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THE SAX ITALIAN SCIENTIFIC SATELLITE. THE ON-BOARD IMPLEMENTED AUTOMATION AS A SUPPORT TO THE GROUND CONTROL CAPABILITY

Andrea MARTELLI

Alenia Spazio S.p.A. - Turin Plant
Corso Marche 41
10146 Torino - Italy

ABSTRACT

This paper presents the capabilities implemented in the SAX system for an efficient operations management during its in-flight mission.

SAX is an Italian scientific satellite for X-ray Astronomy whose major mission objectives impose quite tight constraints on the implementation of both the space and ground segment. The most relevant mission characteristics require an operative lifetime of two years, performing scientific observations both in contact and in non-contact periods, with a low equatorial orbit supported by one ground station, so that only a few minutes of communication are available each orbit.
This operational scenario determines the need to have a satellite capable of performing the scheduled mission automatically and reacting autonomously to contingency situations.

The implementation approach of the on-board operations management, through which the necessary automation and autonomy are achieved, follows a hierarchical structure.
This has been achieved adopting a distributed avionic architecture. Nine different on-board computers, in fact, constitute the on-board data management system. Each of them performs the local control and monitors its own functions whilst the system level control is performed at a higher level by the Data Handling Application software.
The SAX on-board architecture provides the ground operators with different options of intervention by three classes of telecommands. The management of the scientific operations will be scheduled by the Operation Control Centre via dedicated operating plans.

The SAX satellite flight model is presently being integrated at Alenia Spazio premises in Turin for a launch scheduled for end '95.
Once in orbit, the SAX satellite will be subject to intensive check-out activities in order to verifiy the required mission performances. An overview of the envisaged procedure and of the necessary on-ground activities is therefore depicted as well in this paper.

INTRODUCTION

The SAX satellite is part of a scientific program whose objective is to observe celestial X-ray sources in the broad energy band from 0.1 KeV to 300 KeV. The SAX mission has been planned to achieve a systematic, integrated and comprehensive exploration of galactic and extra-galactic sources, providing significative improvements for more complete and extensive studies in X-ray astrophysics.
SAX is a joint program managed by the Italian Space Agency (ASI) and by the Netherlands Agency for Aerospace Programs (NIVR) coordinating the scientific interest of the Italian and Dutch scientific community and funding an international industrial team whose overall organization structure includes:

- Alenia Spazio as main contractor for the Space Segment
- Telespazio as main contractor for the Ground Segment
- Martin Marietta - Commercial Launch Services - as main contractor for the Launch Vehicle
- Italian and Dutch Scientific Institutes as Scientific Consultancy.

The SAX Payload hosted on-board consists of the following six scientific Instruments (Ref. 1):

- Low Energy Concentrator Spectrometer (LECS) whose task is to perform X-ray spectrometry/imaging in the 0.1-10 KeV energy range
- Medium Energy Concentrator Spectrometer (MECS) whose task is to perform X-ray spectrometry/imaging in the 1-10 KeV energy range
- High Pressure Gas Scintillation Proportional Counter (HP-GSPC) whose task is to perform X-ray spectrometry in the 3-120 KeV energy range
- Phoswich Detector System (PDS) whose task is to perform X-ray spectrometry in the 15-300 KeV energy range and gamma-ray burst monitoring in the 60-600 Kev energy range
- Two Wide Field Cameras (WFCs) whose task is to perform X-ray spectrometry/ imaging in the 2-30 KeV energy range.

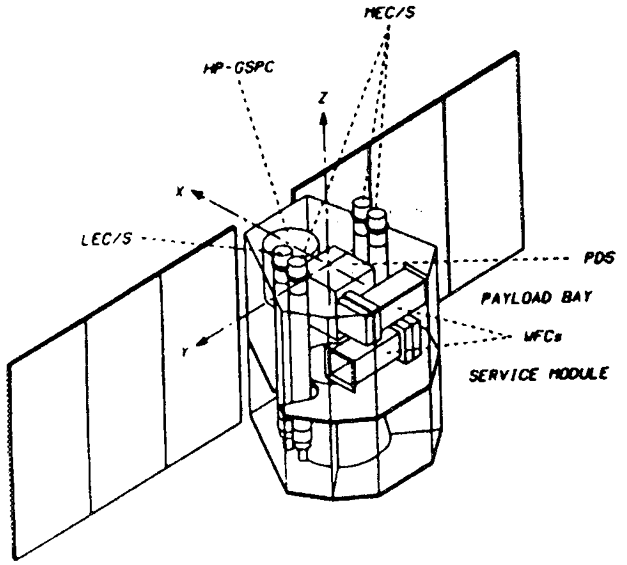

Fig. 1 - Satellite Overall Configuration

The WFCs are mounted along the +Y and -Y satellite axes, allowing an observation of a wide sky portion, whereas all the other Narrow Field Instruments are aligned along with the +Z axis. Fig. 1 illustrates the satellite overall configuration.
The SAX pointing capability ensures a target measurement accuracy of 1 arcmin and a pointing of 3 arcmin for a maximum of 10^5 seconds, i.e., one day.
All the project design has been developed to cope with a mission of at least two years preceeded by a commissioning phase period, estimated to extend for about eight weeks.
The satellite is currently in a very advanced C/D phase. The Flight Model is under integration as the last step of a system integration and test campaign involving the developing of a Structure Model, an Engineering Model, and a Software Verification Facility. The launch will take place by end '95 with an Atlas Centaur vehicle. The SAX Ground Station will be located in Singapore and will be connected via Intelsat to the SAX Operation Control Center and the Scientific Data Center, both located in Rome.

