KEY TECHNOLOGICAL SOLUTIONS TOWARDS THE SACI-1 MICROSATELLITE DESIGN

Neri, J.A.C.F.; Rabay, S.; Dos Santos, W.A.; De Souza, P.N.; Fonseca, I.M.; De Paula Júnior, A.R.
INPE - National Space Research Institute
São José dos Campos - SP - Brazil

Abstract

The advantages of a small scale space program over its bulky and complex space counterparts have been extensively documented in the technical literature. These systems are carrying on affordable solutions to telecommunications, earth observation, small-scale space science besides their direct effects in improving general education and training. Cost-effectiveness with reciprocity of mission needs is the utmost driving factor brought up in the process design. Hence the emphasis of this paper is on the key technical solutions adopted in the SACI microsatellite program currently under development by INPE, in Brazil.

SACI-1, which stands for Scientific Applications Satellite, is a 60 kg Low Earth Orbit microsatellite spin-stabilized on a modular architecture carrying four scientific payloads. SACI-1 is scheduled to be launched in October 1997 using a Long March 4 as a piggyback of CBERS (China Brazil Earth Resources Satellite).

SACI-1 payloads were chosen from an open opportunity announcement which resulted in the following experiments: ORCAS, an investigation of the anomalous cosmic radiation fluxes; AIRGLOW PHOTOMETER, a monitoring of the terrestrial airglow emissions; PLASMEX, a study of the plasma bubbles life cycle which interferes particularly in low frequency bands in the equatorial region; and MAGNEX, a research on the geomagnetic field and its effects over charged particles.

Space hardware for some subsystem equipment was conveniently selected in an off-the-shelf inventory which in turn may accelerate development and test time. The microsatellite program is being cooperatively conducted among research institutions, universities and small industries. A dedicated and compact team with short lines of communications and succinct and essential documentation were adopted to minimize bureaucracy.

Two receiving stations in Brazil will cover the ground segment employing a LAN PC-based approach. Moreover, as a trend, Principal Investigators can have interactive direct access to their scientific payloads from their own institutions. A computer network as the INTERNET will greatly enhances the efficiency of data dissemination and payload configuration.

Introduction

If the mainframe computer's manufacturers were to use today the validated technology and the conventional ideas of 20 years ago, their supercomputers' performance and software would be significantly inferior to our personal computer. This would occurs 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 every eleven years.

Unfortunately the hypothetical event above mentioned is still reality in space area. The conventional satellites use demonstrated technology and keep an extreme engrossment about theoretical reliability and documentation. On the other hand the microsatellites use recent technology to reduce costs and to increase performance[1]. Since their achieved lifetime and reliability are usually higher than expected, these performances can be considered ideal by many space agencies.

The Scientific Applications Satellite 1, SACI-1, conceived by INPE, is based in the microsatellite vanguard technology and in the knowledge resulting from the development of the Brazilian Space Program. This project will be totally financed by FINEP (Projects and Studies Financier of the Brazilian Government) under grant FINEP-5694074200 of US$ 4.6 millions.

The development of this project will be performed in cooperation with universities and other research institutions. The execution of the engineering and qualification model has already been started at INPE.

Objectives

The main objective of the SACI-1 project is to proportionate to the Brazilian Scientific Community the following opportunities:

- to promote the state-of-art scientific research at moderate costs;
- to increase the national and international cooperation in space science and technology;
- to stimulate the scientific space development outside INPE in Brazil;
- to reduce the distance and filling "lacks" left by big space programs.

Some relevant technological aims also related to this project are:

- development of a versatile platform (bus) for application in multiple missions;
- improvement of the cooperation between research centers and universities, as well as promotion of technology transfer to small industries;
- diffusion of the state-of-art technology to universities, industry and research institutes at affordable prices;
- consolidation of the available space technology in Brazil by its continuous use, directing it to cost reduction.

Methodology

The SACI-1 is a low earth orbit satellite, with scientific technological purposes. 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 important modifications in the subsystems.

Although INPE has good experience in boarded payloads (including rockets and balloons), the experiments were selected by an Opportunity Announcement opened to all the Brazilian Scientific Community and foreign partners. The Brazilian Academy of Sciences was responsible for Opportunity Announcement occurred on September 8, 1995.

