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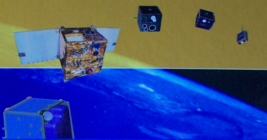

Small Satellites for Earth Observation

Selected Contributions

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BIRD Microsatellite Thermal Control System – 5 Years of Operation in Space

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Abstract Microsatellite BIRD (***B***ispectral ***I***nfra***R***ed ***D***etection) with mass 92 kg and overall sizes 0.55 × 0.61 × 0.62 m operates in a sun-synchronous orbit more than 5 years. The temperature range $-10\ldots+30^{\circ}\mathrm{C}$ for payload with average power about 35 W and peak power of 200 W in observation mode, continuing 10–20 min, is provided by passive thermal control system (TCS). Operation of TCS foresees a thermal stability of payload structure by use of heat transfer elements – conductors and grooved heat pipes, thermally jointing the satellites segments. Two radiators, multilayer insulation (MLI) and low-conductive stand-offs provide the required temperature level. Review of TCS performance is based on an analysis of daily telemetric data, collected by 33 temperature sensors and power consumption. The analysis includes the definition of minimal, maximal and averaged temperatures of satellite main units and comparison with designed parameters. TCS successfully supports the required temperature level of satellite components during the whole period of exploitation.

1 Introduction

The main features of BIRD (***B***ispectral ***I***nfra***R***ed ***D***etection), having launched on 22nd October 2001 by PSLV-C3 Indian rocket and operating till now (nominal operation time is 1 year) in the sun-synchronous 568 km orbit, are presented in [1],

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and the description of thermocontrol system and some summaries – in [2, 3]. This satellite is intended to demonstrate in space new compact infrared imaging sensor technologies and the approach to modular design of a microsatellite. The BIRD microsatellite is a cubic shaped, 3-axis stabilized microsatellite without a propulsion system. The mechanical structure (satellite bus) is designed as a three-boxes cubic main body, and consists of the service segment, the electronic segment and the payload platform (Fig. 1). The main body is covered with MLI except the instruments windows and 2 radiators. One fixed and two deployable solar panels as well as the reject mechanism are mounted to the body.

The payload is mounted to the special payload platform, which makes about 1/2 of the body volume and 1/3 of the total mass of the spacecraft. To keep the line of sights of the instruments very stable, the payload platform is connected deformation free with the lower satellite segments. The heat transfer from (or to) the payload platform to (from) the main radiator on the bottom side of the service segment in +Y – direction is realized by two heat pipes [4]. The heat removal from the IR instrumentation is realized to the separate IR – radiator, positioned in −Y direction. BIRD TCS is designed as a passive, when a heat rejected by radiators, through MLI and devices windows is compensated by inner heat generation. The temperature limits of major satellite units are typical for space components [3]. The solar panels generate about 40 W each and 8 NiH_2-cells can accumulate 240 W*h to supply up to 200 W in peak power during 20 min observation.

2 BIRD Thermal Regime in Flight

The temperature measurements are performed by 33 temperature sensors of the type AD590 (by Analog Devices, USA). The sensors have been spread over the satellite structure, payload instruments, housekeeping equipments and solar panels (see Fig. 1).

The temperature telemetry covers the most of satellite operation time (about 98%). Figure 2 illustrates the volume of a daily collected thermal telemetry (in DOS format) during 2001–2006 years, where daily averaged telemetry is 4.2 Mb. The typical period of temperature data gathering is 30 sec with the storage period of 24 hours (near 15 orbits). During the day the temperatures of satellite units have the evident periodic character similar to the radiator (see Fig. 3) that deals with non-uniform external condition for the main radiator along the orbit and tight thermal contact between radiator and other units, which are thermally connected by two heat pipes.

