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SACI-1 - A COST-EFFECTIVE MICROSATELLITE BUS FOR MULTIPLE MISSION PAYLOADS

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ABSTRACT: In recent years, new generations of relatively small satellites, the so called microsatellites, are emerging in many domain applications and are employing new technological solutions. The outcome is a reliable, high performance and inexpensive design of space systems.

This paper underlines the key technological approaches adopted in SACI-1 - Scientific Applications Satellite currently under development at INPE. The SACI-1 is the first of a series of Low Earth Orbit microsatellites. The spacecraft shall be launched in October 1997 in a piggyback configuration having the CBERS satellite (China-Brazil Earth Resources Satellite) as a co-passenger in the Chinese Long-March IV launcher.

The payload of SACI-1 is composed of four scientific experiments namely: ORCAS, an investigation of the anomalous cosmic radiation fluxes; FOTSAT, an airglow photometer to measure the terrestrial airglow emissions; PLASMEX, a study of the plasma bubbles evolution and MAGNEX, a research of the geomagnetic field effect on charged particles.

The SACI-1 bus is composed of six subsystems: a modular structure, a power conditioning unit, a S-Band communications, an active attitude control, an on-board transputer-based parallel computer and a passive thermal control. The driving factors being adopted throughout the design phases of SACI-1 are: development of a versatile bus supporting multiple missions, cost reduction with recurrent mission, design time acceleration, mission simplification, decentralized development.

The ground segment will be covered by two receiving stations in Brazil and by users data collecting ground stations. A cost effective LAN PC-based solution will be employed for tracking and control. In addition, the scientific data dissemination and the on-board payload configuration will be implemented through the Internet in order to decentralize and facilitate the interfacing between the payload and its customers.

1.INTRODUCTION

Lets suppose that the car manufacturers were to use nowadays an advanced technology accomplished with the same evolution that occurred with the electronic components from the beginning of the space age until now. Their vehicle features and performance would be: the motor would fit on the period at the end of this sentence and it could carry you to the moon with just a liter of gasoline. This would occur because in the electronic world each one of the parameters as mass, volume and power consumption has been divided by a scale factor of 100.000 during the last 30 years. Unfortunately the hypothetical event mentioned above about cars is not a reality.

In the space area we witness the technological contrast between the conventional satellites and the new generations of microsatellites [Flee 92]. The conventional satellite makes use of expensive and proved technology and performs an extreme engrossment on documentation and theoretical reliability. On the other hand the microsatellites use recent technology to reduce costs and to increase performance. In practice the lifetime and reliability achieved by microsatellites seem to be usually higher than those achieved by conventional space programs. It can be verified by comparing the whole set of cost-risk trade-off taken during both designs.

SACI-1 is the first one of a series of scientific microsatellites under development at INPE (The Instituto Nacional de Pesquisas Espaciais). The project is based upon novel technological solutions as well as on previous background in developments of the Brazilian space program. This project is totally financed by FINEP (Projects and Studies Financier of the Brazilian Government) under a grant of US$ 4.6 millions. The development of this project is being conducted in cooperation with universities and other research institutions. The execution of the engineering and qualification model has already been started at INPE. A Long March IV launcher is expected to put in orbit the microsatellite piggybacked to the CBERS (China-Brazil Earth Resources Satellite) whose launch is due on October, 1997.

1. METHODOLOGY

It is important to note that all the subsystems of the satellite were designed aiming multiple missions. The satellite bus can meet the requirements of different payloads without major redesign in the subsystems.

The design principles for cost reduction are based on some general principles that can be applied to the whole activity, be it technical or managerial. To these general principles some others can be added related to more specific aspects of the system design. They can be divided into three groups:

- Major design principle;
- Cost-effectiveness engineering design;
- Reliability design;

A lot of major design principles well known by the microsatellite developers are being used in the SACI-1.

- Sort out the causes of major cost and then adopt vanguard engineering solutions or determine the boundaries of alternative methods. This principle may be the most important one. It is not easy to specify, to purchase and to adapt a space qualified subsystem to your microsatellite. However the difficulty increases when you try to develop one. Nevertheless the greatest difficulty is to determine the balance among expenses, performance and reliability, mainly when you have only innovation as allied.
- Avoid the "Nice-to-Have" requirements. It is very important to identify all your real needs regarding accuracy and performance. This principle can save money, time and reduce problems as well.
- Assume that your space project shall be low-cost and a positive feedback will come out. Expensive projects have a negative feedback because they need to be highly reliable, accurate and to have a long lifetime. All these parameters increase the cost and for this reason the project expenses grows like a snowball.
- Remember that the “perfect” is the great enemy of the “best”. The perfect spacecraft will never be finished. (The perfect spacecraft is a virtual one)
- Design all subsystems to maximize the return rather than ease to use.
- Conduct the project far from all those who have done well under the old technology. The innovation is almost impossible to emerge from a retrograde mind environments. However do not neglect people experience.
- Try to reduce the duration of the project and the number of people involved on it.