MISSION CHARACTERISTICS

The major constraint entailed by the scientific objectives requires a satellite orbit such that the background particle radiation for X-ray detection be very low and the effects of radiation from the South Atlantic Anomaly region be reduced. This leads to the choice of a circular low Earth orbit at a 600 Km altitude - Begin of Life (450 End of Life) - and an inclination of about 4°. The orbit period is thus of 97 minutes with an alternance of 60 minutes of sunlight and 37 minutes of eclipse.

One single ground station, located near the equator, will support the mission offering satellite visibility each orbit. The coverage period is anyway no longer than 11 minutes so that about 90% of orbital life is out of visibility.
The pointing domain is limited by the allowed sun incident angle range on the satellite solar array surface. A maximum of 30° (with occasional excursions to 45°) inclination is allowed with respect to the sun direction to ensure a proper battery charge. This implies a pointing domain for the Narrow Field Instruments limited within a band in the sky 60° wide available for observation each orbit (except some possible occultations by celestial bodies). In a one year period, the whole sky will be observable for a scientific activity that can be estimated as performing between 2000 and 3000 independent observations (Ref. 2).

THE SYSTEM ARCHITECTURE

The above introduced operational scenario determines the need to have implemented on-board the capability of supporting, in an autonomous way, the execution of on-ground pre-defined mission plans. That also requires the on-board architecture to manage the nominal activities as well as the pre-conceived anomalies, in all the mission phases, taking into particular account that most of the mission is out of the ground coverage.
The implementation approach of the required operation management is based on an avionic architecture which makes extensive use of a distributed on-board intelligence (Ref. 3). Nine on-board intelligent terminals constitute the SAX system architecture as shown in Fig. 2 (see following page).
Each of them performs the autonomous control of the relevant subsystem (S/S) local functions including the surveillance of its health status. The control of the system overall activity is assigned to a higher hierarchical level and is implemented in a Central Terminal Unit (CTU). The CTU is devoted to coordinating and controlling the Data Management and Communication System as well as to managing the system nominal operations and to undertaking the system level recovery actions. A set of non-intelligent subsystems, including the Telemetry Tracking & Command S/S, the Reaction Control S/S and the Electrical Power S/S are placed under the direct control of the CTU via serial lines through a Remote Terminal Unit.
The interprocess communication is based on the ESA standard serial digital bus arbitrated by the CTU and composed of:

- Interrogation Bus for CTU to local terminals interrogations
- Response bus for local terminals to CTU transmission of Housekeeping Data (HKD)
- Block Transfer Bus for Scientific Instruments to CTU transmission of Scientific Data.