The on-orbit temperature variation for radiator is about 1–3.5°C, for payload platform less than 1°C. Sometimes the radiator has the rise of the temperature due to satellite manoeuvres as shown in Fig. 3 after 12:00. Solar panels, which have essentially less thermal mass, are directly illumined by sun flux, and therefore they have the widest range of temperature excursions. The central panel, which is cooled from one side, has the maximal temperature 75 . . . 90°C and minimal −20 . . . − 40°C in shadow (Fig. 3). The side panels −X and +X (two sides radiate) have

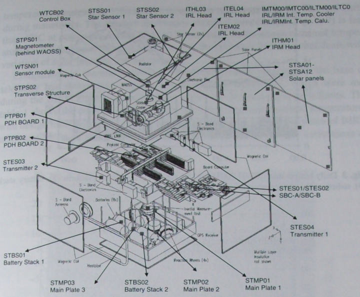


Fig. 1 Scheme of temperature sensors layout on satellite BIRD

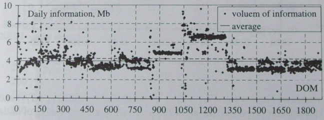


Fig. 2 Variation of daily downloaded thermal information

the maximum temperature 65 . . . 70°C and minimum −70°C and less. The period between maximums is about 96 min.

There is a certain interest to review the satellite temperature during the whole period of its exploitation, as every daily telemetry reflects events partly. Simple summarizing of each daily information will produce extremely large file, which is inconvenient in processing by commonly used software such as EXCEL. In order to reduce the volume of summarized file, having saved the most important features of thermal performance during each day, presenting by the values of temperature and

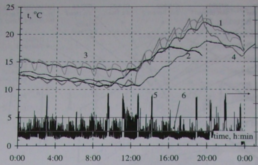


Fig. 3 Daily temperature (03.07.2003) for star sensors (1), payload platform (2), battery stacks (3), radiator (4) and consumed power (5 – instant, 6 – averaged)

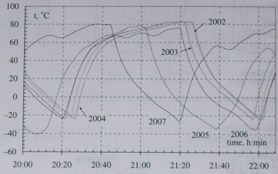


Fig. 4 Averaged temperature (for 4 sensors) of central panel for 01.01.2002–2007

power: maximal $T_{\max} = \max(T_{\tau 1} : T_{\tau 2})$, minimal $T_{\min} = \min(T_{\tau 1} : T_{\tau 2})$ and mean integral for the certain period, the algorithm of reading and processing of initial daily telemetry has been proposed. Figures 5–10 present the overview of most important temperatures for period till day of mission (DOM) 1897. Averaged daily power lays within the range of 40–50 W during DOM 1 . . . 846, reducing to 20 W for the period DOM 846 . . . 1037 and 30–35 W for 1040 . . . 1897. The radiator temperature is always within the planned limits −10 . . . +25°C, except DOM 1000 . . . 1037. The rise of the temperature within DOM 846 . . . 1037 deals with the loss of sun-pointed orientation due to the failures of 2 reaction wheels. After a new attitude control scheme was introduced (DOM 1037), the orientation on the Sun was recovered.

Satisfied main radiator temperature provides the temperature limits for other units, as it is the reference one for most of them. Variation of the radiator temperature is caused by changing of daily power consumption (variation in 1 W causes the temperature changing in 1°C) and by orientation with respect to the Sun and Earth during maneuvers. The level of electronics maximal temperature (Fig. 8, 9) is less than 40°C at power generation of 5–10 W per units. Solar arrays maximal temperature has evident oscillation of function with the period in 365 days that deals with variation of solar intensity during the year.

Comparison of thermal requirements with the results obtained on the base of telemetry has shown that minimal and maximal temperatures, which were met during the BIRD flight performance lay within the design temperature limits. The table 1 shows the correspondence of obtained maximal and minimal temperatures with design limits. An analysis of flight temperature data during five years of BIRD microsatellite exploitation (10. 2001–12. 2006 years) confirms the correctness of

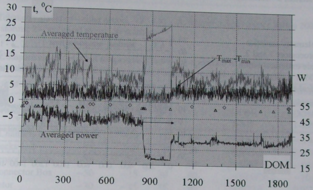


Fig. 5 Radiator averaged temperature its maximal temperature change during each day within 2001–2007 *1* – solar storms, *2* – technical events on satellite

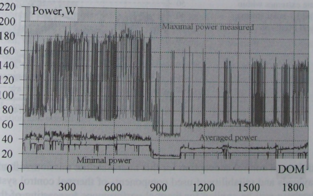


Fig. 6 Averaged per day, minimal and maximal consumed electrical power during 2001–2007

