# SACI-1 Ground System and Operations Concept

Maria de Fátima Matttiello Francisco, Romualdo Alves Pereira Júnior, Manoel Jozeane Mafra de Carvalho and José Ângelo C. Ferreira Neri
*Instituto Nacional de Pesquisas Espaciais (INPE) – Brazil*

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Abstract: Focusing on the microsatellite SACI-1 application, this paper addresses the Ground solutions adopted to control it such as unattended control of a satellite passing, quick-look of payload data in real time, playback of telemetry data and remote mission planning by the investigators through the Internet. Matching the satellite orbit with the SACI-1 Ground Station position (in Natal, northeast of Brazil), the satellite visibility shall occur twice a day, in 5-8 minutes passes, with an average of ~18 Mbytes per pass. As a consequence of both the SACI-1 short contact and the high data payload acquired by the on-board scientific experiments, the Ground-Satellite protocol communication has been robustly implemented and the TM/TC application software shall provide essential autonomous features. In order to meet those requirements with low cost, a compact satellite control system in ground was designed to aggregate in a same environment the functionality of Ground Station, Control Center and Mission Center.

# 1. SACI-1 MISSION

SACI-1 is a low earth polar orbit scientific microsatellite intended for systematic observation of the ionosphere [1]. It shall be launched as CBERS (China-Brazil Earth Resource Satellite) piggyback, by the chinese launcher Long March IV, on July 1999.

There are four scientific experiments on-board of SACI-1 – PLASMEX, ORCAS, PHOTO and MAGNEX – which will acquire data from the space plasma environment simultaneously during the entire mission life [2]. The payload telemetry plus the satellite telemetry will be transmitted to Ground Station in 500 Kbps rate (an average of 60.4 packets per second). Briefly, the four experiments are:

- PLASMEX - intends to investigate the plasma bubbles generation phenomena, its development and decay over the brazilian area.
- ORCAS - intends to monitor, in the inner magnetosphere, the fluxes and spectra of electrons, protons and He to Ne ion populations of energies bellow 100 MeV/nuc.
- PHOTO - intends to investigate the equatorial ionospheric anomaly, South Atlantic Magnetic Anomaly (SAMA) and dynamic process in the mesosphere in global scale.
- MAGNEX - plans to conduct vector geomagnetic field measurements continuously in three-axis orthogonal components on the microsatellite.

# 2. GROUND SEGMENT

In order to meet the Ground System requirements for SACI-1 mission with low cost, a compact satellite control system in ground was designed to aggregate in a same environment the functionality of Ground Station, Control Center and Mission Center. The Ground Station is responsible for collecting every mission plan defined by the investigators of each on-board experiment.

That compact SACI-1 Ground System (Fig. 1) is based on a platform of five personal computers, under Windows NT, Windows 95 and Linux operating systems, interconnected through Ethernet local area network.

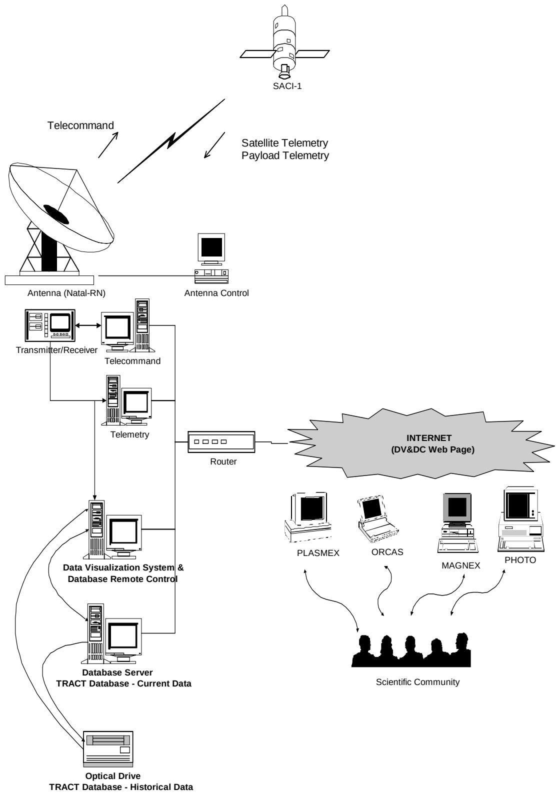


FIGURE 1 – SACI-1 GROUND SEGMENT

Two computers are dedicated to perform respectively Telemetry (TM) and Telecommand (TC) functions, interconnected by a serial link which supports the implementation of the ground-satellite protocol communication. Another personal computer is dedicated to the antenna control tracking based on the satellite orbit preview calculation. The last two deal with data dissemination activities such as quick-look preview of payload data and database server for remote controlling of both current and historical data of the mission.

