TUBSAT, Low Cost Access to Space Technology

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Abstract

TUBSAT is a low cost platform for space technology experiments. Although its size is modest (micro-satellite class), it provides remarkable volume and space to the experiment. TUBSAT-A has been launched already and is not attitude controlled. TUBSAT-B and consecutive models will be provided with high accuracy (arc sec) attitude control to any desired direction via star sensor plus 3 reaction wheels. The launch of TUBSAT-B is presently scheduled for October 1993.

1. Introduction

TUBSAT (Technical University of Berlin Satellite) provides a low cost test facility for space technology experiments.

The low cost target has been achieved by:

- Reduction of launch costs (secondary payload)
- Straightforward and transparent design
- Small but very efficient team.

Low cost has not been achieved by sacrifing performance. The ingredients are first choice: solar cells (Hughes Spectrolab), batteries (SAFT, Eagle Picher), reaction wheels (Teldix), star sensors (cooperation with Kayser-Threde), transceivers (Yaesu). These modules can be re-arranged on a case by case basis to provide maximum service to the experiment and to maintain the overall envelope within acceptable limits.

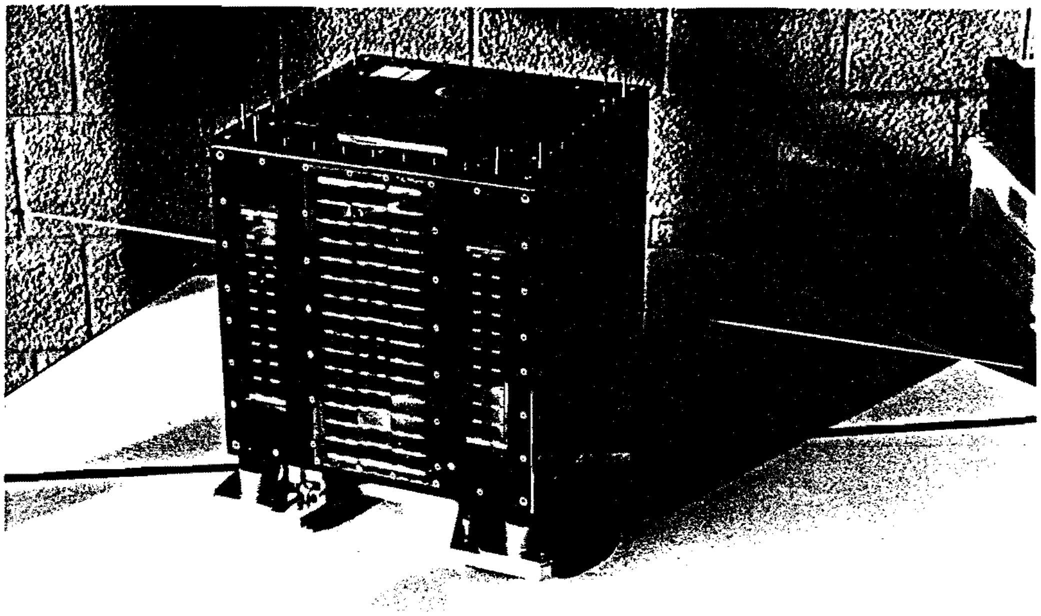

Fig.1. TUBSAT-A

2. TUBSAT - A

The first experimental platform, TUBSAT-A, was launched on 17 Juli 1991 as a secondary payload on Ariane 4 together with ERS-1 as the main passenger and three other micro-satellites. A cube of 38 x 38 x 38 cm (Fig. 1) weighing 35 kg contains a GaAs solar cell experiment (FIAR, ESA) on its front panel, an L-Band planar antenna experiment (Panatec) on its upper surface, a transputer experiment (Kayser-Threde) inside the spacecraft and as shown in Fig. 2, the star sensor experiment of the University. A rather challenging experiment on the ground together with the spacecraft was the development of an ultra-mobile ground station (Fig. 3) to remotely operate the spacecraft and to transmit and receive short messages. The handheld ground station can be connected to a pocket calculator via serial interface (Fig. 3) for more comfort, but if mass and size ist ectremely important, the unit is self contained.

