3rd International Symposium "Small Satellites Systems and Services"
June 24th - 28th, 1996 - Annecy, France

TUBSAT-C,
A MICROSAT-BUS FOR EARTH OBSERVATION PAYLOADS

P. Butz, U. Renner

Technical University of Berlin, Institute of Aerospace
Marchstr. 12, D-10587 Berlin
Tel.: +49 (0)30 31422308, FAX: + 49 (0)30 31421306
E-Mail : pius@tubsat.fb12.tu-berlin.de, udo.renner@tu-berlin.de

ABSTRACT *- Based on the flight experience of TUBSAT-A and B, TUBSAT-C has been developed as a microsatellite bus with high precision attitude control, intended mainly for earth observation payloads. A payload with a focal length of one meter and a resolution of better than 10 m can be accommodated and pointed to any target on the earth.*
This bus is already being used by CRTS in Morocco (launch 1997) and DLR in Germany (launch 1997). The attitude control subsystem is being used by DASA for INSPECTOR and by KAIST (SaTReC) for the Korean KITSAT-3 program.

1- INTRODUCTION

Increased technical possibilities of earth observation by satellite and the corresponding growth in possible applications in themselves stimulate a growing demand for remote-sensing data. This is in part a natural result of the basic human need to explore our environment, to understand it or at least be able to fit it into available paradigms. But it these times of continuous budget cuts for space programs, there are significant developments in opposition to this trend. Indeed, the traditional, large satellite projects face mounting doubts from a critical public, and are increasingly difficult to justify. Given this situation, a growing community in recent years has been committed to the idea of "an easier, cheaper, faster access to space", and therefore advocated small satellite projects.

The main advantages of small satellites are their short development time, a low number of team members, and the possibility of using "off the shelf technologies" with correspondingly lower financial risk. By properly exploiting these conditions, small user-groups concentrated on particular applications can arrange to initiate reception of specific data from space in the shortest possible time. Success, and the future prospects of additional projects, very much depend upon how far the quality of the information gathered meets the expectations and demands of the customers, and how the potential of this technology will be evaluated by the large space agencies. Looking to the current availability of launch possibilities for small satellites, a cost-benefit analysis for many projects reveals that they are only viable for launch as secondary payloads, with all the parameters which that implies.

Over the last few years, the Technical University of Berlin has performed a satellite concept for low-cost, high-resolution earth observation [4]. One important part of this concept is the TUBSAT-C bus, which will be described in further detail below.

2 - THE TUBSAT-C BUS

To accomplish the requirements of the two next missions (DLR-TUBSAT, Morocco-Sat), the standard bus system must be adaptable to different kinds of payloads. This implies a special flexibility concerning the electrical interfaces and in addition to that a modular mechanical design.