The personal computers dedicated to Telemetry & Data Visualization System are provided with developed-in-house microcontrolled cards, allowing both systems to receive simultaneously the telemetry application packets transmitted from SACI-1 On-Board Computer (OBC) to Ground Station. Also, inside the telecommand personal computer, there are developed-in-house microcontrolled cards for sending the telecommand packets.

The Ground Segment is compound of four systems:

- Antenna Control and Positioning System;
- Telemetry and Telecommand System;
- Telemetry Data Visualization and Storage System;
- Telemetry Data Dissemination System;

## 2..1 Antenna Control and Positioning System

The Antenna Control and Positioning System is responsible for performing the satellite acquisition and tracking. It realizes the orbit determination and propagation considering the tracking data obtained from the last passages. The orbit parameters evaluation are based on the Doppler measurements. Also this system provides the satellite ephemerides (predicted positions of SACI-1 microsatellite for each second), and contains other data of interest to the mission such as ground station event predictions (passes, eclipse periods etc).

## 2..2 Telemetry and Telecommand System

Telemetry and Telecommand (TM/TC) system is an autonomous software running in a Pentium II platform under Windows NT operating system. It supports the SACI-1 controlling and data reception during the ground station visibility of the satellite.

TM/TC System is compound of two independent subsystems – Telemetry Subsystem and Telecommand Subsystem. Concerning the Telecommand Subsystem, the implementation of ground-satellite communication protocol follows the Consultative Committee for Space Data System (CCSDS) recommendation [3].

The Telemetry Subsystem receives and stores all the telemetry data received at S-band TT&C ground station. According to the application specification, SACI-1 satellite will generate two categories of telemetry messages which shall be received in ground: real time telemetry and stored telemetry (non real time telemetry). The non real time telemetry consists of the payload data of the four experiments on-board of SACI-1 plus the housekeeping telemetry. All telemetry is transmitted in frames (2Kbytes) compound of two data packets (1Kbyte) each. Therefore, seven different types of non real time telemetry packets will be received by the Telemetry Subsystem: PLASMEX, ORCAS, PHOTO, MAGNEX, Sensor Solar, Housekeeping and Stored type.

The Telecommand Subsystem provides the editing, management, logging and transmission of Telecommand messages to the satellite through the up-link equipment chain installed in the TT&C station.

Software developed for TM/TC to support the SACI-1 controlling and data reception during the ground station visibility of the satellite is named SACI-SOL . Telecommand messages scheduled by users to be sent to the satellite are organized under the SACI-1 Flight Plan. Both SACI-SOL and SACI-1 Flight Plan are explained below:

### 2..2.1 SACI-SOL Software

The design of SACI-SOL followed the incremental approach. It was developed in graphical language LABView and LabWindows/CVI [4]. These development environment were one of the main project solution adopted by the developers of SACI-SOL software.

In order to meet TM/TC requirements, SACI-SOL was designed to operate in a platform of two personal computers interconnected by serial link RS-232 [5]. One of them is dedicated to perform TC control while another is doing TM functions. The serial link between them is used for data transmission related to the protocol communication tasks. In the Telemetry computer, telemetry packets are received by the inside card which interfaces with a CVI program in order to transfer these packets to computer memory. It consists of the following software modules:

1. *TM Physical & Codification Module* – deals with acquisition, decodification and separation of the telemetry bits in frames.
2. *TM Transfer Module* – deals with the TM frames validation.
3. *TM Application Module* – deals with the high-level functionality of storing and treating TM packets received from satellite, including TM packet type identification and validating processing.
4. *TC Physical & Codification Module* – deals with TC bit codification and transmission to satellite, following CCSDS recommendation.
5. *TC Transfer Module* – deals with TC frames treatment following CCSDS recommendation.
6. *TC Application Module* – deals with the high-level functionality of the flight plan automatic control in order to transmit all the telecommands selected for each passage.