Fig. 3. Ultra Mobile Ground Station

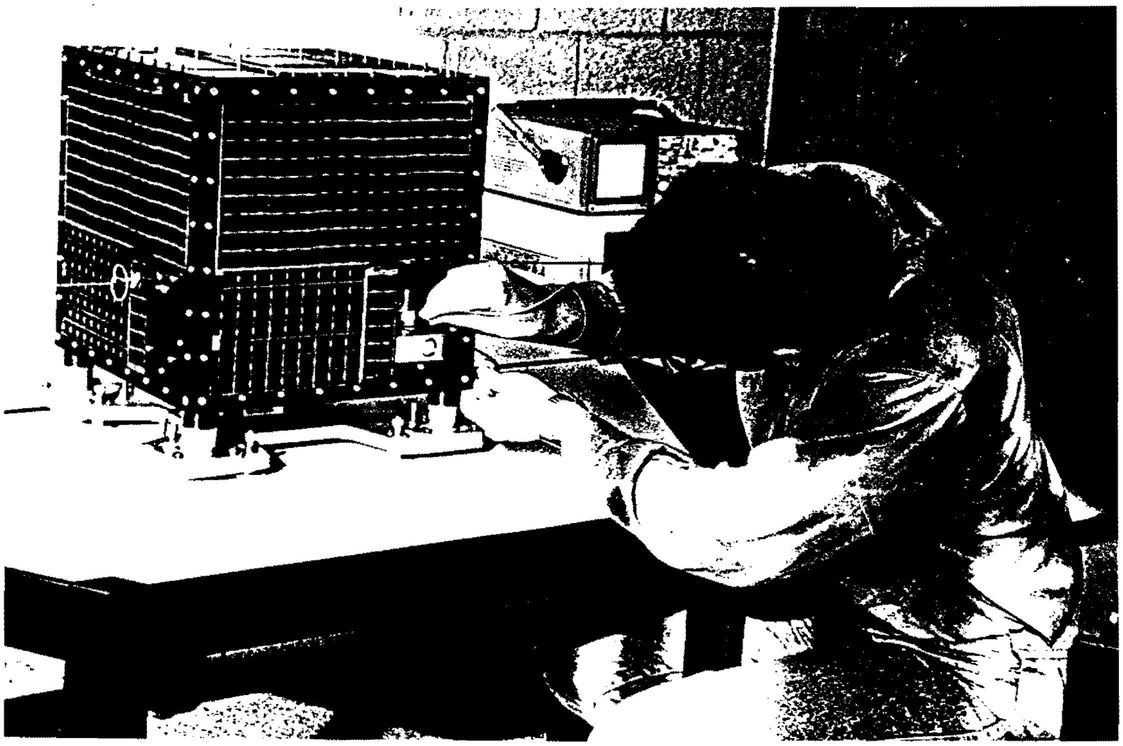

Fig. 2. Final Assembly of TUBSAT-A

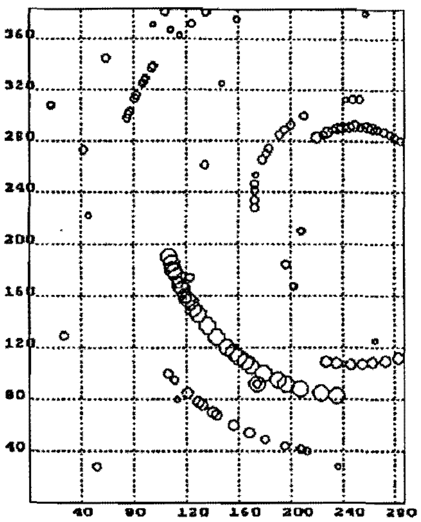

Fig. 4. Raw Data

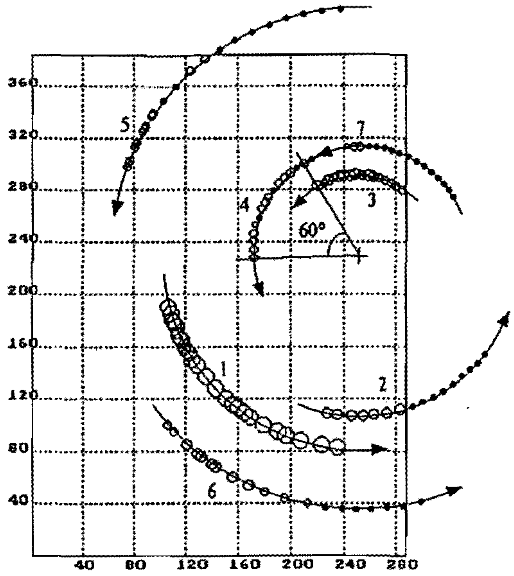

Fig. 5. Data Reconstitution

The attitude of TUBSAT-A ist not controlled but very precisely reconstituded via a 3 axis-magnetometer and mainly the star sensor. Figure 4 shows a typical sequence of 16 superimposed star pictures at 0.5 sec intervals. This "raw material" containes a few single spots (i.e. sensor noise) and missing star pictures. The star sensor processor eliminates the noise, interpolates the missing stars (Fig. 5) and identifies - in this case - seven different star tracks. Since two are sufficient for 3 axis information, the processor selects the best pair (Fig. 6), according to a number of criteria like brightness, sufficient distance from each other and sufficient distance to the picture frame.

The processor is now able to reconstitute:

