The Data Handling system for the AGILE Satellite

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Abstract—**AGILE, Astrorivelatore Gamma ad Immagini LEggero, is a small space mission of the Italian Space Agency (ASI) devoted to observations for astrophysics in the gamma ray energy range 30MeV–50GeV with a simultaneous window in the X-ray band 15keV–45keV. AGILE Payload is composed by four scientific detectors: a Tungsten-Silicon Tracker, a CsI Mini-Calorimeter, a Silicon based X-ray imager and an anticoincidence system for particle background rejection. Moreover, the Payload is completed by a Power Supply Unit (PSU) and a Payload Data Handling Unit (PDHU) and by three ancillary sub-systems (a GPS receiver and two Star Sensors). The PDHU tasks are: the Payload scientific and ancillary sub-systems control, the operational modes management, the scientific data processing and the Telemetry and Telecommands management. The scientific data processing involves the gamma-ray photons filtering, the X-ray data acquisition and a Burst acquisition logic able to perform an on-board Burst coordinates determination. The HW and SW design and implementation is in charge of the Alenia Spazio S.p.A. - Laben. In this paper we present a general description of the PDHU and the guidelines for the scientific simulations and the HW and SW testing activities.**

I. INTRODUCTION

AGILE is a Small Scientific Mission dedicated to high-energy astrophysics supported by the Italian Space Agency and scientifically developed in CNR and INFN laboratories [1]-[2].

AGILE is currently in Phase D, and planned to start operations during the year 2005.

The AGILE instrument is highly innovative and designed to detect and image photons in the 30MeV-50GeV and 15-45keV energy bands. AGILE is characterized by an excellent spatial resolution and timing capability, and by an unprecedently large field of view covering ~1/5 of the entire sky at energies above 30MeV.

The AGILE spacecraft will be of the MITA class (total satellite weight of ~300kg) to be launched in a low-background equatorial orbit of height near 550km. The AGILE scientific data will be of great relevance also for joint studies of high-energy sources with other scientific satellites and ground-based facilities for radio/optical/TeV observations.

The AGILE Payload is composed by four scientific detectors (see Fig. 1): a Tungsten-Silicon Tracker (ST), a CsI Mini-Calorimeter (MCAL), a Silicon based X-ray imager named Super-AGILE (SA) and an anticoincidence system (AC) for particle background rejection. Moreover, the Payload

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is completed by a Power Supply Unit (PSU) and a Payload Data Handling Unit (PDHU) and by three ancillary sub-systems (a GPS receiver and two Star Sensors).

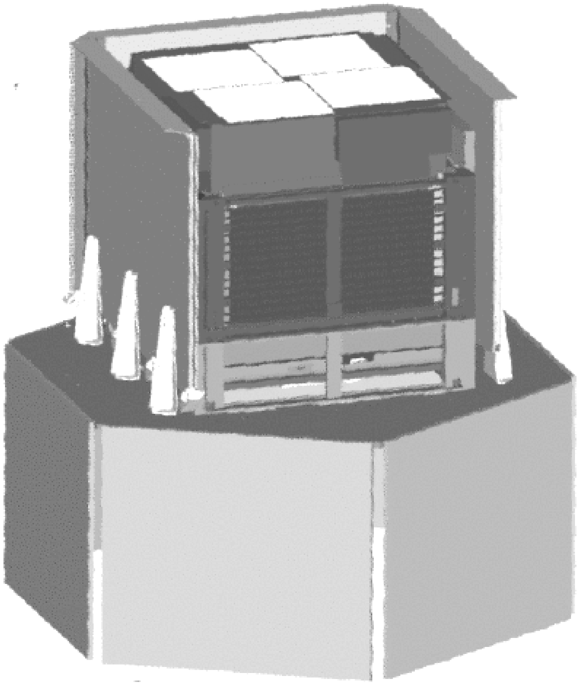

Fig. 1. Schematic view of the AGILE Payload (AC system partially displayed). The gamma-ray imager is made of a Tracker (10 Tungsten-Silicon planes + 2 Silicon planes) and a Mini-Calorimeter (two layers of 15 CsI(Tl) bars each). Super-AGILE has its detection plane with 4 independent Si-detectors on top of the first Tracker tray, and an ultra-light coded mask system positioned above it.

II. THE PAYLOAD SCIENTIFIC DETECTORS

The principal features of the Payload Scientific Detectors are summarized below.