   Concerning the automatic control requirement for TC transmission, which aims to reduce the number of staffs in the Ground Station, the design solution adopted in the TC Application Module was the finite state Automata where the states represent the situation in which the system stays after treating a specific event and waiting for a next one. Events are the occurrences which make the state machine change from one state to another one. Actions are procedures which must be executed to take the state machine to the next state.

   The relevant occurrences for the TC automatic control are:

1. Beginning of the passage;
2. Ending of the passage;
3. Time to transmit the next TC to the microsatellite;
4. Information related to the TC local protocol services;
5. Out of sequence TM frame;
6. Information related to the TC protocol received from TM frames.

Some of the relevant occurrences (item 4 above) are already interpreted as events by the TC application module because they come from TC transfer module that follows the queue mechanisms for data communication. On the other hand, there are occurrences which must be interpreted. Due to the two different nature of them: from the serial link (items 5 and 6) and internal information (items 1, 2 and 3), two distinct concurrent processes are defined to take care of them: *TM Events Monitor* and *Internal Events Monitor, respectively*. Monitors are dedicated programs which pay attention to specific occurrences in order to both transform them in events and insert them in queues.

The Automata keeps the state table data with states, events and actions. When the Automata starts to run, it is set to the initial state; initialize monitors and queues; and calls the Read Event to get event. The Read Event stays running until getting an event. The Read Event returns the event to the Automata, it consults the table in order to determine what action must be called and what is the next state. The right action is executed and, after that, both the current state is changed and the Read Event is called again by the Automata.

One of the implemented actions is responsible to transmit the next TC listed in Flight Plan to the microsatellite sending it to the TC Transfer Layer queue.

### 2..2.2 SACI-1 Flight Plan

In fact, to generate the SACI-1 Flight Plan, telecommand messages [6] will be, at first, selected via web pages, allowing users to organize, schedule and edit them focusing on the predicted passages information supplied by the Antenna Control and Positioning System (item 2.1). There are thirteen possible on-board destination for the telecommand messages:

- Telecommand Processing
- DAC Driver
- Telemetry Tx Control
- Stored Telemetry
- FT Router

- General Extended Memory Manager
- Memory Dump
- Experiment Control
- Loader
- Status / Event Reporter
- Diagnosis
- Telemetry Protocol
- Satellite Control

The original Flight Plan solution didn't consider the use of internet environment. Every task would be done *in loco*, by the telecommand operator in the SACI-1 ground station. If investigators wanted to send a telecommand for their own experiments, for instance, they should inform it to the operator by phone, e-mail, fax or any other media. With this new approach, authorized users can organize and prepare their telecommand messages, sending it via web pages to the ground station operation.

Basically, it is a client-server web-based system compound of some interface pages with dynamic fill-out forms whose command data (telecommands) selected by users are stored and maintained in a relational PostgreSQL database server.

There are at least seven distinct stages for preparing the Flight Plan:

- *Stage 1: Authentication*: the user authentication and the destination identification are realized. In the server there's an encrypted table containing username, password and related destination. Also, there are information on the IP addresses if specific users can access the system only through determined machines.
- *Stage 2 – Message Preparation*: the known users can select, group, put in sequential order and send specific experiment telecommand messages, directly or time-delayed, considering a given date originated from the SACI-1 integrated ephemerides system.
- *Stage 3 – Additional Information*: some destinations requires complementary data.
- *Stage 4 – Operation Result* : the result are reported presenting a status message and a Telecommand list for each destination and satellite predicted visibility.
- *Stage 5 - Editing*: scheduled telecommand messages are presented for the next SACI-1 predicted visibility, so any modification in those ones can be made before the telecommand process effectively starts.


- *Stage 6 – Auditing*: every telecommand message put in the schedule is associated with an specific user, machine (optional) and timestamp so that an auditor (possibly the operator) can verify the Flight Plan before sending it to the satellite.
- *Stage 7 – Noticing*: when the Flight Plan closes for a predicted visibility (two hours before the satellite passage), an automatic system process send an e-mail message for every user concerned in that Flight Plan to notice them that their telecommand messages will be sent soon.