- the centre of rotation
- the rate of rotation
- the displacement angles α, β, γ,

i.e. to provide the same information as a gyro package of 3 rate gyros plus 3 rate integrating gyros. As a last step, the absolute attitude can also be established as long as the stars can be identified (Fig. 7).

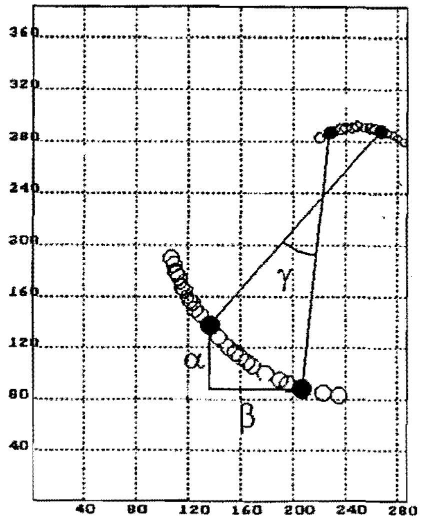

Fig. 6. Relative Attitude

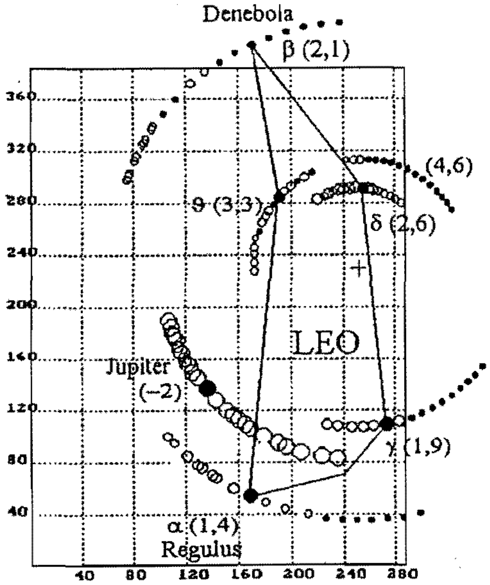

Fig. 7. Absolute Attitude

The precision of attitude reconstitution depends on the pixel resolution. The star sensor of TUBSAT-A provides a field of view of 20 x 30° and a CCD matrix of 288 x 384 pixels, so that a resolution of 0.1° can be achieved. The experiment was very valuable for TUBSAT-B because a) the star sensor could be qualified and calibrated, b) the dynamic behaviour of the spacecraft could be analysed and c) the disturbance torque environment could be established, so that the appropriate size of the reaction wheels for TUBSAT-B could be identified.