ST, a gamma-ray pair-converter and imager, is made of 12 planes, with two Si-layers per plane providing the x and z coordinates of interacting charged particles [3]-[4]. The Silicon detector unit is a tile of area 9.5x9.5cm^2 produced by HAMAMATSU, microstrip pitch equal to 121μm, and thickness of 410μm. Four tiles are connected together edge-on to create a "ladder". Each ladder has 384 readout channels for a strip pitch of 242μm while the physical pitch is 121um, given the presence of a floating strip. Each ladder is read by 3 low noise self-triggering TAA1 ASICs produced by IDEAS. Each tracker view is made of 4 ladders for a total of 1536 readout channels and an active area of 38x38cm^2

The first 10 planes are made of three elements: a first layer of Tungsten (0.07 X_0) for gamma-ray conversion, and two Si-layers (views) with microstrips orthogonally positioned. For each plane there are then 2x1536 readout microstrips. Two more Si-planes are inserted at the bottom of the Tracker without Tungsten layers. The total readout channel number of for the ST is 36864. Both digital and analog information (charge deposition in Si-microstrip) is read by TAA1 ASICs. The distance between mid-planes equals 1.9cm and it has been optimized by MonteCarlo simulations.

Two front-end and trigger boards (FTB) are the supervisor boards of the ST front-end; they have to interface the silicon detectors front-end to the readout system, to properly handle the trigger signals, the power lines and the ST Housekeepings. Each FTB handles the 12 ST views related to the same projection (x or z) and the relevant front-ends electronics. The ST has an *on-axis* total radiation length of the order of ~1 X_0.

SA is made of four square Silicon detectors (19x19cm^2 each) and associated FEE placed on the first ST tray plus an ultra-light coded mask system supporting a Tungsten mask placed at a distance of 14cm from the Silicon detectors [5]-[7]. Two Interface Electronics boards are in charge of actively interfacing the four Super-AGILE detector units with the PDHU. The total number of readout channels is 6144.

MCAL is made of two planes of 15 CsI(Tl) bars each, for a total (on-axis) radiation length of 1.5 X_0 [8]. The bars, whose dimensions are 15mmx23mmx375mm, exhibit a low light attenuation combined with high light output. The signal from each Csl bar is collected by two photodiodes placed at both ends. The MCAL front-end is composed by two data acquisition chains:

- a Gamma-Ray Imaging Detector (GRID) chain providing energy information for the particles generated by the ST pair conversion and interacting in the MCAL. The GRID chain is slave of the ST trigger logic.
- a Burst chain detecting gamma ray impulsive events in the energy range 250keV–250MeV. In this case MCAL works as a burst monitor detector independently of the GRID trigger logic.

AC is aimed at both charged particle background rejection and preliminary direction reconstruction for triggered photon events. The AC system surrounds the other scientific sub-systems (SA, ST and MCAL). Each lateral face is segmented into three plastic scintillator layers (0.6cm thick) connected to photomultipliers placed at their bottom. A single square plastic scintillator layer (0.5cm thick) constitutes the top-AC layer whose signal is read by four photomultipliers placed at the four corners.

III. THE PAYLOAD DATA HANDLING UNIT

The PDHU performs the following principal tasks:

- Payload internal control;
- scientific data processing;
- operative modes management;
- on board time management;
- telemetry management;
- telecommands management.

The PDHU on board time is based on a high precision 28MHz temperature compensated crystal oscillator (TCXO). A time counter clocked by the TCXO signal is continuously re-synchronized using a pulse per second signal (PPS) provided by the on-board GPS. This system will guarantee a PDHU time-tagging accuracy better than 1.8μs @ 3σ, with respect to the Universal Time.

The scientific data processing is composed by (see Fig.2):

- the GRID Trigger, based on the simultaneous acquisition and analysis of data from the ST and the MCAL GRID chain and the veto signal provided by the AC;
- the Burst Search, consisting of the analysis of the SA and MCAL Burst ratemeters integrated on different timescales and energy ranges and of the SA Burst Imaging implementation;
- the SA Acquisition Logic, consisting of the simultaneous acquisition of the SA data in the energy range 15-45keV and the veto signals provided by the AC, the ST and the MCAL.