Experiments

The Brazilian Academy of Sciences has selected the following experiments:

- **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 wavelengths regions, i.e. 557.7nm, 630.0nm, 715.0nm and 724nm plus a frequencymeter and an interface for telemetry.

The photometer will be installed with its optical axis normal to the satellite spin axis that will allow the space sweeping. It will collect the data across the orbit in the tangential direction to the surface of the earth. Since the orbit is polar and sun-synchronous, the photometer will collect data in all latitudes and longitudes in 24 hours. This will provide important support for the study of global airglow emissions distribution.

- **Plasma Bubbles Experiment - Plasmex**

The main objective of the study of plasma bubbles 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 the bubble and associated plasma turbulence in several space application systems (remote sensing with radar, space geodesy, trans-ionosphere telecommunication etc.).

The *in loco* measurements of the critical parameters of the plasma bubbles will result in important improvement in the data about them. This is fundamental for more detailed studies of the electrodynamics processes of generation and development of plasma bubbles. It is important to observe that the development of bubbles reaches its peak around 22:00 local time. The sun-synchronous orbit of the Brazilian satellite also located close to the 22:00 local time meridian. This offers perfect conditions for the observation of bubbles. It is intended to perform several measurements as density, temperature and spectral distribution of the plasma irregularities. It will be performed by using the following instruments:

- a high frequency capacitance probe to measure the plasma density.
- a Langmuir probe to measure the critical electronic density and the space spectra of the irregularities of the plasma.
- an electron temperature probe, to measure the temperature of the electrons of the ionospheric plasma.

- **Solar And Anomalous Cosmic Rays Observation In The Magnetosphere - ORCAS**

The telescope ORCAS, to be launched during the period of minimum solar activity, will have the capacity to measure fluxes, spectra and composition, temporal and spatial variations of ions from *He* to *Ne*, and protons and electrons with energy less than 50 MeV/amu.

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

The second important aspect is the presence of *He* ions. It is not expected to find *He* in the population of ACR in this altitude. The *He* was observed by the INJUN satellites only during solar eruptions in the 70's and also by OHZORA. SAMPEX observed again a thin belt of *He* at L=1.8. The source of the *He* and mechanisms of its entrance and trapping in the magnetosphere is an interesting problem. By measuring the *He* flux the ORCAS telescope will determine its source. During the ORCAS experiment few solar eruptions are expected.

Relativistic electrons with energy greater than 1 MeV should also precipitate into the atmosphere at altitudes of about 60~70Km. A physical-chemical process, related to the precipitation of these electrons, predicts the formation of Nitrogen radicals that may have influence in the global Ozone quantities.

- **Geomagnetic Experiments - MAGNEX**

In the last 25 years, electrical currents aligned with the magnetic field have been subject of important studies with on board magnetometers in satellites. Remarkable research of the space plasma has been performed by some satellites on low earth polar orbit (Triad, Magsat, Dmsp/F7, Akebono and Viking), similar to the one in the SACI-1 mission.

It is important to note that more than 170 geomagnetic experiments have been performed in satellites, most of them dedicated to the investigation in aural regions. These experiments represent about 67% of the scientific missions.

A triaxial high precision fluxgate magnetometer is intended to be boarded in the SACI-1. Its main objective will be 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.

It is important to note that all the instruments selected and related to ionospheric studies will give important complementary information for the study of the geophysics effects.

The Satellite

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).

