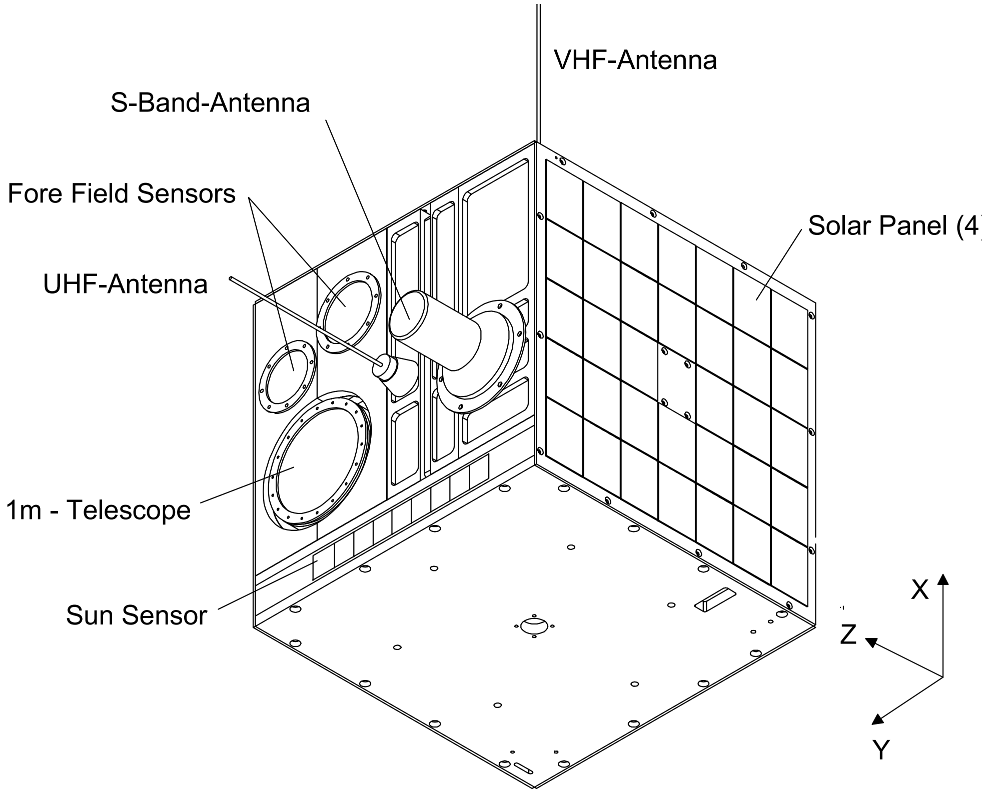

Figure 2: Microsatellite DLR-TUBSAT

2 – SYSTEM DESCRIPTION

DLR-TUBSAT was jointly developed by the Technical University of Berlin (TUB) and the German Aerospace Center (DLR); TUB was responsible for the satellite bus and DLR for the payload. In the frame of operation the TUB has a cooperation with the German Remote Sensing Data Center (DFD) of DLR in Neustrelitz and a radio amateur ground station in Kiel. The TUB Satellite Control Centre is responsible for the health monitoring and the ground stations at Kiel and Neustrelitz for receiving the wide band video signals.

2.1 – Space Segment

The final configuration of the space segment is shown in figure 2 and 3. The cube shaped satellite measures $32\times32\times32$ cm^3 and weighs 44.81 kg. DLR-TUBSAT is subdivided into a Payload, a Housekeeping and a Attitude Control Module. The last two modules represent the TUBSAT-C bus. The lower compartment is mainly the interface for the separation system.

The Payload Module contains two fore field cameras with low and medium resolution and a high resolution telescope with a focal length of 1 m, a pixel size of 8.3 μm and a ground pixel resolution of 6 m. Each CCD-chip contains 752×582 pixels, and each camera can transmit video images in CCIR-standard and single digital pictures. The focal length of the fore field cameras is 16 mm and 50 mm respectively. The S-band antenna is physically located on the Attitude Control Module in order not to obstruct the field of view of the payload sensors, and 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 $^\circ$.