- Offer more reward for success than penalties for failures. In this environment people will plan to succeed not to avoid failure.
- Conduct the project with a small and motivated team.
- Prefer short duration but frequent meeting instead of long and occasional reviews.

As stated above, there is no unique system design philosophy which allows a low-cost approach. A system design depends on systematic cost-risk analysis. However, there are some common elements on cost-effectiveness engineering design. They are:

- Delineate interfaces that are simple, clear and standard if possible;
- Maximize integration of technological advances;
- Use screened components (commercial or MIL) instead of space-qualified ones;
- Accept reduction of satellite lifetime;
- Take calculated risks;
- Establish rules for product quality assurance.
- Select contractors compatible in size with the needs of the external developments;
- Keep only essential documentation;

Some guidelines were followed to obtain a low-cost reliable design:

- Use redundancy of all essential subsystems;
- Make in-house qualification by tailored tests rather than qualification certificate;
- Share responsibilities;
- Inspect and test all purchased material and components;
- Review and examine frequently all programmatic elements.

1. THE PAYLOAD

The total cost for the scientific payload is US$ 800,000. This low-cost result of cooperation and use of already developed rocket experiments. The selected experiments are following:

Airglow Photometer - FOTSAT

This experiment has the objective of measuring the intensity of the terrestrial airglow emissions in global ranges of Oxygen OI 557.7nm, OI 630.0nm and OH(8,3). The photometer system is composed of 4 sensors to measure 4 distinct wavelength regions, i.e. 557.7nm, 630.0nm, 715.0nm and 724nm. The photometer will be installed with its optical axis normal to the satellite spin axis which will allow the space sweeping. This will provide important support for the study of global airglow emissions distribution.

Plasma Bubbles Experiment - PLASMEX

The main objective of the bubbles plasma study in the ionosphere is to investigate its generation, development and decay, particularly in the Brazilian region. This investigation intends to elucidate the strong influence of bubbles and associated plasma turbulence in several space application systems (remote sensing with radar, space geodesy, trans-ionosphere telecommunication etc.).

Solar And Anomalous Cosmic Rays Observation In The Magnetosphere - ORCAS

The main objective of the telescope ORCAS is to measure Anomalous Cosmic Rays (ACR) fluxes, from *C* to *Ne*, “trapped” in the belt. The telescope will use solid state detectors to identify the time and the arrival direction of the particles.

Geomagnetic Experiments - MAGNEX

A triaxial high precision fluxgate magnetometer will be boarded in the SACI-1. Its main objective is the investigation of the phenomena related to the currents aligned with the trans-equatorial field and the plasma electrodynamics that involves the Earth, specially in the region of the South Atlantic Anomaly.

1.SPACECRAFT MAIN CHARACTERISTICS

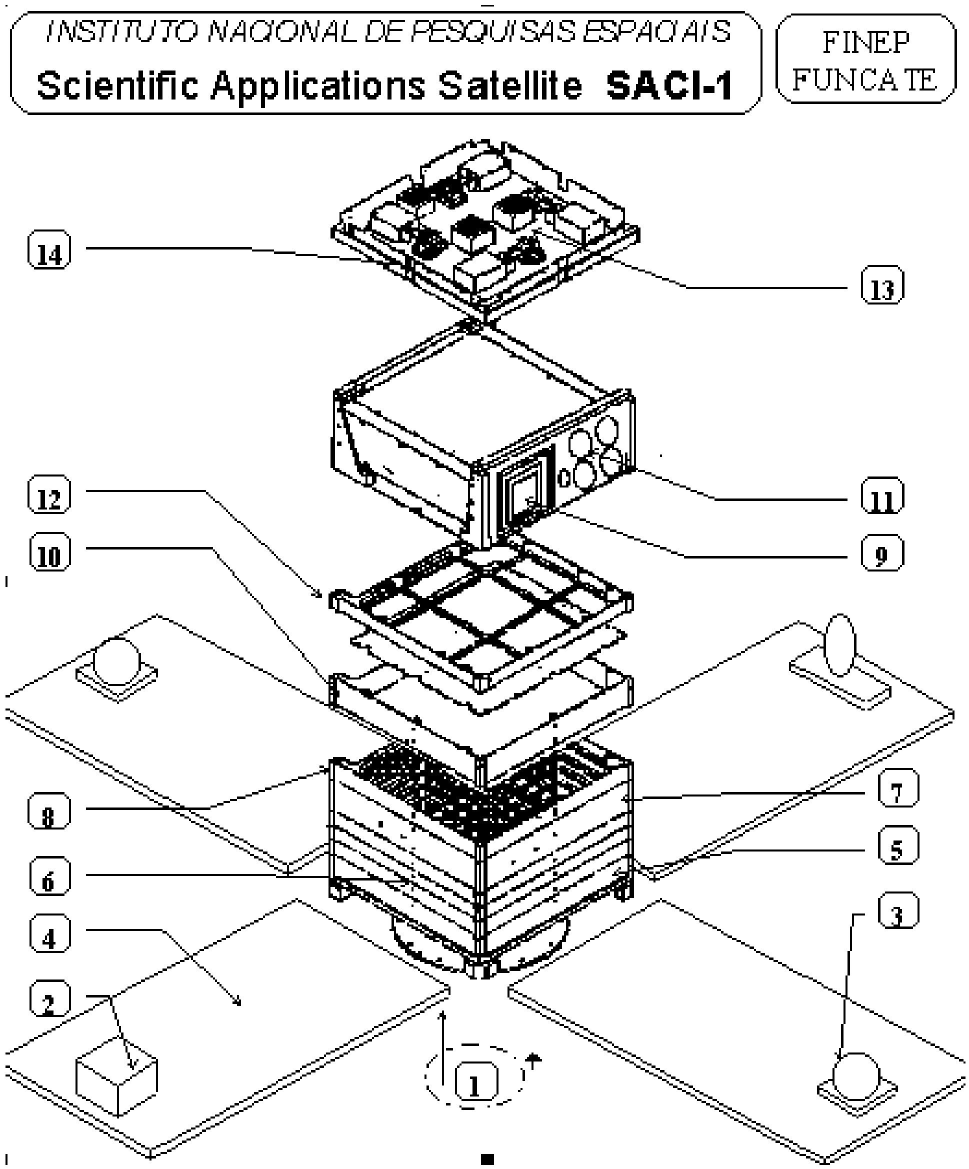
The satellite will fly in a circular orbit inclined about 98 degrees with respect to the Earth's equatorial plane, at an altitude near 750 km. During the visible crossing either from the tracking stations or user's ground data collecting stations, scientific data will be transmitted to ground. The data can be collected and stored in the on board computer (OBC).