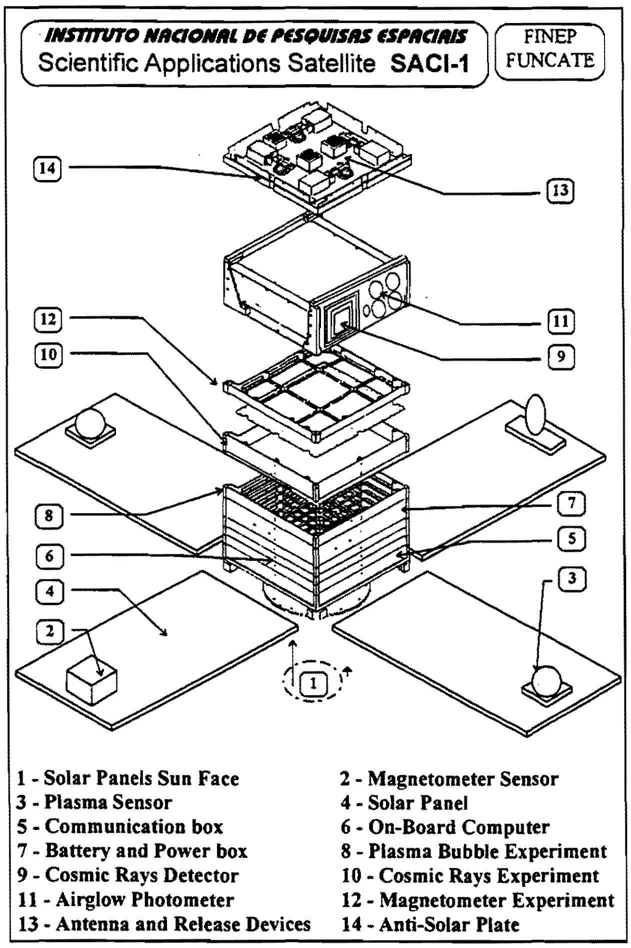

Fig. 1: SACI-1 -1 Exploded View.

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.

Structure

The shape of the spacecraft mechanical structure is a 400 x 400 x 600 mm parallelepiped with the greater dimension parallel to launcher axis. The main structural elements are the aluminum standard modules that are piled up. Four deployable panels accommodate the solar cells. The Figure 1 shows the exploded view of the satellite. In the SACI 1 there will be four solar panels. Three of the solar panels will support ionospheric sensors and the forth panel will support a magnetometer head. In each deployable panel will be mounted two panel hinges which will connect the panel to the mainbody satellite structure. Details concerning the structural design and analysis can be found in reference[2].

Power Supply Subsystem

The main design considerations are: simplicity; cost and reliability. In order to keep the power supply subsystem design simple, a non-regulated distributed bus was selected. This selection also reduces the cost because a reduced number of parts is used. The use of standard parts from other INPE's projects contributed also to the reduction of the costs. As the reliability is affected by the number of parts, the simplicity improves the reliability.

A single electronic unit, called power conditioning unit or PCU, is responsible by the whole power supply. The PCU is composed essentially by two cold redundant switching regulators. When the spacecraft enters the eclipse two nickel-cadmium batteries of 3.5 Ah supply the power to the spacecraft. The unregulated bus voltage directly connected to the batteries, to supply power to the spacecraft and payload through DC to DC converters. As the satellite leaves the eclipse zone, power generated by the solar array progressively reduces the discharge current of the battery until all the current is supplied by the solar array. A further increase in the current driven by the solar panels causes the PCU to begin the battery charge. As the charge current reaches its maximum value or as the battery is fully loaded the switching regulator increases the duty cycle without dissipating any excess power generated by the solar arrays. The battery lifetime is assured by a maximum nominal depth of discharge of 1/5 of its capacity.

The Solar Array Generator (SAG) is composed of 3 (three) deployable panels. A forth panel is used only for structural purpose. The SAG structure is made of aluminum honeycomb core and aluminum facesheet. The power output is 125W generated by the AsGa cells.

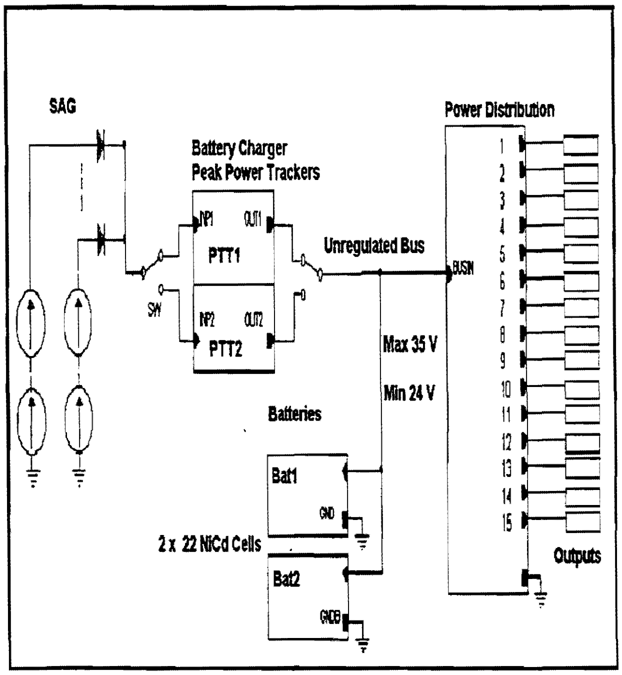

Fig. 2: Power Supply Subsystem Block Diagram.