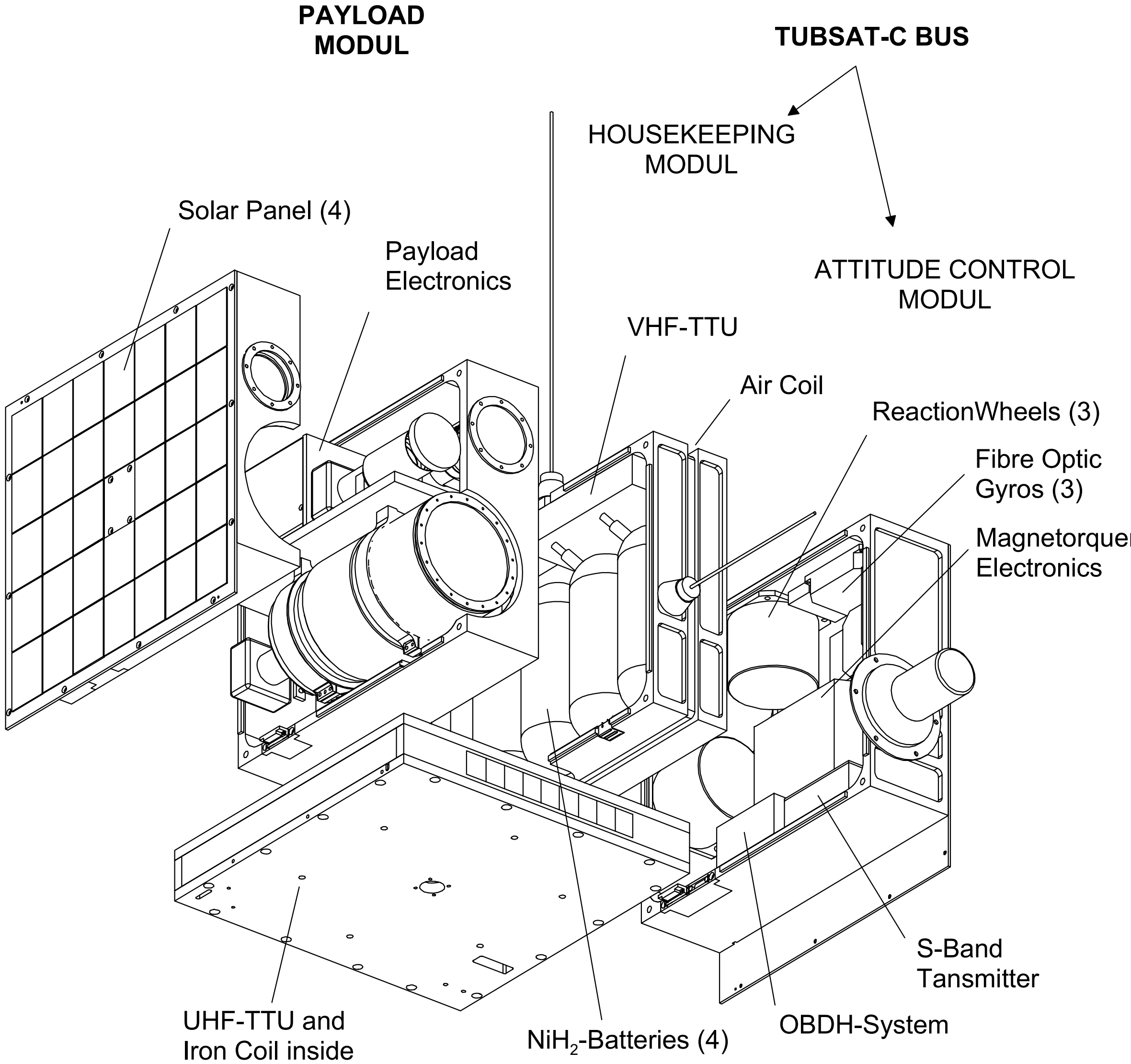

Figure 3: Exploded view of the microsatellite DLR-TUBSAT

The House Keeping Module contains the batteries, the Power Control Unit (PCU), the air coil and the two Telemetry Telecommand Units (TTU) in VHF and UHF band, as well as the two antennae. Four 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 960 mA. The PCU 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 / VHF-TTU 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.