The main characteristics of the satellite are the following:

- The total mass 60 kg;
- The payload mass 28 kg;
- The overall dimensions are 600 x 400 x 400 mm;
- The conception is modular, with simple technical solutions;
- The thermal control is passive;
- The development of the micro-satellite shall be done in less than 28 months;
- The total cost, including bus and scientific payloads, shall be less than US$ 4.6 million;
- The satellite expected lifetime is of 18 months;
- The payload power requirement is 30 W;
- The satellite is spin-stabilized;
- The pointing accuracy is 1 degree.

1. THE STRUCTURE

The structure of the SACI-1 satellite follows the small satellites trend towards a modular design. According to this approach the subsystems are designed as standard modules. The use of a standard lay-out also makes the whole preliminary activity of design faster and easier. Another advantages are compactness, high reliability, and lower production costs. The structure includes a Mainbody (platform and payload), an adapter, four deployable panels and the holddown and release mechanisms (HDR). Its overall shape resembles a parallelepiped measuring 600 x 400 x 400 mm (Mainbody only) and weighting about 65 kg (Mainbody plus adapter). The platform consists on a pack of 9 aluminum ribbed frames of different thickness stacked horizontally and connected by means of 12 stud bolts. The payload is assembled on the top of the platform and has six ribbed plates that form a box in which most of the payload is assembled. The separation is accomplished by cutting (or releasing) one central rod that joins the platform to the adapter.



1 - Solar Panels Sun Face 2 - Magnetometer Sensor

3 - Plasma Sensor 4 - Solar Panel

5 - Communication box 6 - On-Board Computer

7 - Battery and Power box 8 - Plasma Bubble Experiment

9 - Cosmic Rays Detector 10 - Cosmic Rays Experiment

11 - Airglow Photometer 12 - Magnetometer Experiment

13 - Antenna and Release Devices 14 - Anti-Solar Plate

Fig. 1: SACI-1 -1 Exploded View.

The analysis of this structure was entirely conducted at INPE using a FEM model for static, normal modes, frequency response, transient response and random vibration analysis. The finite element model of each part was developed based on two and three dimensional AutoCAD drawings and solids pre-processed on a PC and exported to the pre-processor of the MSC/NASTRAN. This procedure decreases the time spent on building the model on the computer[Souz 96]. With this analysis it was possible: (a) to verify the preliminary design of the structure and define the necessary changes; (b) to determine the first global frequencies of the assembly and; (c) to verify the accelerations on the printed circuit boards. The last step of the process was to export the final drawings of each part to a milling machine numerical control code generator to prepare the codes necessary to the manufacturing. The entire procedure allows the whole design process, since the generation of the first drawings, until the manufacturing of the final parts, to be integrated on a PC & Workstation network. In this particular case, even the configuration management of the parts was implemented on a PC based commercial database.

As far as the solar panels deployment mechanism is concerned, the choice contemplated a set of off-the-shelf hinges and holddown and release mechanisms suitable to a satellite with SACI-1 size. This option asked for some minor changes on the design of the interfaces but was able to reduce the cost and time necessary to develop this subsystem.

1. POWER SUPPLY SUBSYSTEM

The PSS comprises a solar array generator, two cold redundant battery chargers, two batteries, and a power distribution unity. Fig. 2 shows the SACI-1 power supply subsystem (PSS).