3. In-Orbit Experience with TUBSAT-A

After more than 2 years of operation, TUBSAT-A is still operating without any sign of degradation with the only exception that the NiCd battery (SAFT) has lost approximately half of its capacity. This was to be expected due to the high number of duty cycles in low earth orbit. Nevertheless, since this seems to be the main life limiting factor, for TUBSAT-B a more advanced technology has been selected, i.e. NiH_2 battery cells (Eagle Picher).

In a number of areas degradation was expected but did not occur, in particular neither the solar cells nor the CCD-chip of the star sensor nor the highly integrated single chip processor (Hitachi H8) suffered from any degradation. Single event upsets were not observed, probably because the software is mainly contained in the ROM rather than the RAM area of the processor.

Since TUBSAT-A is not attitude controlled, only minor experiments were on board. In fact, after all, TUBSAT-A is almost empty. More challenging experiments like telescopes, propulsion units, spot beam or laser transceivers, micro-g experiments or inflatable structures (e.g. antenna reflectors) require attitude control to various targets (not always the earth) with in general rather high accuracy requirements in the arc min or even arc sec area.

4. TUBSAT-B

TUBSAT-B will be launched by late October 1993 as a secondary payload from a Russian Meteor-3 satellite into a near polar orbit of 82° inclination and 1200 km altitude. The satellite provides the same base plate dimensions as TUBSAT-A (38 x 38 cm) but is slightly higher (50 cm instead of 38) and heavier (40 kg instead of 35). As shown in Fig. 8, 4 faces of the satellite are covered with solar cells, the lower platform interfaces with the ejection mechanism and contains the antennae ($\lambda/4$ dipole for 143.075 MHz transmission), and the upper panel provides visibility for the sun sensor (right), the narrow angle star sensor (middle) and the wide angle star sensor (left).