The Attitude Control Module contains three reaction wheels, three fibre optic gyros, the magnetorquer electronics, the On Board Data Handling System (OBDH), the S-band transmitter as well as the S-band antenna.

The lower compartment contains the UHF-TTU and the iron coil, which is mounted in the direction of the z-axis of the satellite. A single string of solar cells is attached at the surface in the +z-axis and is used for the sun acquisition maneuver.

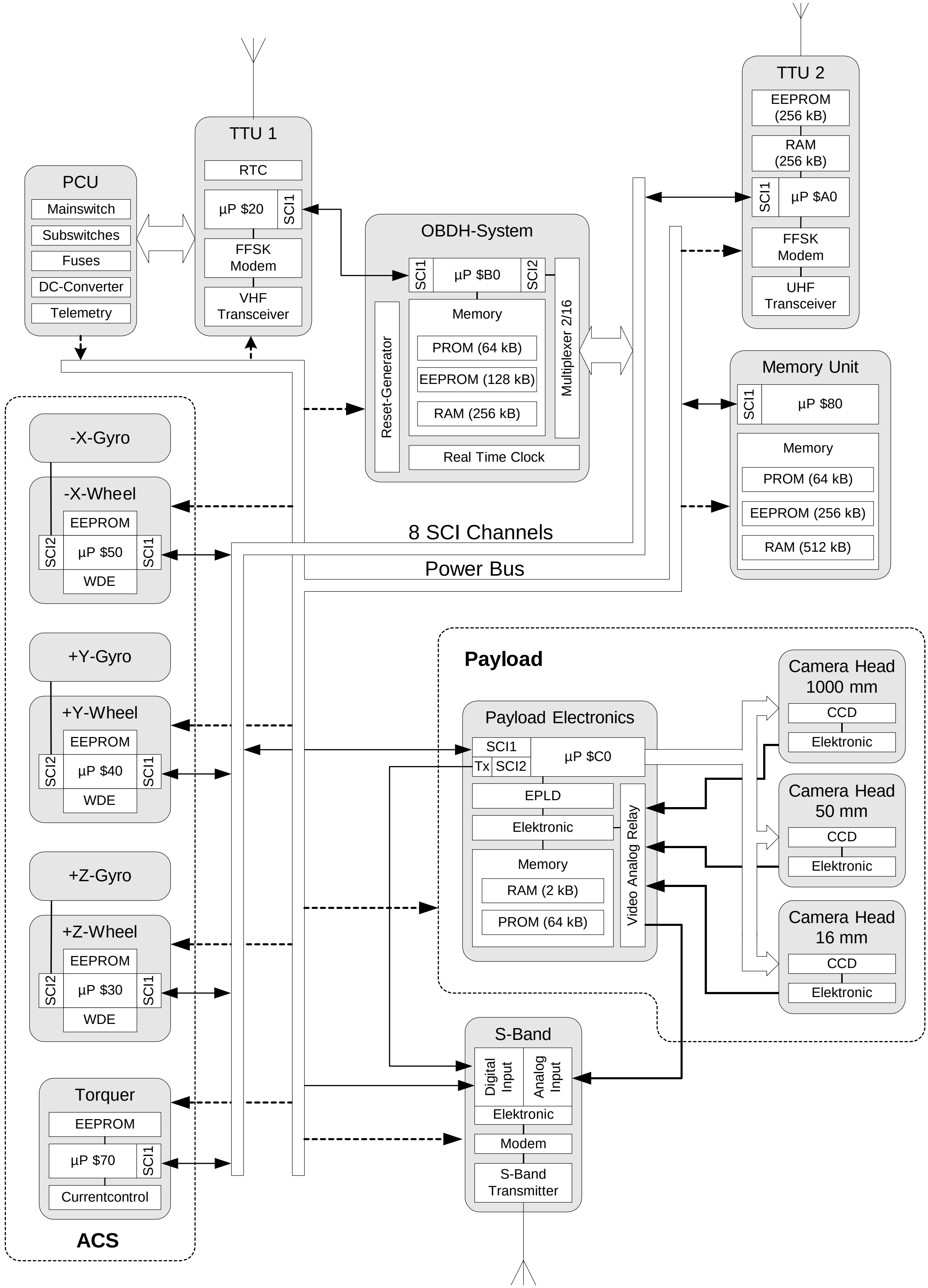

Figure 4: System architecture of DLR-TUBSAT

System Architecture The communication and power system is a radial network, where PCU and OBDH-System are the main devices (see figure 4). The PCU is responsible for power conditioning and distribution and the OBDH-system for controlling the communications. Each device is connected to the PCU via power bus, which consist of +5 V, +15 V and the unregulated battery voltage, and to the OBDH-System via SCI, excluding the TTU1 (VHF-band). The TTU1 is the primary unit which is connected to the first serial interface of the OBDH-System and to the PCU for controlling the switching tasks. The other devices are connected to the second serial interface via multiplexer. The S-band transmitter is connected to the payload, provides the transmission of the video images and the digital pictures with 125 kbaud (bi phase level coded). A summary of the main technical data is shown in table 3.

Attitude Control System The attitude control system is shown in the ACS-group in figure 4. The magnetorquers are used for the reduction of the angular momentum of the satellite. The reaction wheels RW202, developed by the TUB, have an integrated 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 - 6, 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 the angular velocity from the gyro four times