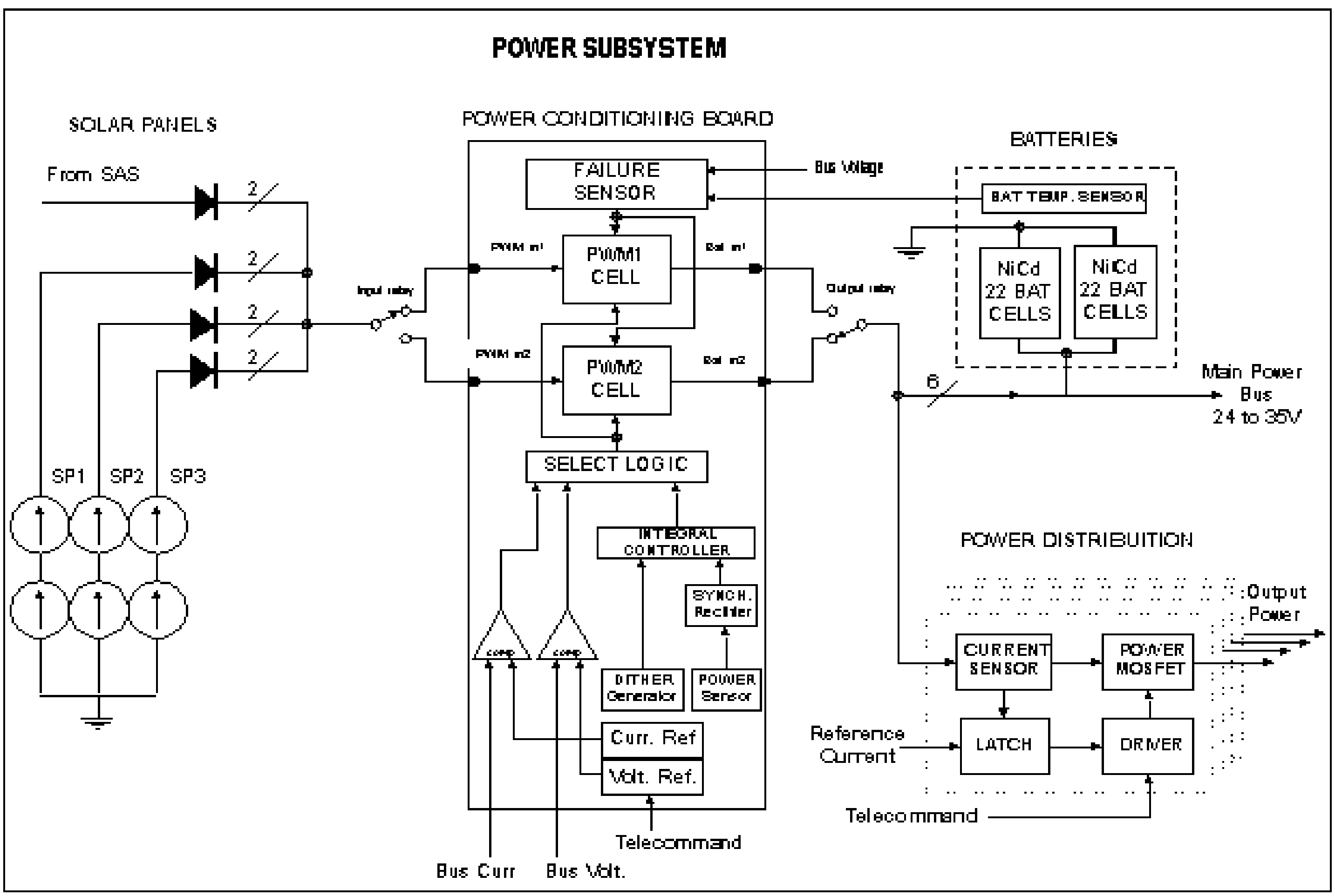


Fig. 2: Power Supply Subsystem Block Diagram SACI-1

The main aspects taken into account to develop this subsystem was cost, simplicity and efficiency. To reach these goals the whole subsystem development and tests are being performed at INPE, except the solar panels.

These will be purchased abroad.

The solar array generator is constituted by a three 570x440 (mm) deployable panels. The panels are covered with GaAs and will generate 113 Watts EOL. A fourth solar panel will be used just for structural purpose and will carry a three axis magnetometer experiment.

The battery chargers are switching regulators with an overall efficiency of 92%. They have a peak power track device to avoid the lock up phenomena. The batteries are connected in parallel. Each one has 22 Ni-Cd D size cells of 4.5 Ah. These will be screened commercial cells. This type of cells are cheaper, 100 time less expensive than the space qualified ones, and this fact compensates the screening test cost. Besides that, the commercial cells present higher charge density than the space qualified ones (3.5 Ah). The batteries will operate with maximum depth of discharge of 1/5 of its capacity. The bus voltage is unregulated and directly connected to the batteries.

The power distribution unit is comprised by fifteen protected lines controlled by the on-board computer. The payloads are fed through DC/DC converters connected to the power distribution output.

1.THE ON BOARD COMPUTER

The SACI-1 On Board Computer (OBC) is responsible for the overall on board data acquisition, data message encoding and transmission to ground; command reception, decoding and distribution; experiment control, rotation and attitude computing and control. The computer development is being done in cooperation with universities.