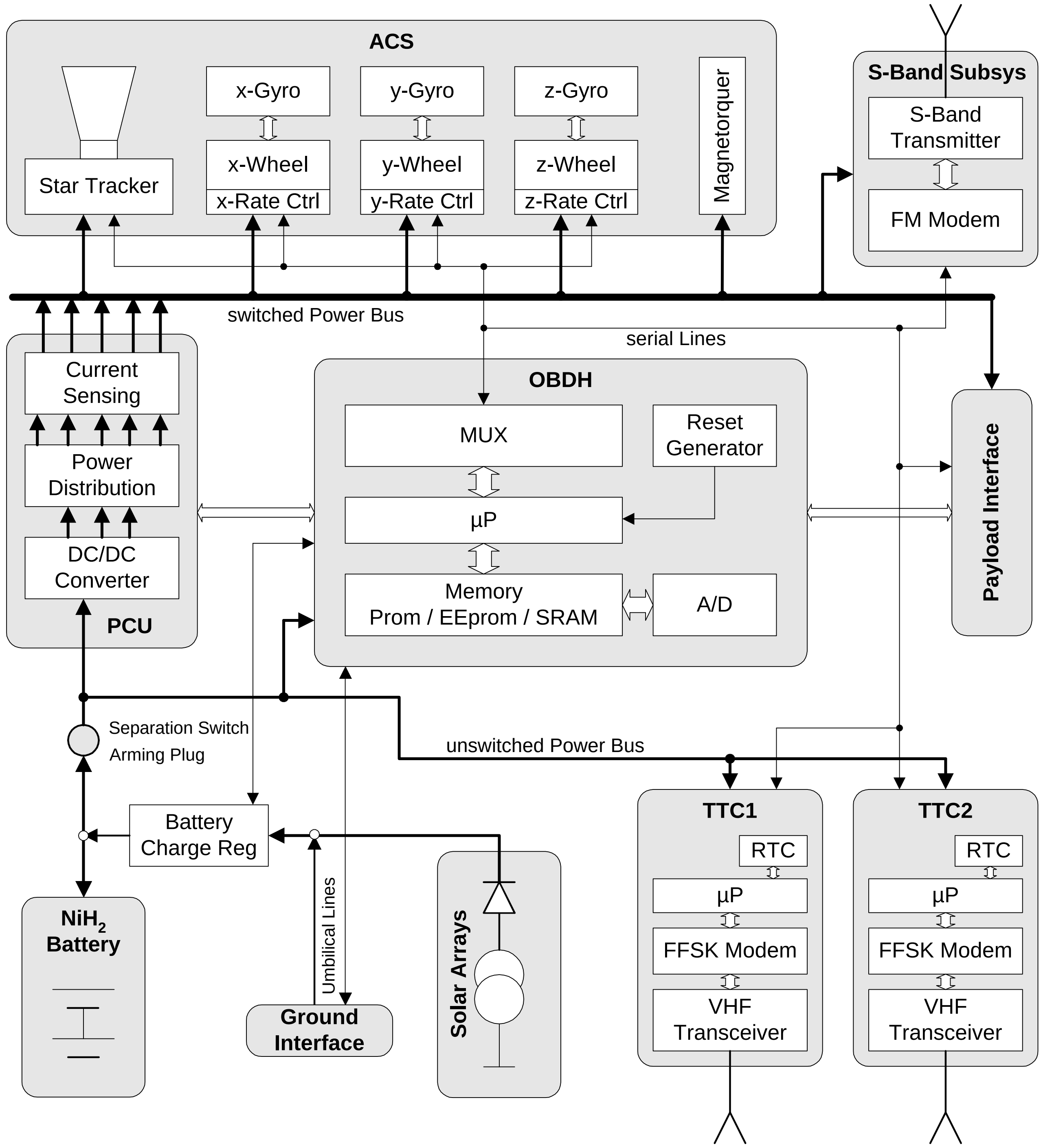

Fig. 1: Block Diagram of the TUBSAT-C Bus Design

2.1 - Structure

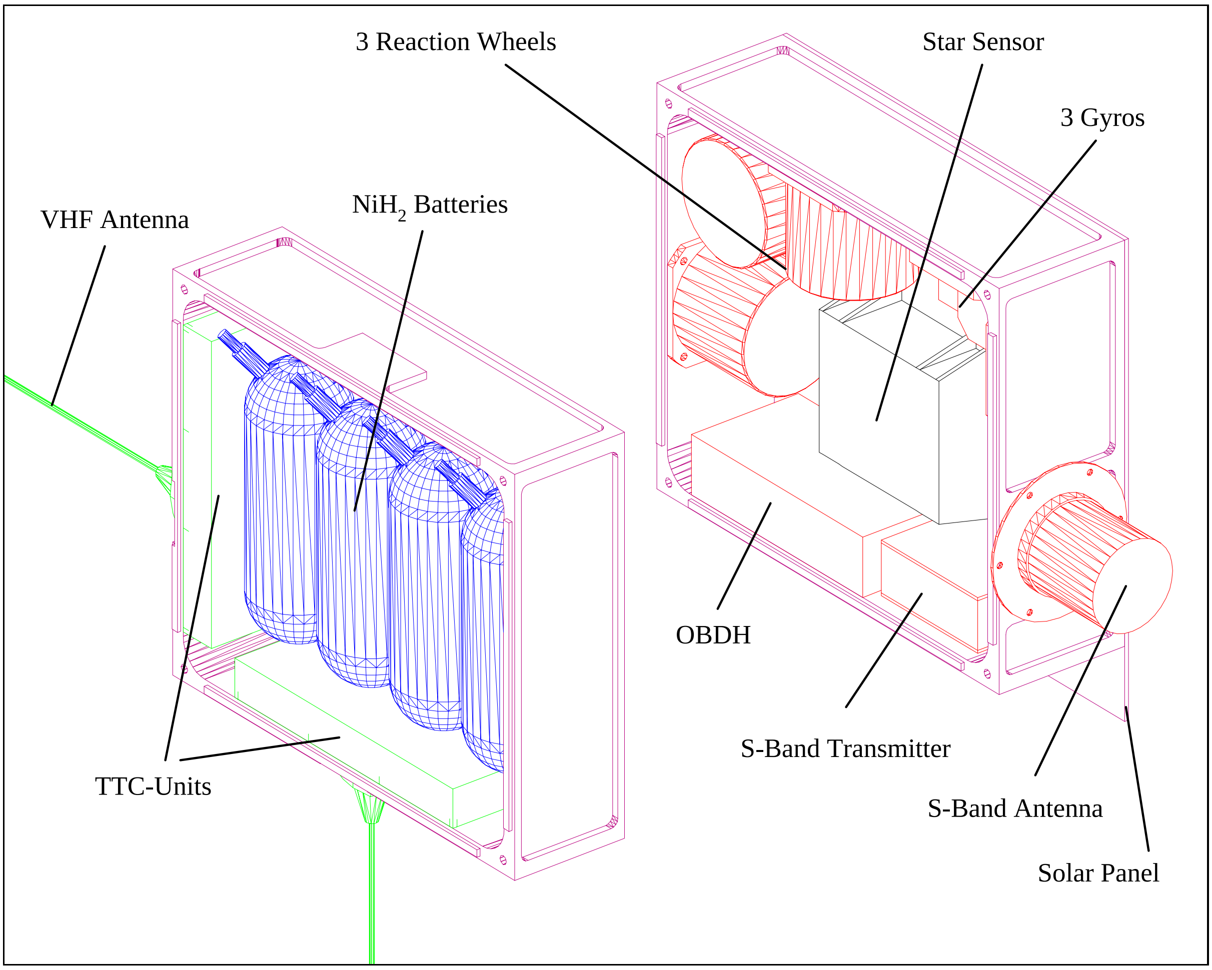

Fig. 2: Mechanical Structure and Assembly of the TUBSAT-C Bus

The TUBSAT-C bus (Figure 1,2) consists of two modular compartments. Each is manufactured of an aluminum block in the form of a box open on one side. All available modules have surface measurements of 320mm x 270mm. The modular design allows a functional division among the various subsystems of the satellite, so that each module can be developed, built, and tested separately. The flexibility thus achieved is highly advantageous for adapting the bus to various payloads or missions. The main compartment contains the entire Attitude Control System (ACS), On-Board Data Handling (OBDH) unit, S-band system, and Power Conditioning Unit (PCU). The battery compartment contains four NiH_2 cells, Telemetry Tracking and Command (TTC) units, and various housekeeping units. The net mass of these two modules is 3.2 kilograms. The first natural frequency of the mounted system is about 250 Hz.

2.2 - Electrical Power Subsystem

The power supply for the TUBSAT-C bus consists of three component groups:

- Batteries
- Solar panels
- Power conditioning and switching unit

The battery block contains four RNCH-12-3 NiH_2 cells, each with a nominal voltage of 2.5V and a capacity of 12 Ah. These cells were developed by Eagle-Picher specifically for aerospace applications. NiH_2 technology has the advantage of allowing a high number of possible charge-discharge cycles. This substantially lengthens battery life, especially in low earth orbit (LEO). Only negligible degradation has been observed in a variety of tests, even after 10,000 cycles (about 2 years in orbit) at a discharge depth of 40%. [1] An additional advantage of NiH_2 technology is that it is not particularly liable to overcharging. For this reason, the most recent bus concept foresees no need for redundancy in the battery charge regulation, and instead connects one solar panel directly to the batteries (Autonomous Trickle Charging).
The solar panels were assembled by DASA on a carbon fiber composite base. Each consists of one row of 34 high-efficiency Sharp BSR silicon cells (17%). Each panel supplies a maximum output power of about 12 W.
The charge regulator constantly monitors all current battery charge levels and provides protection against overcharge or deep discharge, especially in cases where low battery level is detected and all nonessential loads must be switched off.
The DC-DC converter and the power distribution device are located inside the Power Conditioning Unit (PCU). It can switch 8 different loads simultaneously, while constantly monitoring current levels and providing protection against short-circuit.