per second and calculates an accumulated angle. This wheel / gyro-unit ACS202 (see figure 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 kg, gyro: 0.15 kg), small volume (wheel: $80\times80\times70$ mm^3, gyro: $100\times65\times20$ mm^3) and simple interfaces (electrical: 5 V & 12 V, data: 8 N 1). The operation modes and the main data of the performance are shown in table 2.

Figure 5: Wheel / Gyro-Unit ACS202

Operation modes
Current control
Speed control
Torque control
Angular velocity control
Angle control
Performance
M = 0.02 Nm (max.)
H = 0.24 Nms (max.)
Bias drift (1 σ): $< 6\,^\circ / \sqrt{\text{h}}$
Noise (1 σ): $< 0.6\,^\circ / \sqrt{\text{h}}$

Table 2: Wheel / Gyro-Unit ACS202

Mass	44.81 kg	
Volume	$32\times32\times32$ cm^3	
Structure	4 compartments made of aluminium	
Thermal control	passive	
Power	4 NiH_2 battery cells (Eagle-Picher), 12 Ah, 10 V nominell	
	4 solar panels with a single string of 34 silicon cells	
Communication	VHF / UHF-band, 1200 baud, 3.5-5 W	
	S-band, 125 kbaud BPL coded or video transmission, 3.5 W	
Attitude control	3 Wheel / Gyro-Units ACS 202 (TUB), magnetorquer	
Payload	f= 16 mm (D= 1 / 0.95): Pixel resolution = 375 m	
	f= 50 mm (D= 1 / 1.80): Pixel resolution = 120 m	
	f= 1000 mm (D= 1 / 11.0): Pixel resolution = 6 m	

Table 3: DLR-TUBSAT design summary

2.2 – Ground Segment

The ground segment of the DLR-TUBSAT Project consists of three parts and is shown in figure 6. The satellite control center (SCC) at the TUB is the main ground station which is responsible for mission control and health monitoring of DLR-TUBSAT. This is done by the transceiver unit in the VHF / UHF-band and a cross yagi-antenna. The digital pictures of the payload are received with the 1.2 m-antenna, which also not big enough to receive the analog images with a higher bandwidth of 8 MHz.