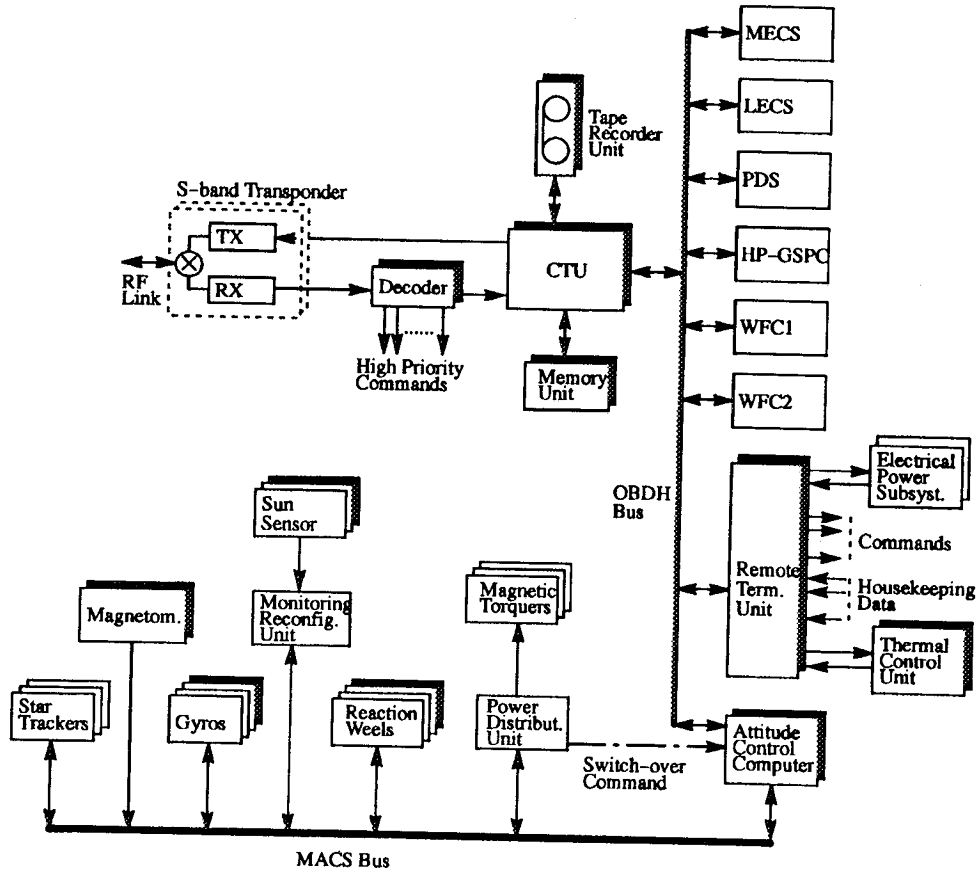

Fig. 2 - System Architecture

The data communication protocol is designed to ensure a collection of about 16 kbit/sec of HKD from the satellite subsystems and science instruments and up to 100 kbit/sec of scientific data. Two different formats of HKD can also be selected: one essential format including a basic set of SAX HKD, one intensive format including some extra information on hot redundant units and Data Handling traced operations. All the data gathered in non-visibility are temporarily stored on a dedicated tape recorder, with a capacity of 510 Mbits, until requested to be dumped to ground during the coverage periods. Two channels are implemented to dump to ground the satellite telemetry in High Bit Rate mode:

* channel "I" for dumping the real-time collected telemetry at 131 kbps
* channel "Q" for dumping the tape recorded data at 917 Kbps.

A 16 Kbps link is also available to implement a Low Bit Rate transmission mode.
The telecommand bit rate allows an uploading of 2 Kbps, that is about 20 frame instructions/sec.

ON-BOARD REDUNDANCY CONCEPT

The SAX mission characteristics have led to a system design with a high degree of reliability to cope with so long an autonomous lifetime.

All the spacecraft S/Ss are designed to be single failure tolerant whereas the Scientific Instruments implement redundancy only at interface level. Critical on-board items (e.g. receivers, decoders, gyroscopes, power units, protected memory) all operate in hot redundancy. In this context single spacecraft unit malfunction does not affect the nominal mission performance.

The intelligent subsystems - i.e., On-Board Data Handling (OBDH), Attitude and Orbit Control S/S (AOCS), Thermal Control S/S (TCS) - are based on a fully redundant architecture. Each of their unit classes includes one redundant item so that one fatal failure can be recovered by properly activating this redundancy.
The Scientific Instruments, not having implemented any internal redundancy, perform only a reduced Failure Detection and Isolation function for specific problems.

All the on-board computers maintain at least the software (SW) basic functions stored in Programmable Read Only Memories so that any reset/switch-over cannot cause the loss of the code, as it is downloaded from PROM to RAM any time a (re)-initialization takes place. Embedded circuitry for error detection and correction of corrupted memory cells by single event upset as well as a watch-dog circuitry for autonomous reconfigurations are provided in all the intelligent subsystems.

All the data considered critical for the proper on-board autonomous maintenance of the mission, in any nominal or contingency situation, are dynamically maintained in dedicated Protected Memory Areas. According to the relevant OBDH and AOCS performed control, this data set is so classified and grouped:

- OBDH Application SW (A/SW) vital data, including the Solar Array deployment status, the launcher separation status, the system and some critical S/S items active configuration (e.g. transmitters, battery discharge regulators, reaction control S/S branches, etc.)
- OBDH Basic SW (B/SW) vital data, including the launcher separation status, the OBDH active unit configuration, the redundancy management data
- Time Tagged commands to be scheduled at their own pre-set time
- Real Time commands to be executed at CTU switch-over
- AOCS S/S active configuration and launcher separation status, maintained in dedicated AOCS solid state latches.

The failure management of non-intelligent S/Ss is performed at centralized level by the OBDH A/SW. Some exceptions deviate from this general approach:

* Power S/S performs the failure management for its own units;
* the hydrazine flow control valves are under control of the AOCS when it makes use of thrusters;

and these are driven by time intervention constraints.

MISSION PHASES

The SAX mission can be divided into four overall mission phases.