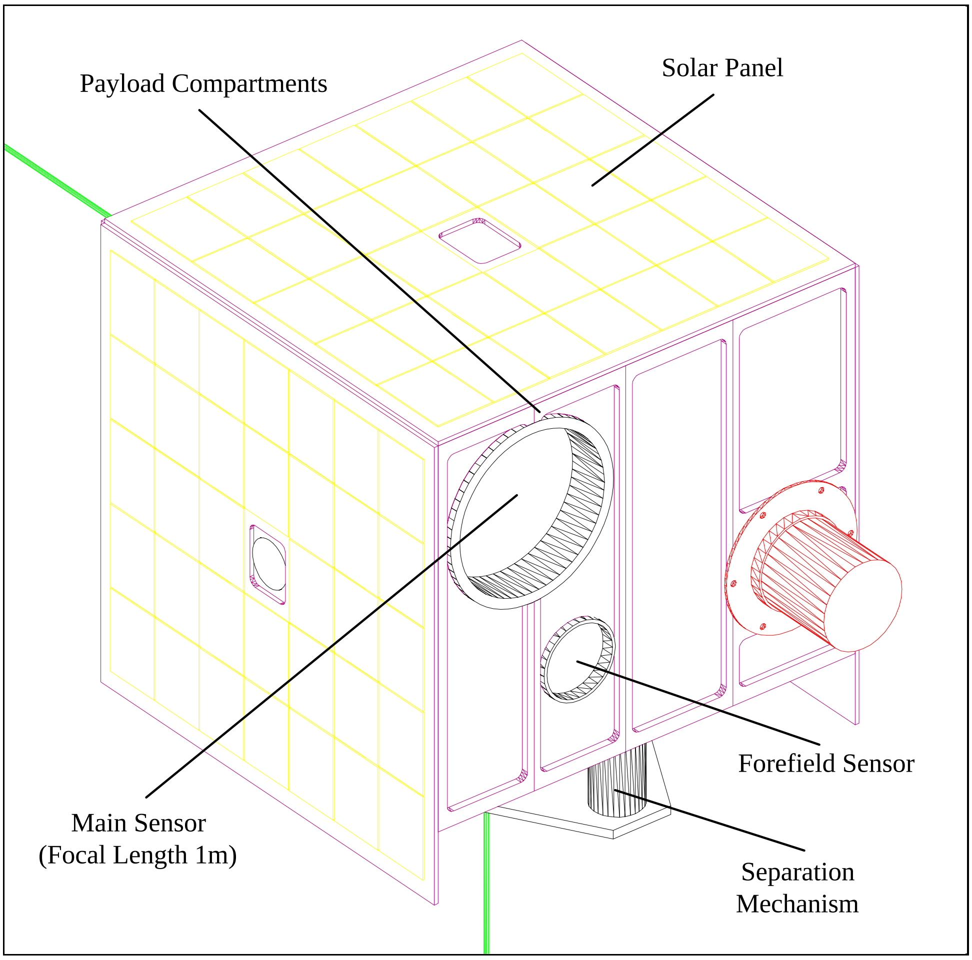

Fig. 3: The TUBSAT-C Bus used in the DLR-TUBSAT Project

2.3 - Thermal Control

Passive thermal control is more than adequate for the TUBSAT-C bus, since most of the time the satellite is on standby attitude control, in a kind of barbecue mode. During the relatively brief operating times when the payload is reoriented to the earth, sufficient thermal control is achieved just by the satellite's excellent internal heat conduction.

2.4 - Telemetry Tracking and Command Subsystem (TTC)

The two redundant TTC Units, located inside the battery compartment, are connected to the OBDH via interrupt-controlled serial links. Both units are always in active mode, powered via a constant, unswitched power line with short-circuit protection.