Due to this problem the cooperation with the German Remote Sensing Data Center (DFD) of DLR was necessary. The ground station is located in Neustrelitz (Germany), which is 150 km northward of Berlin, and receives the video images with a 4.3 m-antenna. A computer with a frame grabber unit digitizes the images and transmits them to a real-server. The computer in the SCC at the TUB with the real player connects the real server at Neustrelitz via internet. The digital pictures are displayed and the size is 320×240 pixels. The transfer rate depends on the utilization of the internet and local area network of the TUB and ranges from one picture per second down to zero. This causes a big problem, because the operator in the ground station needs continuous information about the pointing direction of the cameras to control the satellite via mouse.

Due to the unsteady transfer rate via internet a second cooperation with a ground station near Kiel (Germany) was initiated. This ground station receives the video images with a 6 m-antenna and is digitized with a frame grabber. The size of the digital pictures measures 384×288 pixels and the compression rate is higher. The computer in the SCC at the TUB connects the web-cam-server at Kiel via ISDN (multi link connection). The video images are displayed with a ordinary web-browser with constant transfer rate of one picture per second. The quality is good enough to identify lakes, rivers and coastlines, which is necessary for the orientation and navigation of the operator in the ground station.

3 – SYSTEM OPERATION

Between the events the satellite DLR-TUBSAT is in a hibernation mode with low power consumption. The attitude control system is switched off and the satellite is completely passiv and self contained. At the beginning of each pass the three reaction wheels and the three fibre optic gyros are switched on. Out of the tumbling mode, DLR-TUBSAT will