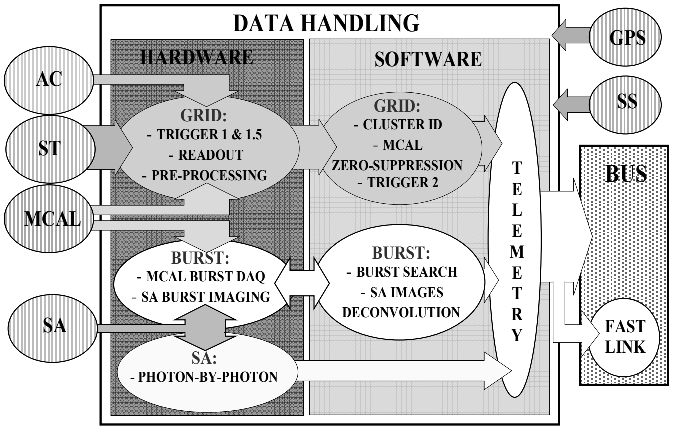

Fig. 2. Schematic view of the hardware and software processing implemented in the PDHU.

A. *The GRID Trigger*

The GRID data processing for the acquisition of gamma-ray data and background rejection is divided in three main levels: the Level-1, the Level-1.5 and the Level-2 trigger stages.

The Level-1 trigger, activated by the ST FEE, verifies if the combination of the fired AC panels and the number of the fired TAA1 ASICs are consistent with the interaction of a photon in the Silicon Tracker.

An intermediate Level-1.5 stage evaluates the event topology defined by the distribution of the fired TAA1 ASICs and starts the readout of the ST and the MCAL data.

Both Level-1 and Level-1.5 have a hardware-oriented veto logic providing a first cut of background events with fast response (~25μs). The charged particle and albedo-photon background surviving the Level-1+Level-1.5 cuts is simulated to be ~100 events/sec for the nominal equatorial orbit of AGILE.

The Level-2 is a software trigger stage which performs, after a dedicated data pre-processing, a last event selection aimed to reduce the background by a factor between 3 and 5.

The Level-2 trigger stage is composed by two separate processing steps:
- a Level-2/step-1 performing a refining of the Level-1 and Level-1.5 triggers;
- a Level-2/step-2 performing a track reconstruction by means of a Kalman Filter and a minimum χ^2 track selection method.

The background rejection is obtained by the Level-2/step-2 comparing the χ^2 factor with a threshold and the reconstructed event incoming direction with the current earth-satellite position computed on-board using the GPS and Star Sensor (SS) data.

The Level-2 trigger (duration of few milliseconds) is a full asynchronous processing stage and does not increase the GRID deadtime which results typically <200μs.

The GRID events surviving the Level-2 trigger are collected in a dedicated TM packet and sent to ground.

B. *The Burst Search*

The Burst Search (BS) is implemented by the PDHU on the basis of the MCAL Burst chain and the SA data. Since the Gamma-Ray Burst (GRB) signal is strongly energy and timescale dependant, the SA and MCAL Burst ratemeters used by the BS algorithm are integrated on different timescales and energy ranges.

SA Burst Logic: the SA Burst Logic is made of three principal components: the SA Normal Burst Search, the SA Burst Imaging and the SA Sub-millisecond Burst Search.

The SA Burst Normal Search is aimed to detect GRBs on timescales from 1ms to ~65s and generate proper SA Normal Burst triggers.

The SA Burst Imaging is aimed, in case of SA Normal Burst trigger, to fast determine the GRB coordinates. For this purpose, two attitude corrected SA images are continuously accumulated in order to provide, during a burst acquisition, a Background image and a Burst image.

The GRB coordinates are calculated after few seconds (~<16s) subtracting the Background image from the Burst image and computing the cross-correlation between the resulting subtracted image and the SA mask code.

A Burst Alert containing the GRB coordinates is sent to the Bus with high priority in order to be transmitted to ground by a fast link based on the Orbcomm constellation.

The SA Sub-millisecond Burst Search is aimed to detect fast transients on timescales <1ms and communicate to the MCAL a special SA Sub-millisecond Burst trigger.

MCAL Burst Logic: the MCAL Burst Logic is made of two principal components: the MCAL Normal Burst Search and the MCAL Sub-millisecond Burst Search.