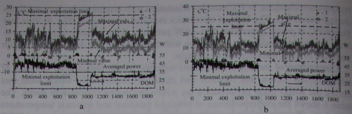


Fig. 7 Telemetry statistics – radiator and battery stacks temperature extremes within 2001–2006. Starting point – 22. 10. 2001, proceeded data – till 31.12.2006: **a** radiator; **b** battery stacks; 1 – solar storms, 2 – technical events on satellite

Fig. 8 Telemetry statistics – board processors 1 and 2, temperature extremes within 2001–2006: 1 – solar storms, 2 – technical events on satellite

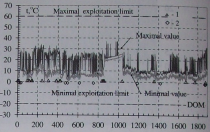
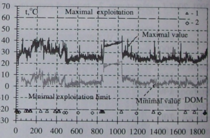


Fig. 9 Telemetry statistics – transmitters 1 and 2; temperature extremes within 2001–2006: 1 – solar storms, 2 – technical events on satellite



accepted thermal control conception for this microsatellite mission with multifunctional payloads and reliability of used components of thermal control system. Collected database will be applied for thermal performance forecasting of the similar equipment for future missions realized by microsatellites.

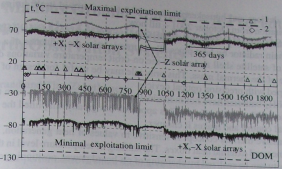


Fig. 10 Telemetry statistics – solar arrays, –Z, +X, –X, temperature extremes within 2001–2006: 1 – solar storms; 2 – technical events on satellite

Table 1 Comparison of designed temperature limits for operation of satellite units and obtained temperature variation during the BIRD microsatellite flight in 2001–2006

Description of unit	Q Low N op	HL	HH	Q. high N op	HL/HH obtained DOM 1-845	HL/HH obtained DOM 1-1897
IR Head, Channels M, L	−35	−15	15	50	−8,4/8,9	−8,4/8,9
Battery Stacks 1, 2	−15	−10	25	35	0,0/26,8	0,0/30,0
Control Sensor Module	−50	−15	30	60	−10,0/26,1	−10,0/ 26,1
Control Connector Box	−50	−15	30	60	−10,0/26,1	−10,0/26,1
Main radiator	−30	−15	35	60	0,0/22,8	0,0/27,2
Payload Platform	−30	−20	30	60	−2,7/18,8	−2,7/23,7
Star Sensors 1 and 2	−30	−25	30	60	−4,2/28,0	−4,2/28,0
Processors boards SBC_A and SBC_B	−30	−15	40	60	10,0/34,0	10,0/38,5
Processor Boards 1 and 2	−30	−20	60	60	1,0/33,8	0,0/37,1
S-B-Transmitters 1 and 2	−30	−20	60	60	−1,5/42,6	−1,5/44,8
Electronic Unit, IR Channel M, L	−50	−40	45	50	−1,4/40,2	−1,4/44,3
Solar Panel +X	−180	−120	100	130	−91,6/73,4	−94,7/ 75,1
Solar Panel −X	−180	−120	100	130	−96,0/70,9	−96,0/72,3
Solar Panel −Z	−180	−120	100	130	−69,5/ 88,7	−71,8/ 88,7

Remark: HL and HH – low and high design temperature limits, Q Low N op and Q High N op – qualification non-operational temperature limits

3 Conclusions

1. BIRD thermal conception, foreseeing the combination of active thermal control and deep cooling of IR sensors with the passive thermal control for all

other devices and housekeeping components, has proved itself during on-orbit exploitation from October 2001 – till now

2. Thermal unification of geometrically stable and thermal conductive payload plate and main radiator by heat pipes allows to minimize the influence of a displacement of satellite shell and reduce the on-orbit temperature variations due to increase of the thermal mass. This principle may be useful for design of satellites equipped with precision optical devices
3. The NiH_2 batteries have not individual cooling system and have been thermally attached to the main radiator. This approach has greatly simplified the design af thermal control and makes it cheaper
4. The passive thermal concept is sensitive to values of heat generation, MLI performance and external heat fluxes. The shifting of temperature level in the case of necessity can be realized by changing of on-board power, positioning of radiator with respect to the Earth and Sun.

Contacts

Authors are interested in exchanging of information in the field of small satellite thermal design/ modeling/ on-ground verification. The person for contact: Dr. Franz Lura, affiliation is presented at the beginning of the paper, http://www.dlr.de/Berlin

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