The computer comprises three fault-tolerant central processing units (CPU) based on the INMOS T805 transputers and three I/O interfaces, see Fig. 3. They are connected through 10-Mbps serial links. Each CPU contain a Watch-Dog Timer used to detect CPU malfunctioning and to generate a flag to the other CPU [Cast 91].

The computer is designed to be able to execute all on board tasks when a processing unit fails. To allow the computer system to degrade onto a single processing unit, a set of switches controlled by watch-dog-timer is used to connect the survived unit to each of the three I/O interface. In this case the computer is able to execute all essential tasks.

To decrease the cost the computer system uses only Military (MIL STD 883-B) off-the-shelf components. The extended memory is implemented using components susceptible to latch up, however a circuit is utilized to power off the extended memory for few milliseconds when a latch up is detected.

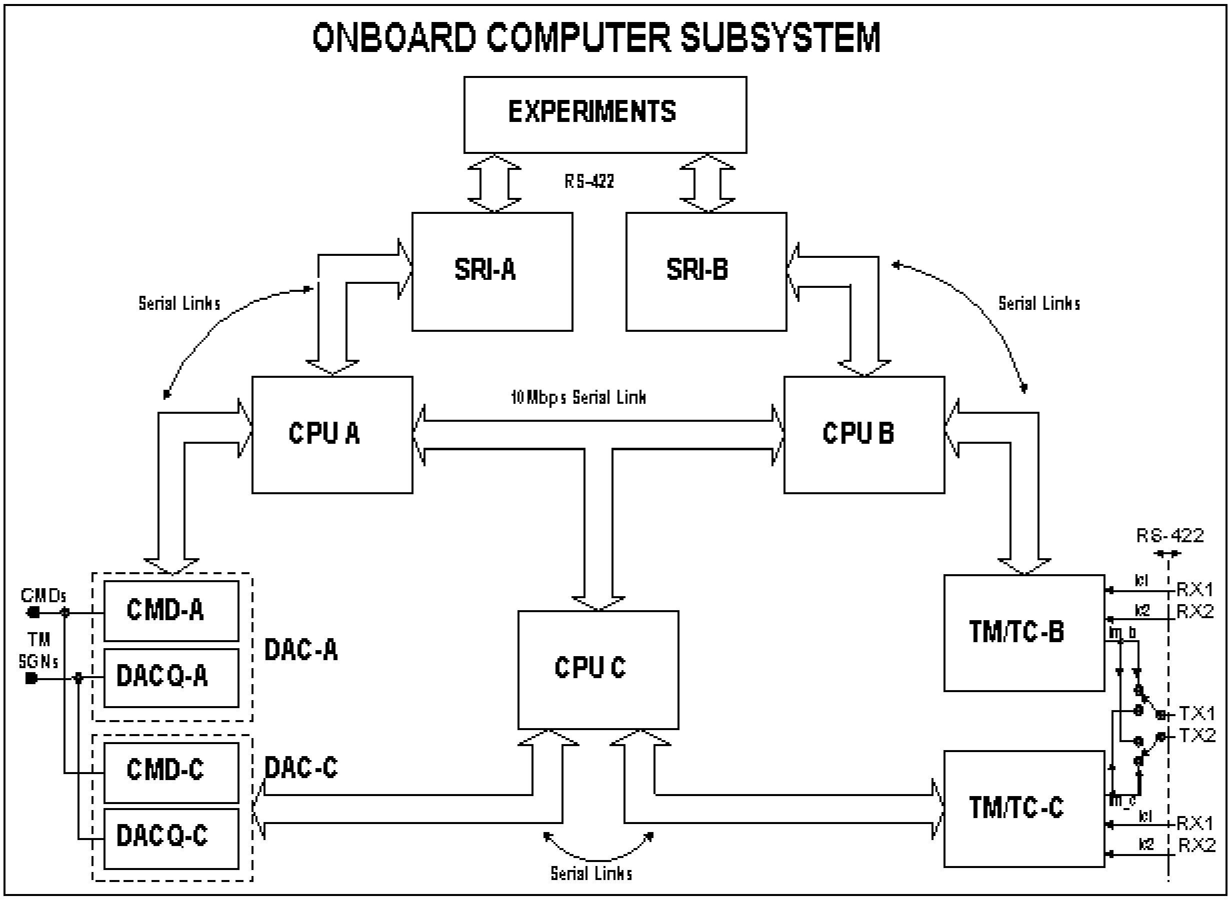


Fig. 3: On-board Computer Subsystem Block Diagram.

Each interface is internally redundant and connected to two processing units. The Telemetry and Telecommand interface receives telecommands frames from the ground communication system at 19.2 kbps and sends telemetry frames back at 250 kbps. The Serial interface implements a communication protocol based on RS-422 between the OBC and experiments at 19.2 kbps. The Data Acquisition and Command interface acquires thermistor, analog and digital readings from the satellite subsystems and generate on/off commands to internal configuration control.