The Power Conditioning Unit (PCU) is composed of two redundant peak-power-trackers that controls the battery current and voltage during illumination periods. In case of maximum demand of power, it tracks the maximum power point of the SAG characteristics (see Figure 2). The PCU assembly also contains the circuits responsible for the distribution and protection of 15 power distribution lines.

The batteries unit is composed of two series association of 22 cylindrical military grade screened NiCd cells wired in parallel. The reduced costs of this option were also considered for its selection. The cells are assembled in a structure that provides minimum heat rejection. The electric isolation between the cells and the structure is made with wrapped Kapton tape.

Attitude Control

The Attitude Control Subsystem of the SACI-1 satellite[3] combines a passive spin stabilization procedure with active spin rate and precession control via Geomagnetic Control The actuators are three magnetic torque coils which interact with the Earth magnetic field to generate the necessary control torque. The satellite control will be autonomous by using an on-board computer.

Two of the torque coils will be attached to the satellite lateral sides with the magnetic moment parallel to the x and y axes respectively (spin plane coils). The third one will be parallel to the z-axis.(spin axis coil).

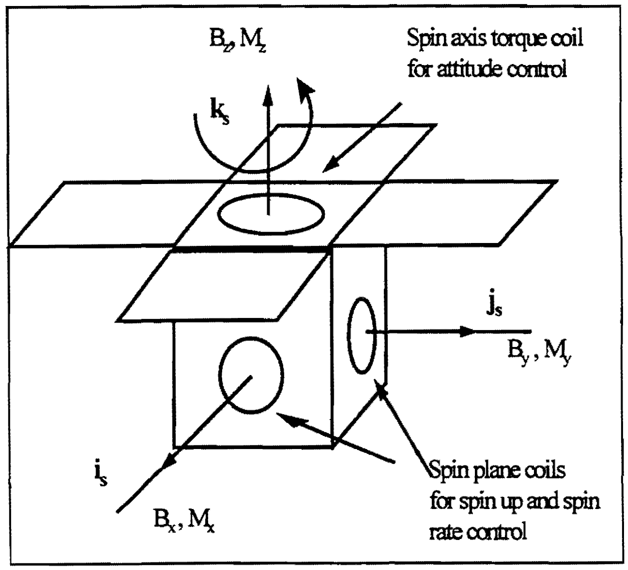

Fig. 3: Torque coils configuration on the satellite.

The whole satellite active attitude control will be performed by using the torque produced by the coils magnetic moment interaction with the Earth magnetic field. The main function of the spin plane coils is to provide spin rate control. These coils will be also used to spin up the satellite up to its nominal spin rate of 6 rpm. The spin axis coil will be used for two basic maneuvers: to point the solar panels towards the Sun (Sun acquisition) and to keep the nominal attitude during the satellite lifetime.(normal mode operation). The pointing accuracy is 1 degree. To execute these tasks a three-axis magnetometer and an analogue Sun sensor are required. The magnetometer will detect the magnetic field magnitude and direction The analogue Sun sensor will inform the Sun direction. These information will be used by an onboard computer to calculate the control. The spin axis torque coil shall provide a magnetic moment of 8.0 ± 1.0 $A.m^2$ in the positive or negative sense. The spin plane coil shall provide a magnetic moment of 4.0 ± 1.0 $A.m^2$ in the positive or negative sense.

Thermal Control

The thermal control of the spacecraft uses only passive means. An appropriate thermal behavior is achieved by selecting adequate surface properties (using paints, tapes and thermal blankets), and by controlling the heat conduction. The principal way to achieve a good thermal control solution is the selective painting of the exterior surfaces, and eventually the selective painting of the interior surfaces and electronic boxes, use of insulation blankets and the control of the conduction heat paths.