Upon receipt of the standard telemetry request command from the ground station, 32 different telemetry channels are sampled, including temperature, voltage, current, etc. The results are transmitted back directly as a standard telemetry report. This telemetry sample routine is also carried out automatically at regular intervals, and stores the housekeeping data in a ring buffer inside the OBDH system as whole orbit data. In addition, on-board memory can be employed as part of store-and-forward communication. This is especially useful when replacing or supplementing TUBSAT-A in running projects (deer tracking, polar research, etc.) Access to TTC is codeworded and protected by CRC, and includes user priority handling. All successfully received commands are stored in the on-board command history log.

As a rule, the accuracy of the public domain NORAD data, until now normally used for tracking TUBSAT-A and B, is no longer adequate for missions requiring high image-resolution. The TTC therefore employs a simple but efficient method to complement NORAD data. Sunrise and sunset times are recorded with high accuracy using the status of the solar cells. The information is incorporated in the on-board orbit model through numerical filters. This allows the calculation of the true anomaly with accuracy's of up to 0.06° (TUBSAT-A, B).

Frequency	VHF
Antenna	Monopole
Output Power	2-5W
Modulation	FFSK FM
Baudrate RF	1200-4800 Baud
Mass	0.8 kg
Dimension	204 x 75 x 26 mm
Interface	serial TTL / RS422

Table 1: Summary of the TTC Unit

2.5 - S-Band Subsystem

Image information is conveyed from the payload camera to the ground station via the S-band subsystem. The S-band transmitter is designed such as to allow both digital and analogue transmission. In case of an interactive steering of the satellite by the ground station, the spacecraft controller uses information presented via graphic interface to control satellite position and rotation using a trackball-joystick combination. An on-board image compression algorithm reduces

required graphic information to achieve an image repetition frequency of about 1 Hz. All other data (telemetry, star sensor data, etc.) can also be sent over S-band, controlled by the OBDH.
A modified transmitter with BPSK modulation and a baud rate of 256 kBaud has been chosen for use in the satellite built in cooperation with CRTS Morocco.

Frequency	2200 MHz
Antenna	Hemi (4dB)
Output Power	2-5W
Modulation	FM
Baudrate	128 kBaud
Mass	0.6 kg
Dimension	100 x 70 x 40 mm