1.THERMAL CONTROL

Although there are both active and passive approaches in the thermal design, a passive thermal control technique is suggested for the SACI-1 satellite as the most efficient solution with respect to power and weight.

An appropriate thermal behavior is achieved by selecting adequate surface properties (using paints, tapes and thermal blankets) and by controlling the heat conduction paths.

In order to simplify the assembly and to reduce the costs, the exterior surfaces will be covered by a mosaic of black and white paints instead of thermal tapes to obtain the adequate thermal optical properties calculated by the thermal mathematical model.

The preliminary results also indicate that will be necessary to use multiplelayer insulation (MLI) at the connector side of the lateral wall and for the Geomagnetic, plasma sensors that are fixed on the shadow face of the solar panels.

The thermal and integration / testing groups are developing a program to design, to construct, to assembly, to test and to qualify MLI using materials manufactured by the Brazilian industry that will permit us to lower the total costs of the Thermal Control Subsystem.

The thermal model used in SACI-1 is based on the nodal method [PCTE 88], in which the satellite is divided in a finite numbers of nodes (55 nodes) that are assumed isothermal. These nodes are connected each other by conductive and radiative couplings. They can receive thermal load from external radiations or internal heat dissipation.

The temperature is calculated at each node by a numerical method, considering all thermal couplings and loads and the boundary conditions. The results for the operation phase in the case of a good conductive coupling between the modules are presented in the diagram of Figure 4 below.

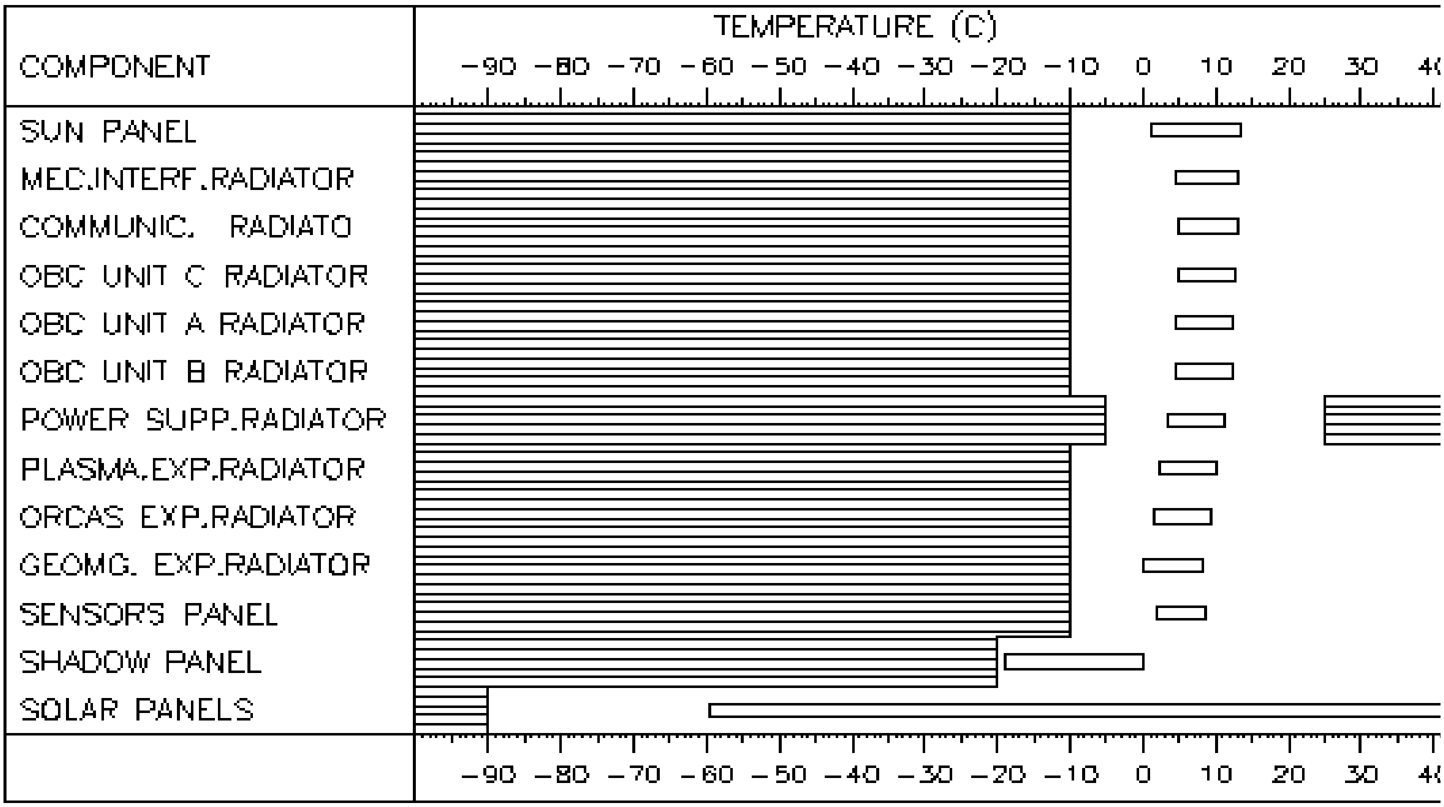


Fig. 4 : Predicted Temperature For The Operation Phase.