A MCAL Normal Burst Search Logic is aimed to detect GRBs on timescales from 1ms to ~65s and generate a proper MCAL Normal Burst trigger. The OR signal of the SA and MCAL Normal Burst Triggers activates a saving procedure of the MCAL Burst data normally stored in a set of cyclic buffers. The data are collected in a dedicated TM packet and sent to ground.

The MCAL Sub-millisecond Burst Search is aimed to detect fast transients on timescales <1ms and generate a special MCAL Sub-millisecond Burst trigger.

The OR signal of the SA and MCAL Sub-millisecond Burst Triggers activates the saving of the MCAL Burst data. The data are collected in the MCAL Burst TM packet and sent to ground.

C. *The SA Acquisition Logic*

The SA event data are received by the PDHU from the SA Interface Electronics in a 60-bit packet format. The PDHU performs a correction procedure based on the readout ASICs temperature dependence and non-linearity and the compression of the 60 bit/event format into the 32 bit/event format foreseen by the telemetry packet. The PDHU is also in charge of generating and distributing to the SA FEEs the AC, the ST and the MCAL veto signals.

IV. THE PDHU HARDWARE AND SOFTWARE ARCHITECTURE

The HW and SW design and implementation is in charge of the Alenia Spazio S.p.A. - Laben. The PDHU box contains the following electronic boards:

- 1 Tracker and AntiCoincidence Electronics (TACE) board providing the AC veto signals and implementing the GRID Level-1 and Level-1.5 trigger stages;
- 2 Tracker Acquisition Boards (TAB) receiving, digitalizing and pre-processing all the scientific analog data coming from the Silicon Tracker FEEs;
- 1 DSP board hosting a TEMIC 32 bit floating-point TSC21020F Digital Signal Processor and providing serial interfaces towards the spacecraft, the scientific subsystems, the PSU, the ancillary subsystems (GPS and SS) and the PDHU system bus;
- 1 Super-AGILE Digital Electronics (SDE) receiving and processing the SA scientific data;
- 1 Mini-Calorimeter Digital Electronics (MDE) receiving and processing the MCAL scientific data;
- 1 backplane hosting the PDHU system bus making possible the signal exchanging between the PDHU boards.
- 1 motherboard devoted to the multiplexing of the configuration serial busses and analog housekeeping collection of the Front End boards.

The HW processing required for the PDHU, together with low power and low weight constraints, has been fulfilled by widely using Field Programmable Gate Arrays (FPGA). In fact, the PDHU hosts 12 FPGAs (RT54SX32S by Actel) each with 32 equivalent kilo-gates.

The software of the AGILE Payload is embedded into the processor of the DSP board and is composed of three physical packages: the Boot application, the Maintenance application and the Nominal application. The Boot application and the Maintenance application run in EEPROM, while the Nominal application runs in RAM. The EEPROM area where the Boot and Maintenance applications lie cannot be modified.

The Boot application performs initialization and checks at power-on. The Maintenance application allows code and data reloading. The Nominal application is in charge of all the scientific and control tasks committed to the on-board SW.

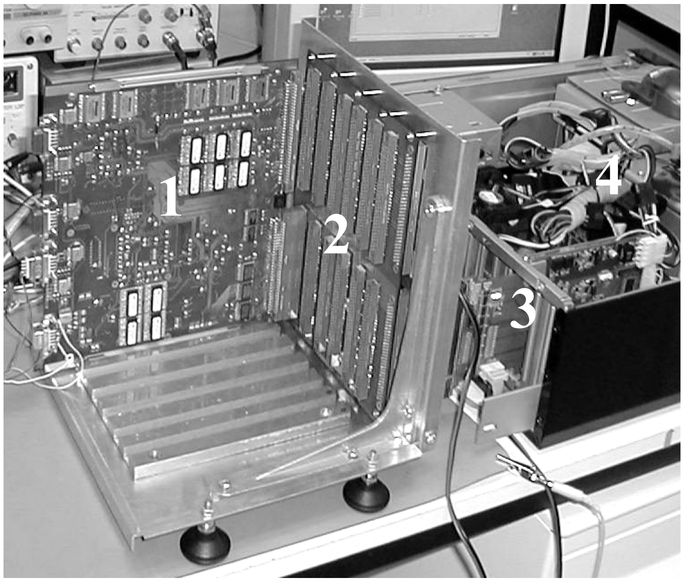

Fig. 3. The PDHU Functional Model composed by: 1. the DSP Board; 2. the PDHU backplane; 3. the PCI custom made board that statically simulates the other PDHU boards; 4. the MMI PC.