FIGURE 2 – SACI-1 TELECOMMAND MESSAGE PREPARATION

The SACI-1 Fligh Plan table contains information about beginning of visibility, on-board destination, sequence identification, position in the sequence, message code, operating mode (direct or time-delayed), on-board delayed time (in seconds), additional data.

In order to make feasible the auditing process (stage 6), there's an audit table containing information on username, IP address source and timestamp.

Since cost-effectiveness has oriented all design solutions in SACI-1 Ground Segment, software used for the SACI-1 Flight Plan system development is totally free and it refers to the users' freedom to run, copy, distribute, study, change and improve the software. For SACI-1 Fligh Plan system, the chosen operating system, HTTP server, scripting language and database management system are, respectively:

- The operating system: *LINUX*, an independent POSIX implementation which includes true multitasking, virtual memory, shared libraries, demand loading, proper memory management, TCP/IP networking, and other features consistent with Unix-type systems. Developed under the GNU General Public License, the source code for Linux is freely available to everyone.
- The HTTP server: Apache Project, a collaborative software development effort aimed at creating a robust, commercial-grade, featureful, and freely-available source code implementation of an HTTP (Web) server.
- The scripting language: PHP 3.0, a server-side HTML-embedded scripting language. Much of its syntax is borrowed from C, Java and Perl with a couple of unique PHP-specific features thrown in. The goal of the language is to allow web developers to write dynamically generated pages quickly. A significant feature in PHP is its database integration layer. The source code is available for free use.
- The database management system: PostgreSQL, a sophisticated Object-Relational DBMS, supporting almost all SQL constructs, including subselects, transactions, and user-defined types and functions. It is one of the most advanced open-source databases available anywhere.

## 2..3 Telemetry Data Visualization and Storage System

During the passage, the Telemetry Data Visualization and Storage System is dedicated to perform Real Time Telemetry reception and visualization while both the Telecommand software system controls the telecommand transmission and the Telemetry software system receives, separates and stores in hard disk the non-real time satellite and payload telemetry data.

For Real Time telemetry reception and visualization in real time and playback, software was implemented in graphic language using the LabVIEW environment.

For Quick-look of payload telemetry data, software also used LabVIEW facilities. A unique process was developed. It allows the ground station operator to visualize payload data in real time and playback mode. That process is configurable to execute quick-look for each one of the experiments. In playback mode, several instances of this process can be run concurrently allowing the Ground Station operator to monitor, on different windows on screen, the payload data of all experiment on-board of SACI-1.

Additionally, as another operation mode, called data pre-processing, that software executes the separation in files, per type, of all non real time telemetry data received in the passage.

## 2..4 Telemetry Data Dissemination System

Telemetry Data Dissemination System is responsible for the SACI-1 payload treatment. It performs automatic storage of the raw data measured by on-board experiments in CD-units and in Optic Disk units for distribution. These payload telemetry data are delivered to the experiment investigators, according to an operational proceeding.

Immediately after each passage, payload telemetry data, previously separated in files, one for each experiment, will be transferred to Telemetry Data Visualization and Storage System computers.

This multi-user software allows remote controlling of both database and telemetry data recording in CD-ROM and optical drive.

Payload Telemetry application packets with the experiment raw data received in ground are decompressed and stored in the database as active data. The "very old data" called historical data are transferred to optical disk indexed by a predefined period of time (e.g.: per week). Backups and all other Data Base Management System (DBMS) utilities such as loading and performance monitoring are provided by the database server with an efficient fault tolerance system and roll-forward recovery [7].

This system also provides facilities for queries and reports using Web Page. Through these forms the scientific community can access the SACI-1 remote sensing data.

# 3. CONCLUSION

Cost-effectiveness is one of the most attracting characteristics found in space systems based upon micro-satellite technology. This approach deals with a thorough review of the ancient solutions adopted on each design step, from systems conception through ground support, including software development. Concerning Ground System and its operation concepts, the solutions adopted in SACI-1 mission followed that approach aggregating in a same environment the functionality of Ground Station, Control Centre and Mission Centre. A compact and autonomous satellite control system was designed in ground with the integration of TT&C equipment commercially available, freely-available software, PCs network and in-house software development using new tools such as graphical programming environment. In terms of satellite control operation, the developed system proves, in spite of the costs, the possibility to take effectiveness and efficient solutions for user-friendly web applications including fill-out forms, file uploading and database facilities, standing out the power of Open Source information technology.

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