The preliminary results for this model indicate that the temperature of the modules are within the specified limits for the operation phase. For the acquisition phase we must establish some kind of attitude restriction:

1.THE ATTITUDE AND CONTROL

The SACI-1 will combine spin stabilization with geomagnetic attitude control in a 750 Km polar orbit. The choice of active control for the micro satellite had to take into account the following tasks to be performed: I) the satellite spin up; ii) the Sun acquisition; iii) the spin rate control; iv) the attitude control.

The geomagnetic control was chosen because it can reach all those tasks [Fons 96]. Another reason for the geomagnetic option was the philosophy that guides the SACI-1 project. Among other goals the project intends to involve research institutes, universities and small industries in the country as well. Besides these objectives, all satellite subsystems had to be designed keeping low cost as one of the most important compromises. Regarding the Brazilian industries, they could be involved since the hardware required for the ACS is relatively simple. Concerning the cost trade-off, the decision for the geomagnetic control is particularly attractive. It does not require propellant. The hardware is relatively inexpensive and simple (three torque coils, one three axis magnetometer and one solar sensor).

The only hardware imported is the three axis magnetometer. The rest will be manufactured in Brazil. One important aspect of the attitude control is that it will be autonomous. This means that the satellite will have an on-board computer. This computer and the Sun sensor are being developed by INPE.

1.COMMUNICATION SUBSYSTEM

The Communication Subsystem block diagram is presented in Fig. 5. The subsystem functions are: send the housekeeping telemetry, to receive the ground telecommands and also to send the payload data to the earth station. The transmitters operate in cold redundancy to provide the BPSK modulated down-link from the satellite to the ground station at 250 kbits/s data rate, and the output of each transmitter is applied to the two transmission antennas (one in each satellite face) in order to obtain a nearly omnidirectional coverage.