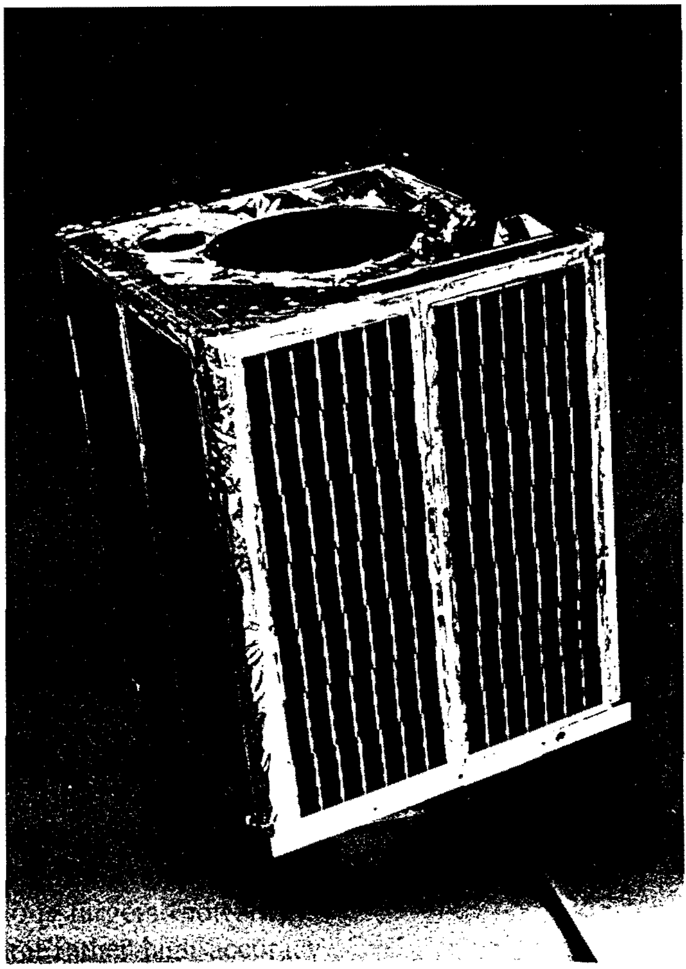

Fig. 8. TUBSAT-B

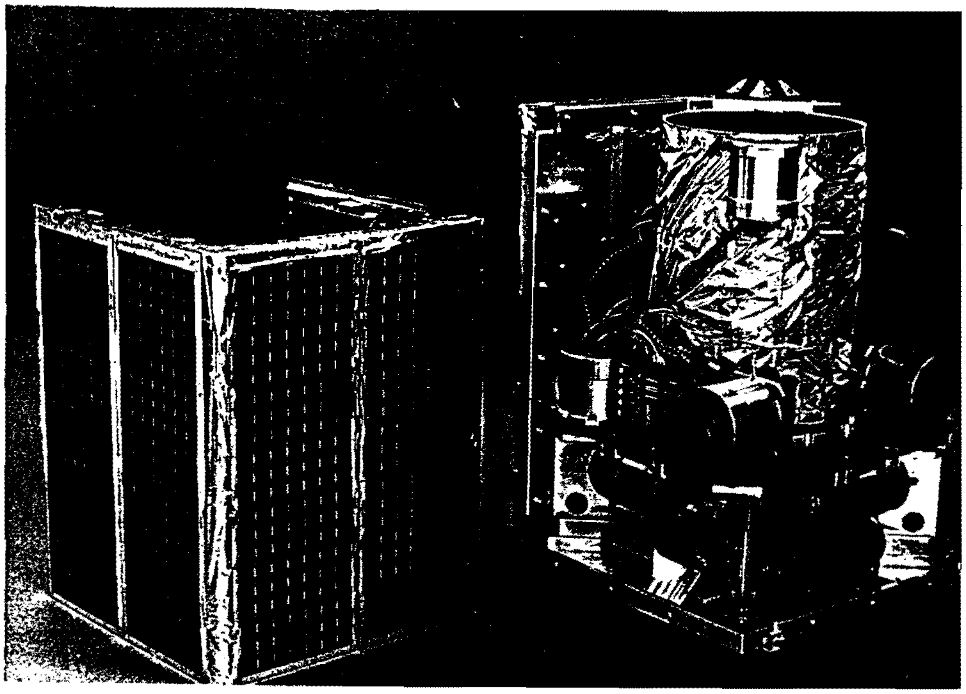

Fig. 9. TUBSAT-B, Exploded View

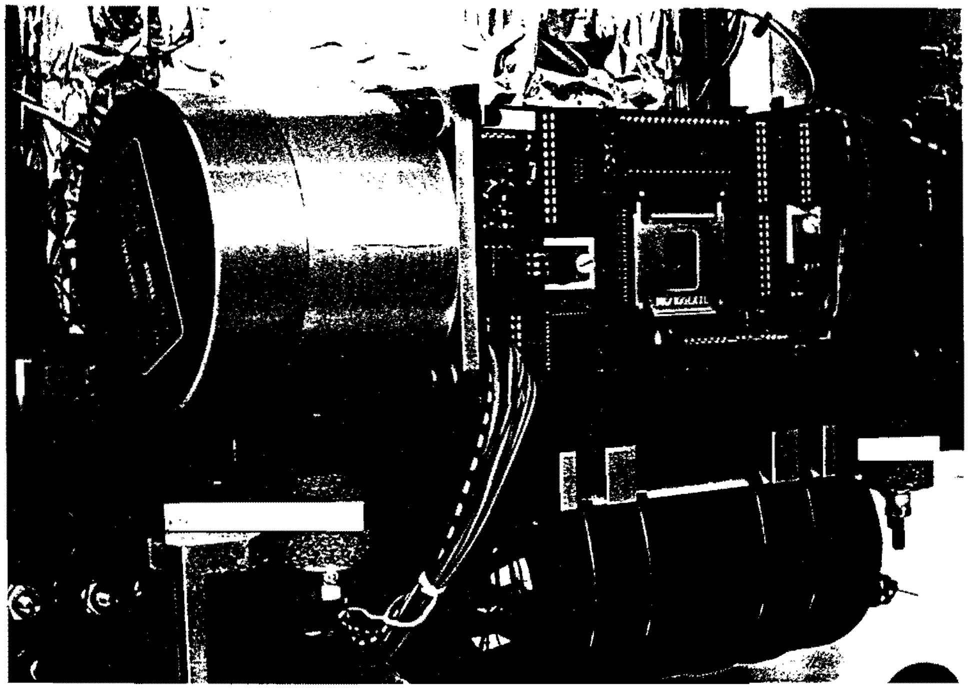

Fig. 10. Interior of TUBSAT-B

Figure 9 shows that TUBSAT-B is 3 axis controlled by 3 reaction wheels in combination with the attitude sensors discussed before. Battery power is provided by 4 NiH_2 battery cells, 3 of them are visible on this picture. One of the two transceivers is also visible at the base plate together with (part of) its antenna.

Figure 10 focusses into the most advanced technology area. The battery cell RNHC-6-1 (Eagle Picher) in dual stack assembly configuration provides a nominal voltage of 2.5 V. The cylindrical vessel is 17.15 cm long and 6.48 cm in diameter with a mass of 0.633 kg. The rated capacity is 6 Ah. The main advantage in comparison with NiCd technology is the far higher duty cycle capacity.

The reaction / momentum wheels (Teldix) are 7 cm long and 8 cm in diameter with a mass of 1 kg. They can be accelerated and decelerated with a reaction torque of up to 60 mNm and reach their nominal angular momentum of 0.1 Nms within seconds. The power consumption in steady state operation at 0.1 Nms and 10 V power supply is less than 1 W. They contain brushless DC motors and ball bearing suspension. The housing is hermetically sealed to maintain the inside pressure of 1 bar.

Also included in the housing is the commutation electronics, the wheel drive electronics and the wheel speed control loop that maintains any commanded speed with an accuracy of better than 0.01 percent.