The first results indicate that the bottom panel will be covered with white paint to minimize the effect of Sun radiation. The white paint will be used on the upper panel too. In this case, the purpose is to keep the sensors panel as close as possible to 0 °C. The lateral wall will be covered with a mosaic of white/black paint and alodine 1000 finish on aluminum, except the connector side that will be covered with multilayer insulation (MLI).

The Geomagnetic, HFC and LP sensors that are fixed on shadow face of the solar panel are also radiatively insulated (wrapped) by MLI and conductively insulated by epoxy-fiberglass composite washers at the fixation points.

Onboard Computer

The spacecraft will be equipped with an onboard computer subsystem to perform all the on board supervision functions that comprises: acquisition, decoding and distribution of ground telecommands, gather telemetry data, encode satellite to ground messages, attitude control calculations and execution of all other functions related to attitude control, and satellite status inventory.

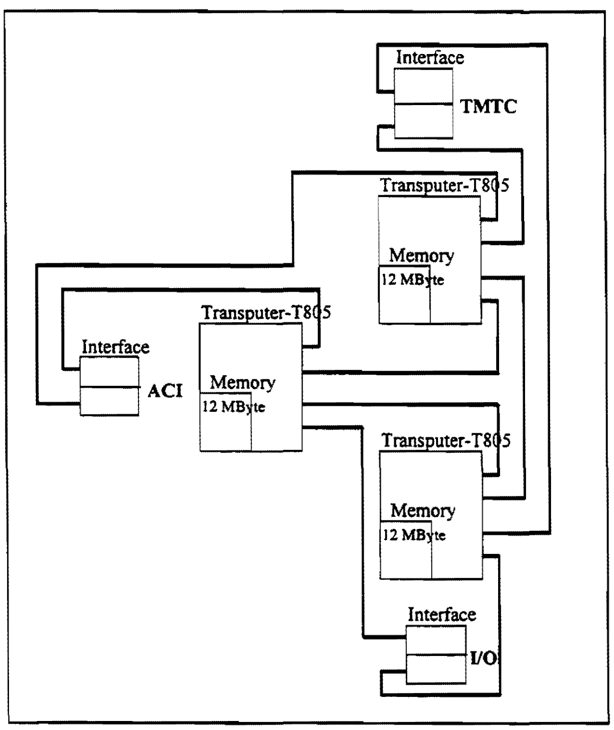

Fig. 4: Onboard Computer Architecture.

The onboard computer subsystem comprises three processing units based on the transputer T805 and three I/O (see Figure 4) interfaces that are connected among themselves through high speed serial links (10 Mbps). Each one of the interfaces is fully redundant[4] and is connected to two processing units. The on-board computer is able to execute all on board tasks if one of the processing unit fails. However, it can operate in a degraded mode executing all the essential tasks with two processing units failed. Each processing unit has a 12 Mbytes extended memory used to store data gathered from the experiments when the satellite is out of communication from the ground stations.

The onboard computer takes care of the management of the spacecraft resources by means of telecommands up-linked and telemetry data for performance evaluation. The telecommands result in control commands being distributed at a predefined time to their destination, where they are executed. The telemetry data, consisting of measurements and status, are gathered from the different on-board elements and correspond to engineering data necessary for the housekeeping of the spacecraft, and mission data.

When a high degree of autonomy is required, the onboard computer subsystem acquires, stores, processes and/or transmits the mission data. The particular case of a small satellite is still more stringent and requires a maximum number of functions to be concentrated in a single unit. Thus, frequently, the onboard computer subsystem, is assigned to additional tasks. Besides the normal data management functions, the onboard computer subsystem of the microsatellite program is responsible for attitude determination and control, power distribution control, thermal control, and in some cases mission data processing.

Communication

The Communication Subsystem (Figure 5) is responsible for sending telemetry, receiving telecommand, and sending also payloads data to the ground. Dual cold redundant transmitters provide standard S-band telecommunication satellite to ground with BPSK modulation and 250 Kbits/second data transmission rate. The modulation bandwidth is of the order of 200 MHz. A 2 watts RF output power of each transmitter is divided over two antennas with gains that assure the reception of data by a 2.4 m diameter ground antenna. A dual hot redundant receivers performs a ground to satellite S-band telecommunication at 19.2 Kbits/second data transmission. The redundant receivers are both connected to two reception antennas though a hybrid device. Once the spacecraft command reaches the two redundant receivers, the output of these two units, in principle identical, is processed by the on board computer (OBC). The final commands are either transferred to command lines or stored to later implementation. The OBC is able to handle up to 64 direct telecommands. This communication subsystem employs equipment off-the-shelves and there is no operation on coherent mode.