- ***Launch Phase***
  LP begins at spacecraft power-on just before vehicle lift-off and extends to the physical separation between the launcher and SAX. In this phase the S/Ss are initialized and perform a continuous control of the powered units. No attitude manoeuvre is of course executed as the AOCS is in its initialization mode until the separation. The on-board produced data are stored on the tape recorder, just after the launch vibrations terminate, for later transmission to ground.
- ***Commissioning Phase***
  This begins at the SAX-launcher separation and extends to the completion of all initial in-orbit tests and calibrations. As a first step, it consists of an Early Orbit Phase which comprises a short post separation coast period, a reduction of any residual S/L body rates and a subsequent Sun/Earth acquisition period. Upon successful completion of these activities the deployment of the Solar Arrays is autonomously operated.
  The commissioning of the satellite shall proceed with an initial health check-out continuing with systematic functional checks of all the subsystem nominal functionalities.
  The Scientific Instrument activation and functional verification shall be operated as a last step. Some overlaps between the two shall be necessary for a complementary check-out of both the spacecraft and the Scientific Instruments. All these operations shall be initiated by ground and supported by the on-board SW tasks.
- ***Operational Orbit Phase***
  This phase covers the period of the satellite's useful scientific lifetime. It shall be nominally two years and shall be characterized by routine scientific operations. The satellite design shall, anyway, allow an extention of the mission beyond the nominal period up to a total four years lifetime.
- ***End of Life Phase***
  This phase covers the period when SAX is no longer capable of producing useful scientific information due to either component degradation or altitude decay.

SATELLITE MODES

The system mode design has been structured to cope with all the SAX mission phases (Ref. 4). The satellite modes - implemented with a direct correspondence with the AOCS modes - drive all the on-board autonomous operations. Their transitions can be initiated either upon ground commands or at the occurrence of automatic fallbacks caused by system autonomous emergency re-configurations. The SAX mode transitions diagram is reported in Fig. 3 (see following page).

The mission/science support modes are the principle configuration to support the scientific activity. The default/safety modes correspond to the main operative configurations to be assumed in case of interim science activity or on-board emergency. Two further modes support special operations during the launch phase and during the orbit raising manoeuvre - if ever needed.

- **Satellite Launch Mode (SLM)**
  Routine operations are performed to ensure an health satellite status ready to operate just after the SAX-launcher separation.

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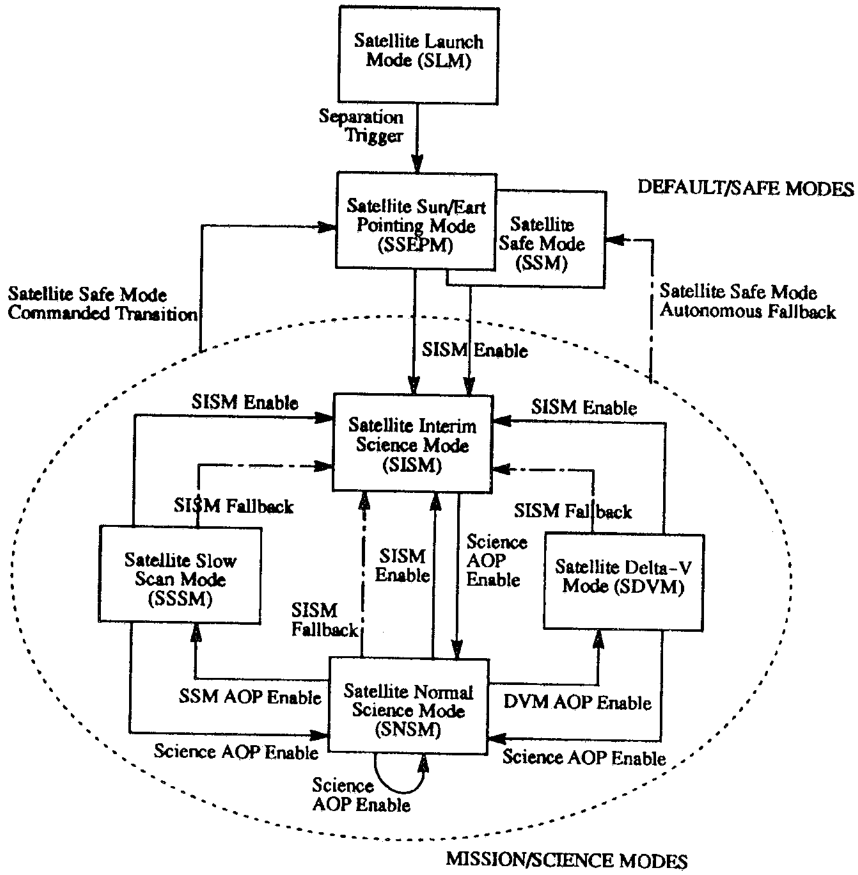


Fig. 3 - Mode Transition Diagram

The produced telemetry is recorded only after the vibration level is reduced - the activation of the on-board tape recorder is made by a time tagged command.

- ***Satellite Sun Earth Pointing Mode (SSEPM)***
  This mode is automatically entered either at SAX-launcher separation or as fall-back from the other Nominal Satellite modes. Purpose of this mode is to maintain the satellite in a 3-axis stabilized attitude optimizing the sun incidence on the Solar Arrays. As this mode is entered from the separation, it has to accomplish a very critical sequence of operations most of them to be performed autonomously since they are out of the ground coverage. The major operations are initiated by the OBDH and AOCS software that have to coordinate the safe attitude acquisition with the Solar Arrays deployment. Trigger of these operations is the SAX-launcher separation, detected by a dedicated fully redundant hardware circuitry and sent to both the S/Ss.