The printed circuit board belongs to the star sensor that can be operated either as a full picture camera or as a star tracker. The same CCD chip as on TUBSAT-A at the rear end of the wide angle and the narrow angle telescope (not visible in this picture) stores a full picture of 288 x 384 pixels within the 128 K byte memory of the sensor electronics (top middle of the PCB in Fig. 9). The processor (middle of the PCB) is able to transmit the full picture with a baud rate of 2400 b/s within 15 minutes to the ground or to transmit the position and brightness of the six brightest objects (compare with Fig. 4) together with the calculated attitude angles (compare with Fig. 6) every 250 ms, so that the dynamic behaviour of the spacecraft can be monitored on the ground almost in real time.

Potential areas of research are:

- attitude control manoeuvers via ground interference
- attitude control via (bootable) on-board algorithms
- close loop control with star targets
- close loop control with light sources on the earth
- fast transmission of full pictures using data reduction and higher baud rates.

Pictures on the earth are scheduled during eclipse periods where targets on the earth look similar to stars. Moonlight scenes may be possible if everything works well. The pixel resolution φ of the narrow beam camera with the focal length f = 1000 mm and the pixel size s = 0.023 mm is:

$$\varphi = \frac{s}{f} = 0{,}023 mrad = 0{,}0013° = 5\ arcsec$$

In the star sensor mode this accuracy can be further increased by interpolation between pixels so that the pointing accuracy of the various control loops can be verified with an accuracy of 1 or 2 arc sec. In the camera mode, one pixel corresponds to an area A on the ground at a distance d = 1200 km:

$$A = \frac{s}{f} \cdot d = 27{,}6\ \text{m}$$

This should be sufficient to identify isolated light sources, illuminated streets, coast lines etc.

Also visible in Fig. 10 are the shock mounts in front and behind the battery cell. They isolate the vibration sensitive telescopes and momentum wheels from the baseplate.