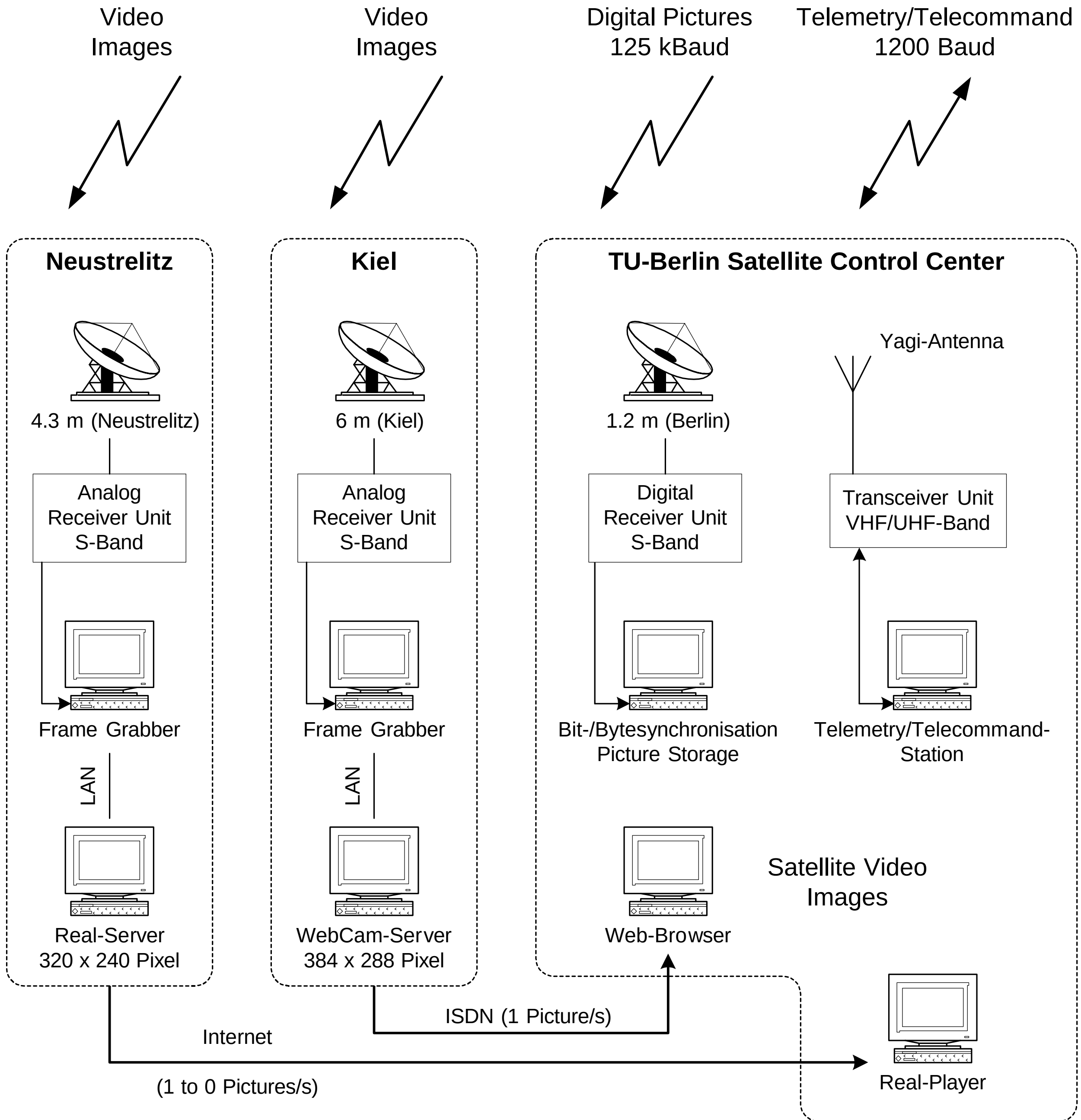

Figure 6: Ground station architecture

be stabilized by a rate reduction telecommand from the SCC at the TUB within less than 20 seconds. The next step is to point the S-band antenna to the ground station to provide the transmission of the video images for the operator. This is done by one of the two different sun acquisition maneuvers by using the information of the solar panels. Both maneuvers will be controlled on board by a program within 60 seconds. Bevor starting the acquisition maneuvers the camera system and the S-band transmitter for the video transmission have to be switched on.

1. -z-axis to the sun

2. +x-axis to the sun and a rotation rate ω_x of 1 rpm

The first acquisition maneuver is used for the observation of the Mediterranean and Adriatic regions, e.g. Corsica, Sicily and Sardinia, in summer time when the sun has a high latitude.