- ***Satellite Interim Science Mode (SISM)***
  This mode configures the SAX satellite in a accurate three-axes stabilized attitude making use of one star tracker, besides all the other used sensors. This fine pointing helps in keeping a default attitude (e.g. Polaris pointing) and in fastening attitude transitions to scientific modes.

- ***Satellite Nominal Science Mode (SNSM)***
  The satellite remains in this mode while operating the planned scientific observations. A very fine pointing is made by use of the AOCS star trackers. All the scientific data produced by the Scientific Instruments are collected by the OBDH according to a dedicated polling algorithm.

- ***Satellite Slow Scan Mode (SSSM)***
  This mode will mainly be used to perform calibrations of Non-Imaging Scientific Instruments by performing sequential slews across a known target.

- ***Satellite Delta-V Mode (SDVM)***
  This mode is designed to cope with the altitude decay, raising the satellite orbit in the case the SAX altitude decreases below the 450 Km.
- ***Satellite Safe Mode (SSM)***
  This mode is entered upon detection of specific system-level failures. A safe attitude is then maintained by the AOCS pointing the Solar Array surfaces toward the sun and aligning the satellite with the earth magnetic field.

OPERATION MANAGEMENT STRUCTURE

The management of the SAX system operating modes is implemented by a multi-level hierarchical structure (Ref. 5) involving, in increasing priority:

- the S/L Subsystems and Scientific Instruments
- the OBDH Application Software
- the Ground Operation Control Centre.

To the upper levels is assigned the task of initiating the scheduling of system level functions as well as the capability of controlling and overriding the lower level decisions. On the other hand, the main nominal operations autonomously performed at local level allow the proper control and setting of the relevant S/S. In particular, the intelligent terminals and Scientific Instruments are designed to be fully autonomous in performing their relevant tasks so that they can in principle continue operating consistently without any external intervention. Few inputs are, in fact, needed only for tuning their performances and their configurations with respect to either the system configuration or the current mission characteristics.
Each of the intelligent subsystems also performs a Failure Detection, Isolation and Recovery (FDIR) management on its own, keeping under control the configuration, functioning and health status of all its relevant units. In the case a malfunction is detected, the fault unit can be substituted by the redundant one. If the main S/S computer is affected an automatic switch-over takes place. The redundant intelligent unit will then be initialized assuming a safe mode of functioning.
The Scientific Instruments, not having a redundant architecture, adopt a self disabling policy, in particular, against a too high level of particle radiation able to damage the instrument itself.
Purpose of the OBDH A/SW is to keep under control all the subsystem level operations; that implies a system supervision to ensure the proper nominal/safety satellite consistency. What has been assigned to the A/SW is the role of the on-board coordinator of all the major flight operations between themselves and with respect to the ground scheduled plans.

It is in particular devoted to:

* perform Solar Array deployment following the launcher separation and sun/earth acquisition
* inform the AOCS of the new inertia matrix to be used after the Solar Array deployment
* support the distribution and enabling of operating plans to the AOCS and Scientific Instruments
* support the Ground-to-Satellite link acquisition and downlink telemetry operations
* enable/disable power resources to the non-essential satellite loads, i.e., Scientific Instruments, Reaction Control S/S, thermal control heaters
* perform the deployment of the Scientific Instrument baffles
* manage satellite mode transitions as a consequence of
  - ° Intelligent S/S switch-over
  - ° AOCS mode fallbacks
  - ° Power S/S protection triggering
  - ° Scientific Instrument particle over-radiation detection.

All the A/SW operations are coordinated and synchronized by the proper activation of dedicated pre-defined command sequences and command loops. These can be activated either by ground or autonomously to accomplish the above introduced operation set. The OBDH A/SW core is based on three principal modules acting as the kernel of the A/SW architecture, as illustrated in Fig. 4 (following page).

- ***The Mission Manager:*** it monitors the mode transitions of all the subsystems and instruments which require corrective operations. It is based on a mode transition table indicating all the actions to be undertaken at the occurrence of S/S mode transitions. It in particular specifies the safe configurations to be adopted in case of some critical mode fall-backs. It also drives the enabling/disabling statuses to be applied to the A/SW controls, as a function of the satellite mode configuration.
- ***The Fault Manager:*** it cyclically checks a pre-defined sub-set of the on-board produced monitors to undertake subsequent actions to isolate and/or recover the related problems. The data set includes all the mission critical on-board items, provided on a periodic basis and kept under control by means of a table driven FDIR manager. The control is performed by periodic tasks scheduled every second.
  A cross-check is then made between the measured values and their relevant expected ranges. Any discrepancy activates a direct recovery action on the non-intelligent S/S with possible extension to a system reconfiguration in the case the malfunction can severely affect the system performance.