The sun sensor (Fig. 11) consists of a pyramid configuration of solar cells. One sensor element is mounted on the top face (see Fig. 8), a

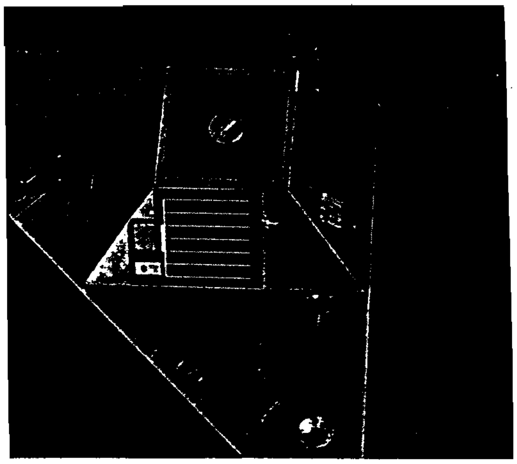

Fig. 11. Sun Sensor

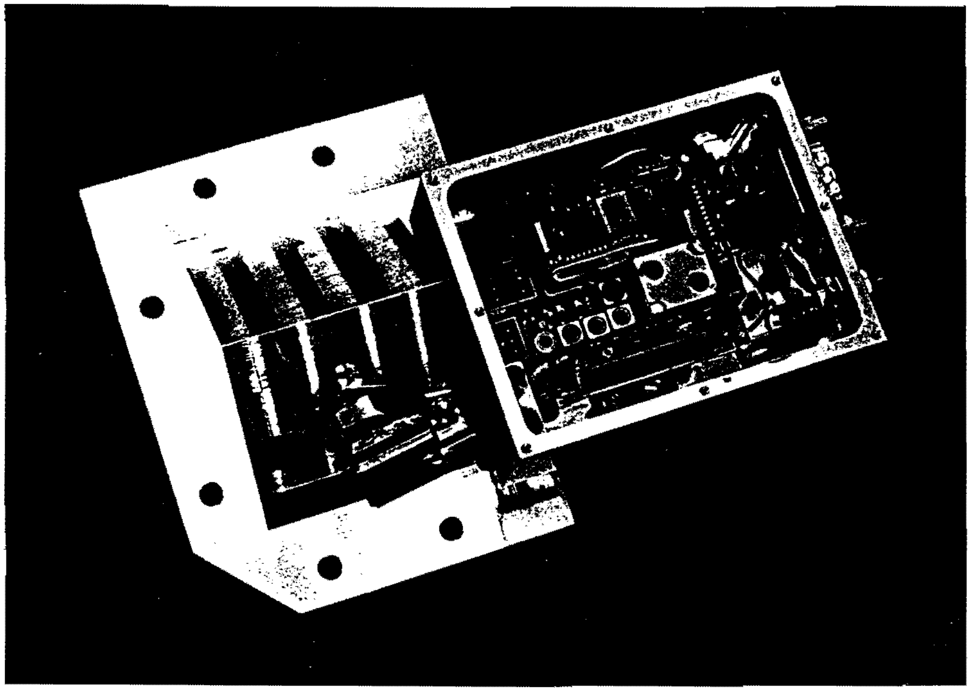

Fig. 12. Receiver / Transmitter

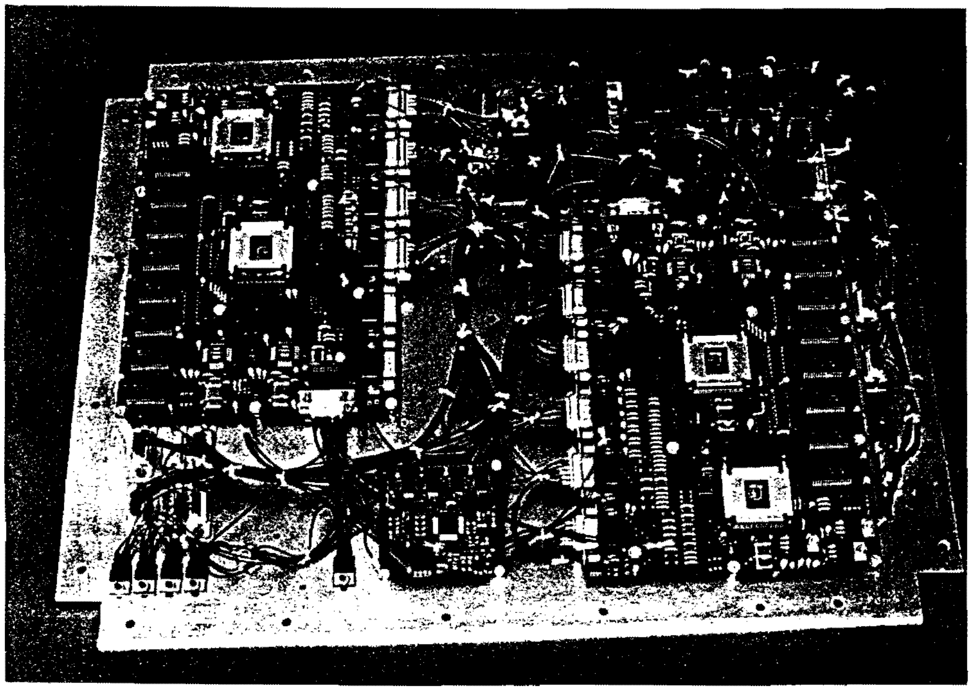

Fig. 13. Data Handling Electronics

second unit on the bottom face, so that full visibility is guarantee. A tiny hole next to each cell permits sun and albedo light from the earth to penetrate into the interior of the sensor, where a photo diode will be illuminated by the omnidirectional albedo light but (with high probability) not by the highly directed sun light. The sun sensor data are disabled whenever albedo light is detected.

Fig. 12 shows the receiver/transmitter including its 5 W power amplifier and the antenna interface. This unit is already space qualified on TUBSAT-A. Telemetry data are FFSK/FM modulated and transmitted to the ground at 143.075 MHz with a baud rate up to 2400 b/s. The data handling electronics (Fig. 13) is attached to one of the spacecraft outer panels in order to save space for the bulky equipment inside the spacecraft. 4 processors (Hitachi H8) operate together supported by 4 Mbyte of RAM capacity. The small circuit board in front contains a sound storage device that, as on TUBSAT-A, is able to store and replay speeches, music etc. of up to 2 minutes duration.

5. Conclusion

The idea of the TUBSAT programme is to design, launch and qualify a universal technology test platform that can be tailored to various applications. The essential elements: momentum wheels, star and sun sensor, battery cells, transceivers and electronics cards are so modest in size and mass that they can be squeezed into the corners and at the same time used as balance masses. The interior of the spacecraft is reserved for the experiment(s).

The pointing direction and accuracy depends entirely on the experiment. Communication experiments at higher frequencies will require a reasonably accurate pointing of the main antenna to the ground station and may require in addition a rather accurate pointing of a second antenna to a cooperating satellite for inter-satellite communication. As soon as chains of satellites are under discussion, relative orbit control is required to maintain equal distances on the orbit. Propulsion units (at least cold gas) are then mandatory as well as attitude control, typically in flight direction.

Telescopes are typically used for earth observation but not necessarily always in nadir direction, in particular if earth horizon measurements are envisaged. Experiments with significant electrical power requirements, typically electric propulsion thrusters, are preferrably operated from a sun pointing bus where solar panels can be deployed into the sun direction. Micro-gravity experiments, including the deployment of inflatable structures, have no preference with respect to the pointing direction so that a sun pointing spacecraft would be convenient as well.

Gravity gradient stabilisation is well established and recommended for nadir pointing experiments. For more sophisticated tasks, attitude control by reaction/momentum wheels is the state of the art, but so far not within such a limited physical and finacial envelope as on TUBSAT-B.

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