Table 2 Summary of the S-Band System

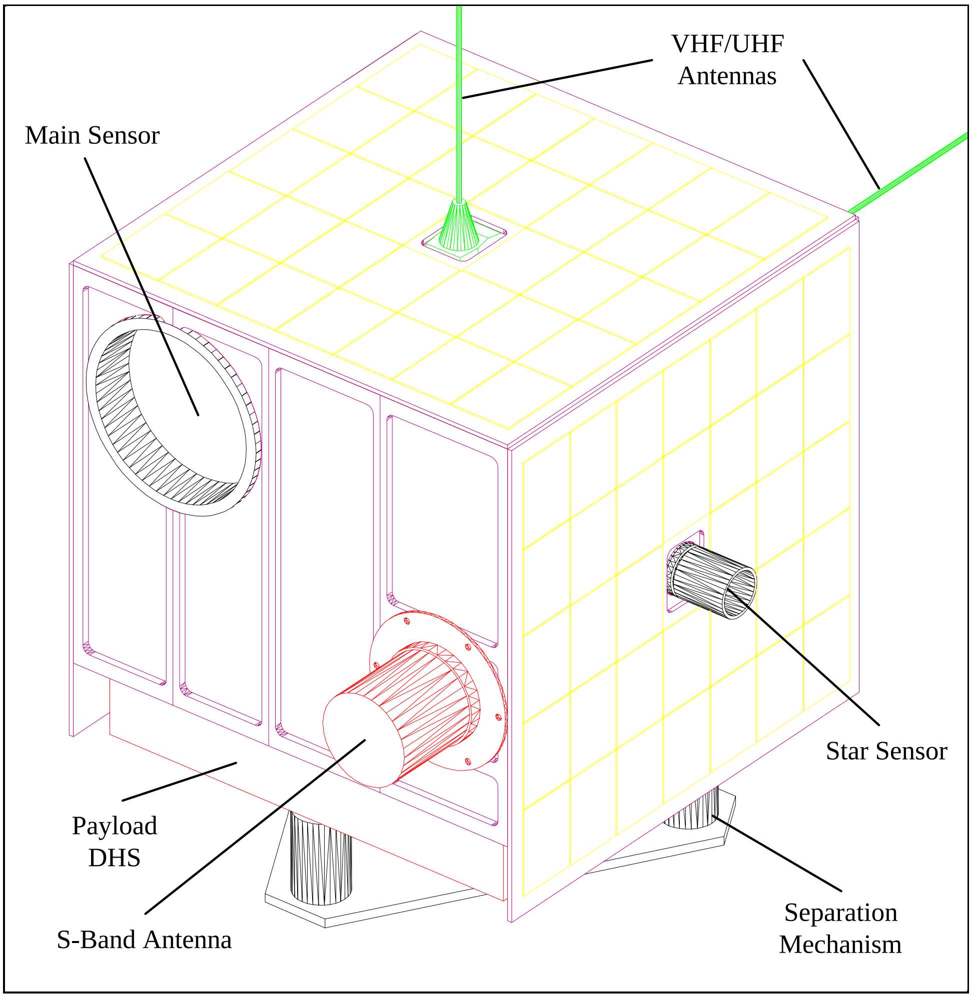

Fig. 4: The TUBSAT-C Bus used in the Morocco-Sat Project

2.6 - On-Board Data Handling System (OBDH)

The OBDH system is the brain of the satellite. The OBDH monitors and controls all important procedures and components, including the Attitude Control Unit, Power Conditioning Unit, S-Band subsystem and payload. Ground station commands received by the TTC units are decoded and executed within the OBDH Command Interpreter. The electronic design is based upon the 16-bit, 16 Mhz, single-chip microcontroller from Hitachi, already used in TUBSAT-A and B. Despite the broad variety of tasks, the amount of memory employed was kept relatively low through effective programming:

Memory	Size (kB)	Function
PROM	64	operation system, default cmd. interpreter, basic attitude ctrl. loops
EEPROM	128	enhanced and rebootable functions (code)
SRAM	128	telemetry, log, attitude ctrl. schedule, store and forward etc.

Table 3 Memory Map of the OBDH System

All of the memory employed is radiation hardened and protected against SEU's (single-event upsets).

Most of the subsystems are connected via an interrupt-controlled serial link in RS422 or TTL standard.

2.7 - Attitude Determination and Control System

The ACS consists of four different components:

- Star sensor
- 3 Reaction wheels
- 3 Optical gyros
- Magnetorquer

The star sensor model, KM 1301, is an electro-optical device designed to collect and process star tracking and attitude determination data. It was developed by the Technical University of Berlin using the flight experience of TUBSAT-A and B, and manufactured by Kayser-Threde.

The core element of the star sensor is a radiation tolerant 288 x 384 CCD matrix (Thomson), which translates star images detected through the lens into electronic information. After correcting temperature-dependent dark current, the analogue signal is converted into digital data and acquired by a microcontroller. The same microcontroller handles sensor timing, for example exposure and conversion times and interfaces with the star-recognition electronics. A second microcontroller, built into the star- recognition electronics, handles a carefully selected star catalogue and a special pattern-recognition database. In the inertial mode, the star sensor provides 3-axis attitude information in form of Euler-Angles, Quaternions or Transformation Matrix. This informations can also be calculated as an 3-axis attitude difference between a reference and an actual star pattern. The default update period is 250ms and the first inertial acquisition is performed within approximately 0.3 seconds. A medium accuracy of ± 0.02° with a focal length of 16 mm is sufficient for the current mission requirements.

dimensions	112 x 95 x 45 mm
mass	0.55 kg
power consumption	4.2 W
input voltage	12 to 15 VDC
pixel size	23 x 23 µm
number of pixel	288 x 384
focal length	16 mm
field of view	21° x 31° (f=16 mm)
update period	250 ms
star acquisition time	0.3 s (first acquisition)
accuracy	± 0.02° (f=16 mm)
interface	serial RS422/485

Table 4: Summary of the Star Sensor KM 1301

The three fibre-optical gyros are used to control the rotation rate around each of the satellite's axis. The loop itself (PI-Type) is closed inside every gyro-wheel couple separately and receives its target value from the OBDH System. There is the possibility to choose between two types of gyros, depending on the occasional mission requirements. The technical data are listed below (Table 5,6).