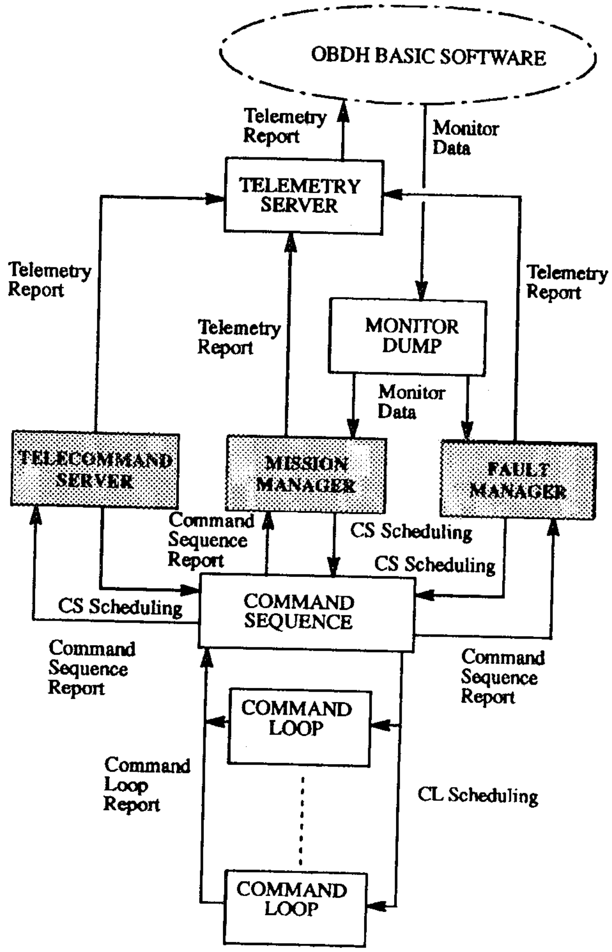


Fig. 4 - OBDH Application Software Architecture

- ***The Telecommand Server:*** it manages the ground initiated operations distributing and verifying the command execution.
  It furthermore applies a consistency checks on the ground up-loaded requests against the current system configuration. In the case a conflict is detected a report is provided in the A/SW telemetry but no action is undertaken until an explicit ground override is operated.

The top level of the SAX operations is, of course, a ground task. It is responsible for acting on the satellite configuration in order to set it up properly to accomplish the planned scientific observations. It has therefore to operate on both the spacecraft and the Scientific Instruments. Besides, routine maintenance operations have to be scheduled to cope with the orbit and mission events/constraints.

Some of the more frequent operations are anyway related to the orbit contact management whose ground intervention extends to:

* linking acquisition via the proper activation of the transmitter linked to the ground facing antenna. This is done by a time tagged telecommand acting on a dedicated A/SW command sequence which is devoted to verifying the correct functioning of the on-board link chain
* enabling the telemetry transmission to ground once the down-link carrier is obtained. This concerns the real-time telemetry and, on request, the on-tape data stored in the non-coverage period
* restoring the on-board data recording and termination of the link before the end of the contact period
* command the issuing of the on-board time samples for on-ground data correlation
* managing the antennae switch-over as the coverage concerning the facing antenna is going to end. Note that two hemispherical antennae are implemented on SAX in order to cover the whole space around the satellite.

Less frequent operations are related to scientific observation management. That involves:

* changes of the satellite attitude via dedicated AOCS Operating Plans
* changes of allowed pointing domains
* changes of Scientific Instrument operating modes
* Scientific Instrument configuration management, in particular at any entry/exit of the South Atlantic Anomaly.

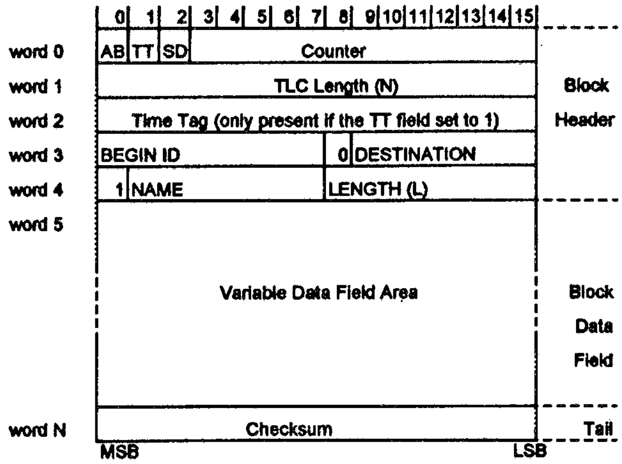
Other infrequent operations are related to performance or maintenance aspects. In this context, the ground control centre shall periodically monitor the satellite dumped telemetry to keep under control the actual on-board configuration. It can therefore intervene for recovering any on-board assumed safe mode or, simply, for tuning some control parameters such as, for example, battery *End Of Charge* and/or *End Of Discharge* levels, thermal loop thresholds and/or enabling/disabling flags, sun vector and attitude quaternion values, etc..