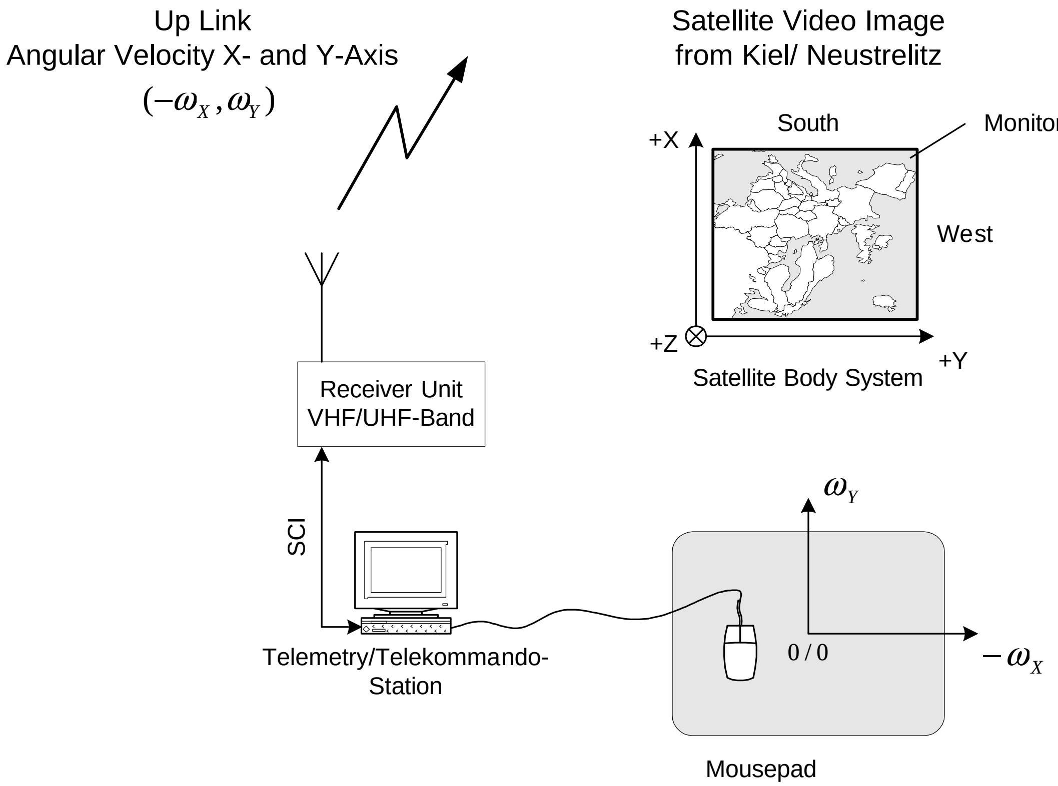

Figure 7: Mouse Control Station at TUB

Due to this orbit with the descending node of 12.00 am we receive the video images automatically at the beginning of the second part of the pass, i.e. after the maximum of elevation, and the pointing direction of the cameras is nadir. This attitude is very useful for the operator, because he is able to determine the area where the satellite crosses the coastline or other areas of interest.

The second acquisition maneuver orientates the +x-axis to the sun. Because the camera system is not in the same axis, the satellite rotates with 1 rpm around the x-axis. When the S-band ground station is in the access area, the operator receives video images from east to west horizon of the earth every minute. Now he needs to stop the rotation of the satellite in the right moment. The final pointing direction of the camera system depends on the operator and has low accuracy.

At the time the operator in the SCC at the TUB receives the video images from Kiel he starts the mouse control mode. The orientation of the video images after the maneuver is shown in figure 7 where the top of the monitor is the southern direction. If not the operator needs to correct the attitude with an angle maneuver in the z-axis before starting the mouse control mode. The computer in figure 7 commands angular velocities for the x- and y-axis in subject to the position of the mouse every second. The axes of the mouse pad refer to the body axis of the satellite, i.e. moving the mouse to the top of the pad results in a rotation of the satellite to the south. The ground operator starts with the fore field sensor with medium resolution to find the target area. To follow and track the target he can switch to the high resolution camera every time. At the end of the pass the attitude control system and other subsystems will be switched off and the satellite returns into its hibernation mode, a passive tumbling mode with low power consumption, to recharge the batteries and to wait for the next event. This microsatellite has a very low duty cycle and is waiting most of his life but has to be operable very quickly.

The biggest problem we have is the weather condition in Germany. We have a lot pictures and video streams of the southern part of Europe, but only a very few of the northern part. Normally we do our sun acquisition maneuver and get an S-band down link, but see only clouds on the monitor. In this case we stabilize the satellite and wait until it comes to the Mediterranean or Adriatic region. Most of the time we have no clouds here and the coastline is suitable to determine the pointing direction of the camera system (see figure 9). One of our main tasks was to follow the coastline with the fore field sensor with medium resolution to Italy to make a maneuver to the island Corsica or Sardinia. Afterwards we switched to the high resolution sensor to observe harbours and so on.

After reaching the target area we took a lot of digital pictures with medium resolution (50 mm-camera). We stored the pictures on board or transmitted them immediately via S-band link to the SCC (Satellite Control Center) at the TUB. Two of them are shown in figure 8 and 9. Both were taken after a +z-axis sun acquisition maneuver, where the orientation of the picture is random. The left one shows southern Italy und Sicily with the volcano Etna (top left part) and the other one the coastline of southern France. Due to the fix aperture and the minimum exposure time of only 0.1 ms the bright clouds produce vertical white stripes in the pictures.