bias drift	< 6°/h
noise	$< 1°/\sqrt{h}$
measuring range	± 1000 °/s
scale factor error	< 0.3 %
dimensions	100 x 65 x 20mm
mass	0.15 kg
power consumption	< 2 W at 5 VDC
interface	RS422

Table 5: Summary LITEF Gyro

bias drift	< 1.5°/h
noise	$< 0.3°/\sqrt{h}$
measuring range	± 200 °/s
scale factor error	< 0.08 %
dimensions	110 x 85 x 70mm
mass	0.68 kg
power consumption	3 W at 5, ±15 VDC
interface	TTL / RS422

Table 6: Summary TELDIX Gyro

The design of the reaction wheels, developed by the Technical University of Berlin and manufactured by IRE, is especially suited to the requirements of mircosatellites.

Three different operation modes are available:

- Speed control mode (a user commanded speed is kept with an accuracy of ± 1°/s).
- Current control mode (the wheel is running with a user commanded current).
- Torque control mode (a user commanded net torque is kept with an accuracy of ±0.02 mNm).

The magnetorquer is used to desaturate the reaction wheels and to keep a reasonable angular momentum, in particular to ensure a slow rotation (barbecue mode) in the times when the ACS is switched off.

max. angular momentum	0.25 Nms at 12 VDC
max. speed	5700 rpm at 12 VDC
max. torque	28 mNm
speed accuracy	± 1°/s
dimensions	80 x 80 x 70 mm
mass	0.9 kg
power consumption	1 W (steady state)
interface	TTL / RS422

Table 7: Summary Reaction Wheels (IRE)

3 - TYPICAL (PRE)-MISSION PROCEDURE

A very important aspect of the mission scenario is a kind of hibernation mode in which the spacecraft spends most of the time. In that mode, there is no need for observing or controlling vital functions via the ground station.
The following general start-up and acquisition sequence describes the steps involved in switching the satellite from hibernation mode (ACS off) into an operations mode for recording specific areas of the earth's surface by the payload camera:

1. At a preprogrammed time, typically a few minutes before the crossing, the OBDH system switches all attitude control systems on, and starts reducing satellite rotation by means of a rate damping process. With the 3 gyros as body fixed rotation sensors, the closed loop is conveying the current angular momentum of the spacecraft onto the three reaction wheels. The residual motion amounts to less than 0.01°/sec.

2. If the star sensor is now blinded by the earth or the sun, a slew maneuver will be performed to align the sensor to stars by using informations gathered from both the internal orbit model and the solar cells. The star sensor now determines the current position of the satellite in the inertial system, making this information available to the OBDH in form of Euler Angles or Quaternions.

3. The OBDH proceeds to carry out a comparison of current position with the preprogrammed intended values, in order to determine optimal parameters for the minimum three different slew maneuvers (controlled by the gyros). In order to minimize inaccuracies arising through axis coupling, the system uses every opportunity to update inertial system positioning through repeated star sensor recordings.

4. After carrying out the slew maneuvers, the predefined position is reached by closing the attitude control loop with the star sensor along all three axes. Pointing accuracy in this mode is better than ± 0.03° and limited by the star sensors performance (mainly the focal length).

5. The position thus achieved serves as an optimal starting point for the subsequent observation mission, whether or not automatic target pursuit is now employed, or an interactively determined profile is instead commanded from the ground station.

One means of determining potential pointing accuracy is to direct the payload camera (focal length 1m) at a star. By using an observer model including the current angular momentum and disturbance torque, a pointing accuracy of a few arcsec can be achieved on two axes.

REFERENCES:

[1] D. Coates, W. Cook, S. Wecker, C. Fox : “Small Diameter CPV Nickel-Hydrogen Batteries for Small Satellite Applications“, *International Symposium on Small Satellites Systems and Services*, Biarritz, France, July 1994

[2] Sven Grahn, Anna Rathsman: “An Attempt to make Microsatellite a useful tool for Space Science“, *9th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, September 1995

[3] Sungheon Kim, Sungdong Park, Dan Keun Sung, Soon Dal Choi: “Mission Overview of Engineering Test Satellite, KITSAT-3“, *9th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, September 1995

[4] U. Renner, B. Lübke-Ossenbeck, P. Butz: “TUBSAT-A,B,C“, *International Symposium on Small Satellites Systems and Services*, Biarritz, France, July 1994