GROUND COMMANDING CAPABILITY

The ground commanding capability is driven by three major parameters:

- the visibility period
- the up-link characteristics
- the on-board command management design & operations.

The major constraint on the commanding capability comes from the very limited visibility window. This requires the Operation Control Centre to prepare a well-defined timeline for a long period, e.g. one week - corresponding to about one hundred passages, operating in the interin of two passages just to analyze the dumped



AB = OBDH A/SW or B/SW routing flag
TT = Time Tag flag
SD = switchover flag

Fig. 5 - Block Command Structure

telemetry and to react to any anomaly detected. All the commands necessary for operating the satellite both in and out of visibility must be up-loaded during the contact period.
The up-link characteristics are based on the ESA PCM Telecommand Standard. It allows the transmission of 2000 bps, that is - as the ESA standard telecommand frame is 96 bits long - a bit more than 20 frames/second. The minimum instruction can be based on a single frame structure. In the case a complex command is needed, a mutiframe message - constituting a block command - can be up-loaded. The block command structure used on SAX is shown in Fig. 5.
Based on the above mentioned standard, the on-board design provides ground with three different options of intervention. Three classes of commands are, in fact, made available and properly managed on board.

- Single frame commands that can be used to up-load high priority command whose purpose is to operate on a critical subset of the satellite hardware devices. This type of commands by-passes any on-board SW control and, via the decoder, directly acts on the end items. This class is thus useful as a back-up in case of an emergency. Typical applications are switching operations involving, for example, unit selection and separation event override command to AOCS.
- Single frame commands that can be used to directly issue single instructions on the OBDH Bus to any terminal. This class might be used only in the case of OBDH B/SW bus management malfunction since they by-pass the OBDH B/SW control. Care might therefore be taken because such asynchronous instructions can affect the proper OBDH Bus protocol functioning.
- Block commands that represent the nominal way of commanding. Their structure can be flexibly filled in so that they can contain either one multi-parameter command or a set of single instructions or one operating plan. Their routing is performed by the OBDH B/SW according to the destination field content. Other syntactic/semantic information is contained in the block header for on-board verification and execution, i.e., begin pattern, destination, name and length.

What is particularly important to emphasize is the on-board capability of managing the block commands as delayed commands. By means of a dedicated flag, ground can, in fact, impose their execution at the time specified in the relevant tag field. A queue of one hundred time tagged commands is dedicated in the OBDH protected memory area. - an estimation of about 60 block commands, as a maximum, has been evaluated as necessary each orbit for nominal spacecraft and Scientific Instrument operations. It is worthwhile noting that a dedicated flag is also present in the block structure indicating whether the command has to be deleted in case of CTU switch-over. Since a system reconfiguration takes place at the CTU switch-over, this option is quite useful to avoid any unwanted override unless not explicitly authorized by ground. The mission critical commands, e.g. *Transmitter ON* command, should, anyway, always remain in the queue until their scheduling time elapses.
Within these commanding possibilities ground can address specific requests to any on-board subsystem coordinating the mission operations both in and out of visibility.

One of the major aspects offered by the OBDH A/SW design is the capability of modifying the OBDH A/SW control, devoted to the system operations, by means of simple enabling/disabling commands. As the most important A/SW functions are implemented by a table driven mechanism, a flag has been associated to each of the table entries.

The relevant control can be made active or inhibited by setting the proper value of these flags. An easy updating of the table elements, used as comparison for activating autonomous recovery actions, can be, as well, easily done by mean of dedicated commands.

One of the more powerful features that are made available for emergency ground intervention is specific command to the OBDH operating system. The OBDH SW - in particular the A/SW - is based on a very modular architecture so that each command loop and sequence has been implemented as a stand alone task. Therefore, proper acting on the operating system primitives can modify the task scheduling mechanism.

In particular, the following main interventions can be run-time commanded:

* change the task priority
* init/start/stop tasks
* send/receive messages on mailboxes.

This mainly allows the introduction of a new task implementing new functionalities or replacing the current ones.
The lowest level of possible intervention by ground is the patching of the Intelligent Terminal software. It can be accomplished through the OBDH support which either autonomously executes the patch command on itself, if so addressed, or routes the new data/instructions towards the relevant Intelligent Terminal via the OBDH Bus protocol. The same can be done by directly sending patching commands to the AOCS and the LECS which implement the capabilities of executing the patching by themselves. This avoids putting the microprocessors in wait state until the patch is terminated.

Both the interventions on the operating system and the code have anyway to be planned very carefully with the support of a Software Maintenance Facility whose team shall have a very thorough expertise.
As far as the telemetry commanding capability is concerned, two major features are provided on SAX.
The first one concerns the housekeeping data transmission to ground whose format can be selected between two:

* one essential format corresponding to the produced data set from all the subsystems
* one intensive format that, besides the previous set, includes extra data packets from the hot redundant battery control unit and the B/SW tracing process.