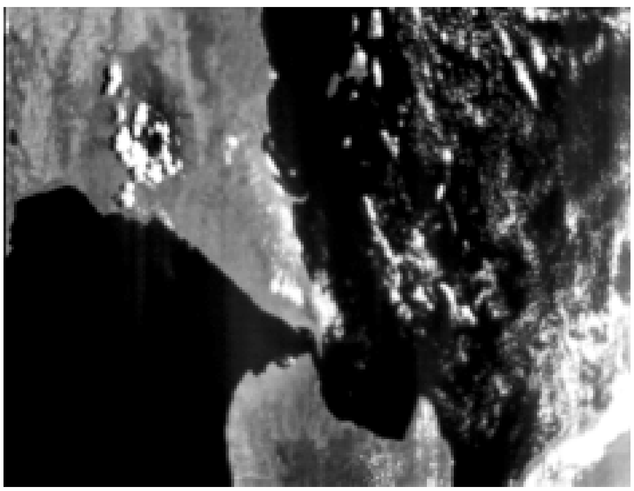

Figure 8: Southern Italy, Sicily and Vulcan Etna (50 mm-camera)

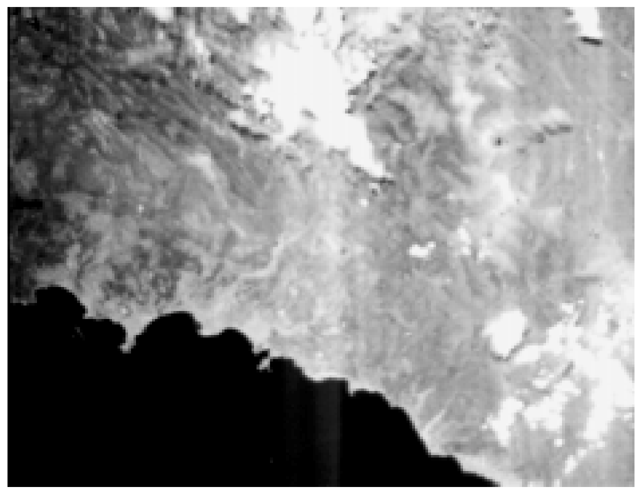

Figure 9: Coastline of southern France (50 mm-camera)

General performance DLR-TUBSAT is functioning well. The temperatures are very stable between -8 and +4 ° C. The NiH_2-battery cells are in good condition, although we do not use a charge regulator. The VHF/UHF-link for telemetry and telecommand is working well except in the southern regions of Europe, specially southern Italy and Spain. The down link in the S-band for transmitting the digital pictures is functioning very well. Due to the fact that the main part of the operation software of each device is stored in the ROM we have not had single event upsets.

Attitude control system The three wheel/gyro-units are functioning well after one year of operation time. Next time we would additionally use a star sensor for the acquisition maneuver to make it faster and more exact. Due to the higher bias drift of the fibre optic gyros the star sensor would be useful in situations in which the satellite needs to be stabilized for a longer period of time e.g. if the operator has no orientation because of bad weather conditions.

5 – CONCLUSION

The microsatellite DLR-TUBSAT is a test satellite for interactive earth observation and is functioning well. We have had a lot of impressive passes, because it is very special to control a satellite in this way. From our point of view it is a very interesting mission and differs from all other existing earth observation projects.

The next satellite will have a star sensor in addition to the information from the solar panels, such as in the project MAROC-TUBSAT, a cooperation between TUB and the Royal Remote Sensing Centre in Rabat. This microsatellite has a star sensor orthogonal to the camera, which has a ground resolution of 320 m. At the moment the satellite is in Moscow and it will be launched with a Russian rocket Zenith at the end of September.

Furthermore the payload of the next satellite consists of only two color cameras, one with a focal length in the range of 50 mm and the other with a range of 1000 mm. A camera with lower resolution is not necessary because the acquisition maneuver has a higher accuracy. Both telescopes will have a bigger aperture in the range of 1/11 due to the very bright clouds. Because of the problems which occurred in the VHF/UHF-band the system for telemetry and telecommand and the video transmission of the next satellite will work in the S-band.

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