V. THE GRID SIMULATIONS AND TEST ACTIVITIES

A preliminary Data Handling test facility has been set-up for a first validation of the on-board GRID software module. For this purpose, the PDHU Flight Model is represented by a reduced FUnctional MOdel (FUMO) composed by the DSP board, the backplane and a PCI custom made board that statically simulates the other PDHU boards. This system is connected to a dedicated PC providing the Man Machine Interface (MMI) (see Fig.3).

Furthermore, the test facility includes the following main items:

- a MonteCarlo simulation code developed using GEANT3 and FORTRAN representative the whole satellite [9]-[10];
- a Data Handling GRID simulator written in IDL and C codes and entirely interfaced with the Ground Segment Software;
- a reduced P/L Electrical Ground Support Equipment (EGSE) plus a Central Checkout Equipment (CCOE), which interfaces the PDHU FUMO, provides the operator console to sequence the test operations, and forwards in near real time the Telemetry (TM) and the Telecommand (TC) packets to the AGILE Science Console.
- a AGILE Science Console (SC), a Linux-PC running the DISCoS based software for the real time acquisition, archiving and processing of the TC and TM packets [11]-[12].

Basically, a stream of GRID events are generated by the MonteCarlo simulator and processed by the GRID simulator. This simulator output represents the expected response of the PDHU and has the same format (FITS event lists) generated with the GRID data extracted from the TM packets by the SC. The same events are processed by the PDHU FUMO and the relevant telemetry acquired by the EGSE and transferred to the SC. At the end, the compliance of the GRID processing implementation with the scientific requirements is verified by the SC Quick Look software comparing, event by event the real PDHU FUMO telemetry with the simulated one (see Fig.4).

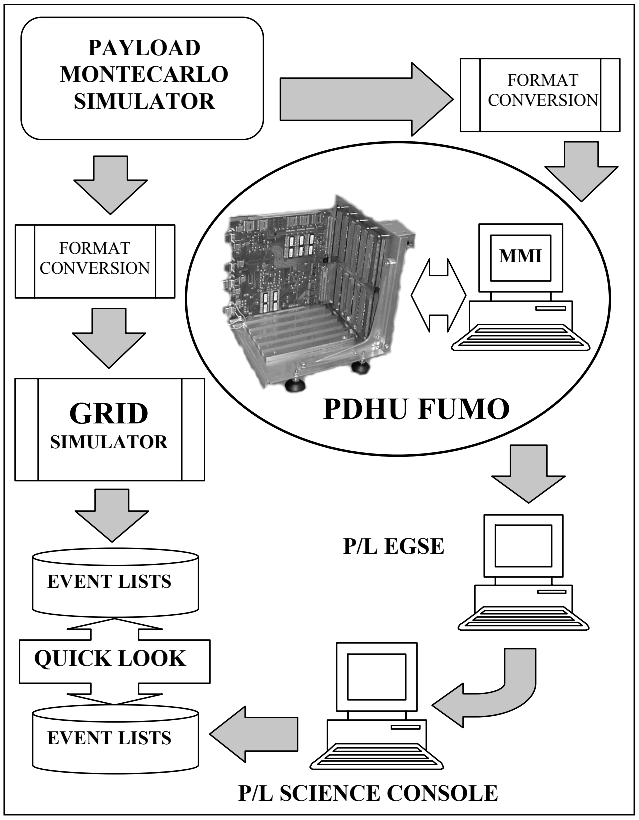

Fig. 4. The Test Flow of the GRID software module at the PDHU FUMO level.

VI. CONCLUSIONS

The AGILE scientific instrument is innovative in many ways, and is designed to obtain an optimal gamma-ray detection performance despite its relatively small mass and absorbed power. The combination of hard X-ray (Super-AGILE) and gamma-ray imaging capabilities in a single integrated instrument is unique to AGILE. The PDHU is designed in order to allow positioning better than ~6 arcmin in the hard X-ray range, instrumental deadtimes for the different detectors unprecedently small for gamma-ray instruments, and microsecond photon timing. Furthermore, an optimal Burst Search Procedure is implemented in the PDHU allowing a GRB search for a wide range of durations from hundreds of microseconds to around one hundred of seconds.

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