The second is devoted to driving the scientific data collection algorithm. The algorithm, once the scientific activity is enabled, is executed every second, polling the six scientific instruments to get the number of ready scientific packets. The share of the successive scheduled acquisitions between the instruments is based on two ground configurable allocation tables, each of their entries indicating one, out of six, instrument address. Adjustment of the content of the two tables can be done by ground according to each Scientific Instrument data production forecast. Two dedicated commands are available for this purpose.
Last but not least, extra data can be required by ground, dumping both the code and the data segments of each Intelligent Terminal for diagnostic purposes. That in particular allows to obtain some memory areas of the Intelligent Terminals devoted to storing history or trace records not included in the periodic provided telemetry.

OPERATING PLANS

Setting the AOCS and Scientific Instrument configurations and modes usually requires many commands. This can overload both the time tagged command queue and the related scanning process. A solution to this potential problem has been found in grouping a consistent set of commands into only one Operating Plan.
Two types of plans are, in particular, implemented on SAX:

- **AOP** - ***Attitude Operating Plans*** - devoted to commanding the mode transitions of the AOCS and to controlling the attitude manoeuvres within the fine pointing modes
- **POP** - ***Payload Operating Plans*** - devoted to setting-up the instrument configuration and the data output formats for the required scientific performance.

These plans can be up-loaded encapsulated into one command block and then stored in a dedicated Parcking Memory Area. Their activation is requested by ground via the associated *Transfer* and *Enable* Commands, either in real-time or delayed with proper time tags. The actual execution, by the destination terminal, shall follow the correct reception and validation of the incoming Operating Plan only once the *Enable* command is received. Supervision of the whole consistency of this transfer/enabling process is centralized and autonomously made by the OBDH A/SW. It is, in fact, in charge, if enabled, of filtering the *Transfer* and *Enable* commands if not consistent with the satellite mode/configuration, e.g. in the case of Safe Mode fall-back.
As far as the *safe* AOCS modes are concerned no AOP are, anyway, needed since the related attitudes are autonomously acquired and indefinitely kept.

COMMISSIONING CHECK-OUT

The in-flight verification of SAX will be performed in a designated eigth week Commissioning Phase following its launch and separation from the launch vehicle.

The purpose of the Commissioning Phase is to validate the functionality and operability of the satellite and give the go-ahead to the scientific mission. The relevant check-out activity is comprised of two principal sub-phases.

Phase I involves the basic functional/ performance verification of each of the spacecraft subsystems.
Phase II complements Phase I by extending the verification to all the Scientific Instruments and completing the verification of the fully active system configuration.

A summary of the planned activities includes:

- ***Mode Functionality Verification***
  All nominal modes shall be verified for functionality, valid telemetry parameters and expected ranges with respect to the inherent functions of each mode.
- ***Commanded Mode Transitions***
  All nominal mode transitions requiring an uplinked procedure from Ground will be performed and verified. Certain transitions will be omitted for specific reasons, e.g. Delta-V mode transitions.
- ***Autonomous Mode Transitions***
  Verifications of autonomous fall-backs will not be performed as they require fault conditions forced by ground.
- ***Cyclic and Selectable Telemetry Verification***
  All the cyclically generated telemetry will be verified for correct protocol handling, telemetry block structures, parameter location and consistent time and block counter fields. Variable telemetry activated by ground will be verified as well, e.g. dumped data and scientific packets.
- ***On-board Memory Patch and Dump***
  Dump operations will be required to evaluate control parameters not visible in regular telemetry, e.g. AOCS database, history areas, etc. Patches of program or data memories are not a nominal activity but could sometimes be necessary for table item updating, e.g. LECS Instrument. A dump should always be required after a patch operation.
- ***Control Function Calibrations***
  Calibrations or maintenance are required to optimize the overall performance of both the Scientific Instruments and the Subsystems, e.g. thermal control loops thresholds, Instrument digital and analogue discriminator levels, etc..
- ***Redundant Unit Check-out***
  Under nominal operations all operative redundant units will be verified for correct functionalities, e.g. gyros, decoders, receivers, etc.. Cold redundant units will not be activated or verified unless necessary because of failures. It is considered more prudent to maintain a good nominal configuration rather than risk possible failure in activating the redundant one.

CONCLUSIONS

The SAX satellite is the result of a quite challenging mission requirement implementation.
Once in orbit it will support the extensive activity of six complex Scientific Instruments performing parallel X-ray observations.
The system design is based on a distributed intelligent architecture allocating to each of the on-board computers its own specific function. This has been designed to provide the maximum flexibility and reliability in autonomously executing the ground mission plans. The SAX implementation of the operating modes, in fact, allows the on-board configuration to be maintained by itself, supporting, at the same time, the ground required operations.

To conclude, the SAX mission will not only provide the most up-to-date results in the field of X-ray astrophysics, but it will also make operative a very powerful system that is the product of Italian scientific satellite engineering.

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