The satellite will use four separated microstrip circular polarized antennas, two for transmission and two for the reception. The connection these antennas using hybrids circuits increase the reliability of the communication subsystem. The key parameters in the selection of these antenna systems were orbit, link geometry and coverage requirements. In addition the solution takes into account the cost, implementation time and technical performance.

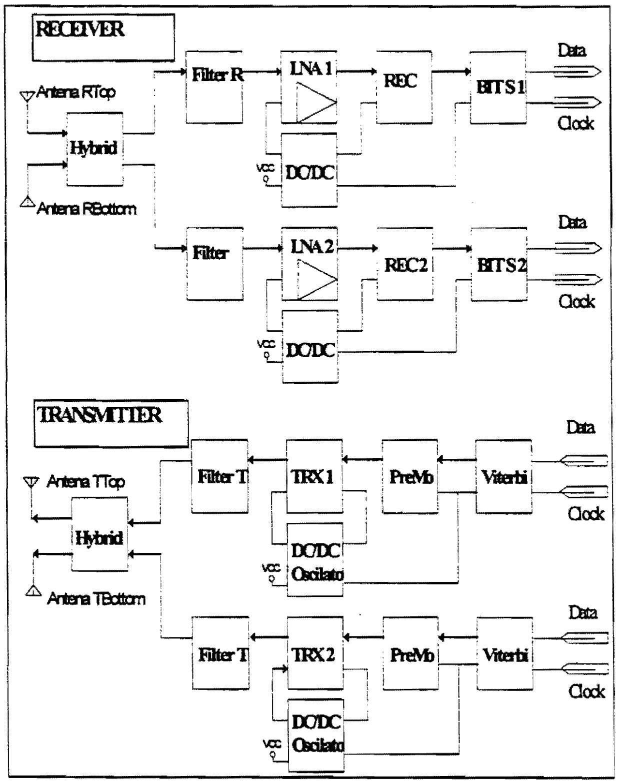

Fig. 5: Communication Subsystem Diagram.

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. The computers shall use adequate software package for telecommand transmission, telemetry reception as well as for performing data dissemination (see Figure 6). 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 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.

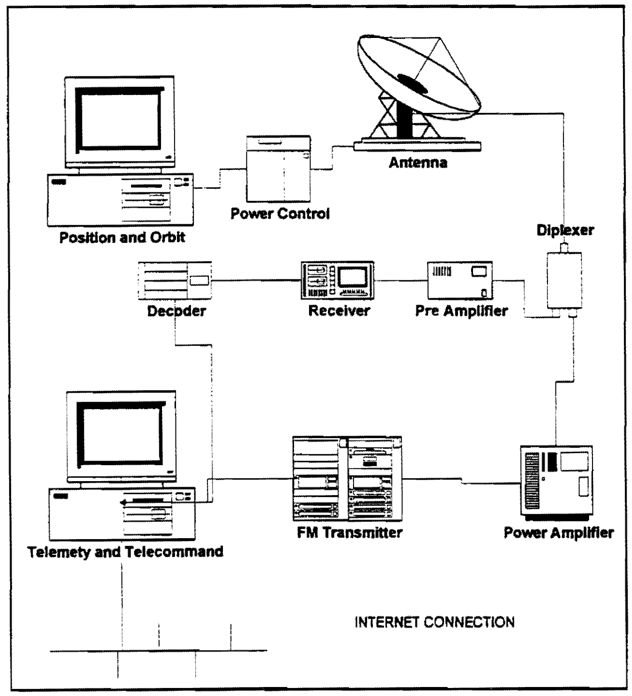

Fig. 6: Ground Station Block Diagram.

Conclusion

This paper presented an overview of the preliminary design of the SACI-1 satellite. The engineering team has updated the conventional initial concept in order to optimize all its features. The result was about three times the payload gain with respect to mass, volume and power.

Finally, the authors would like to thank all those who have devoted efforts and contributions in developing the microsatellite design.

References

[1] 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.

[2] 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.

[3] 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.

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