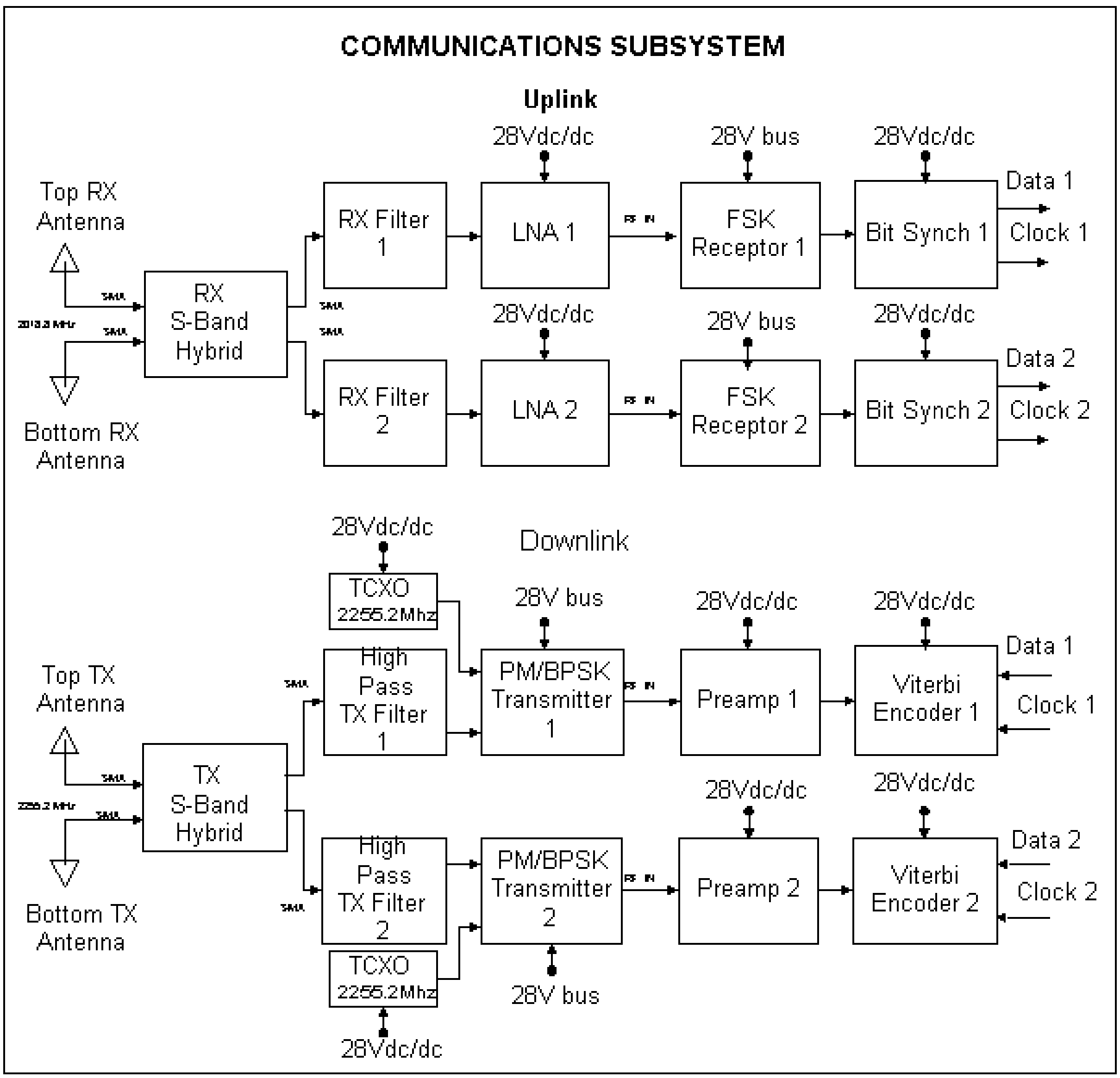


Fig. 6: Communication Subsystem Block Diagram.

The receivers (including the bit synchronizers) operate in hot redundancy to have available the FM modulated up-link (19.2 kbits/s data rate) at any time. The redundant receivers are both connected to the two reception antennas through a hybrid device to obtain a coverage approximately omnidirectional.

The proposed Communication Subsystem makes use (for the receivers, transmitters and bit synchronizers) of standard equipment available from international manufacturers and are designed for operation in aerospace environment where size, weight and power consumption are of prime consideration. The proposed technical solution for the antennas with circular polarization is the probe-fed microstrip antenna. This type of antenna has advantageous mass, dimensions and reproducibility properties when compared with other circular polarization antennas. It is believed that the proposed solution leads to high performance and takes into account factors like cost, implementation time and reliability, which are of prime importance for spaceborn subsystems.

1.THE GROUND STATION

SACI Ground Segment will use two TT&C stations, one of them already in operation at Cuiabá (with a 9 meters antenna) built for tracking and controlling the Brazilian Data Collection Satellite. Another one is a mobile station TT&C located at INPE Natal. This station consists of a 2.4 meters antenna and a computer system. A PC-based station will be used since they are relatively cheaper than a workstation environment. Additionally, as a simple LAN interconnects all computers, the processing load is divided and reasonable efficiency can be attained at moderate systems costs. The computers shall use adequate software package for telecommand transmission, telemetry reception as well as for performing data dissemination (see Figure 7). Foreign TT&C stations like the Japanese south pole station, may supplement the Brazilian receptions and commands during the satellite life and mainly during the acquisition phase.

The Ground Station is responsible for collecting every mission plan defined by the team of scientists who are owners of a specific on-board experiment. The ground computer system shall organize the mission plans in order to send them to SACI-1. On the other hand, this computer system shall both store and deliver to the scientists the payload data received from SACI-1, providing each scientific team only with those raw data measured by its experiments. Additionally, the scientific teams will be informed of the mission operation status related with their experiments through INTERNET. The responsibility for broadcasting these data to the scientific community will be essentially done by the Principal Investigator of each experiment.

1.CONCLUSIONS

Cost-effectiveness is one of the most attracting characteristics found in space systems based upon microsatellite technology. This entails a thorough view of each design step, from systems conception through ground support.

On this paper the INPE experience on building a scientific microsatellite SACI-1 was presented. SACI-1 carries four scientific payloads chosen from many proposals submitted to a call for proposals made by the Brazilian Academy of Sciences.

The spacecraft bus has seven subsystems: structure, thermal control, communications, attitude control, on board computer, electrical integration and power. On each of the SACI-1's subsystems some directions were pointed out towards cost minimization without compromising the overall reliability.

Furthermore, some innovations were introduced from a project management viewpoint in order to expedite developments and to lower administrative expenses. This approach is highly necessary since people as well as hardware/software are active parts of any space mission plan. Some of the developments done in the SACI-1 project will be employed in others Brazilian space projects. The experience on cost-effectiveness acquired during SACI-1 development has contributed to change the way people think about cost-risk in space designs in Brazil.

REFERENCES

[Flee 92] Fleeter, R. & Warner, R. “Design of low-cost Spacecraft, Space Mission Analysis and Design”; 2nd edition, Larson. W. J. & Wertz, J. R., editors, chapter 22, Torrance, CA, USA, 1992.

[Souz 96] Souza, P.N. at al; Structural Design of the Brazilian Scientific Applications Satellite (SACI-1), to be presented at the 10th Annual AIAA/USU Conference on Small Satellite, Sept 16-19, 1996.

[Cast 91] Castro, H. S. A Fault-tolerant Multitransputer System For Space Applications, Microprocessors and Microsystems, Vol 15, No 7, Sept , 1991.

[PCTE 88] PCTER - Thermal Analysis Computer Program - User’s Manual INPE, São José dos Campos, Brazil (1988).

[Fons 96] Fonseca, I.M.; Souza,P.N., Neri, J.A.C.F and Guedes, U.T.V; The Attitude Control Subsystem of the Brazilian Scientific Satellite - SACI-1, ICONE’96 Second International Conference on Non-Linear Dynamics, Chaos, Control and Their Applications in Engineering Sciences, Sao Pedro, SP, Brazil, August 05-08, 1996.