GG – GALILEO GALILEI

PAYLOAD

DEVELOPMENT & VERIFICATION PLAN

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1. GENERAL

1.1 SCOPE OF THE DOCUMENT

This document is written in the framework of the GG Phase A2 study.
The GG - Galileo Galilei project is an ASI (the Italian Space Agency) study assigned to Thales Alenia Space Italia.
The relevant contract/purchase order is n. PE-BA 48590.

1.2 APPLICABLE DOCUMENTS

[AD1] TAS contract/purchase order n. PE-BA 48590

[AD2] GG- Galileo Galilei WP n. 1B1-AD "Payload Architecture" in SGS-TASI-PRO-0063.

1.3 REFERENCE DOCUMENTS

[RD1] Proposta Tecnico – Gestionale, Galileo Galilei (GG) Fase A2, SGS-TASI-PRO-0063, vol. 1, TAS-Torino, Dec.2007.

[RD2] "Proposed noncryogenic, nondrag-free test of equivalence principle in space" A.M. Nobili et al, in New Astronomy 3, 175-218 (1998).

[RD3] GG-Payload Architectures and Trade-off Report, TL25033, TAS-Milano (issue 3, June '09)

1.4 ACRONYMS

ASI	The Italian Space Agency
COG	Centre of Gravity
CPE	Control & Processing Electronics (unit)
CE	Conducted Emission)
DM	Development Model
ECE	Experiment Control Electronics
EGSE	Electronic Ground Support Equipment
EMC	Electro-Magnetic Compatibility
EP	Equivalence Principle
FEE	Front End Electronic
FPGA	Field Programmable Gate Array
GGG	GG on-Ground (experiment)
GSE	Ground Support Equipment
HK	House Keeping data
HV	High Voltage
HW	Hardware
I/F	Interface
MGSE	Mechanical Ground Support Equipment
MOI	Moment of Inertia
PA	Product Assurance
PCB	Printed Circuit Board
PGB	Pico Gravity Box
PI	Principal Investigator
PSU	Power Supply Unit
S/C	Spacecraft
SW	Software
TAS	Thales Alenia Space
TBC	To Be Confirmed
TBD	To Be Defined
TC	Telecommand
TE	Test Equipment
TM	Test Mass

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2. PAYLOAD DEFINITION

2.1 MISSION OVERVIEW

The GG spacecraft and payload is a small and compact satellite. It will fly in an almost circular and equatorial orbit at 520 km altitude around the Earth. The basic shape of the satellite is a cylinder 1m in diameter and 1.3m high. The satellite will rotate like a “spinning top” around its symmetry axis with a nominal rotation rate of 1 Hz. The rotation also provides attitude stabilization. The symmetry/rotation axis is almost perpendicular to the orbit/equatorial plane. The total mass at launch is about 250 kg.

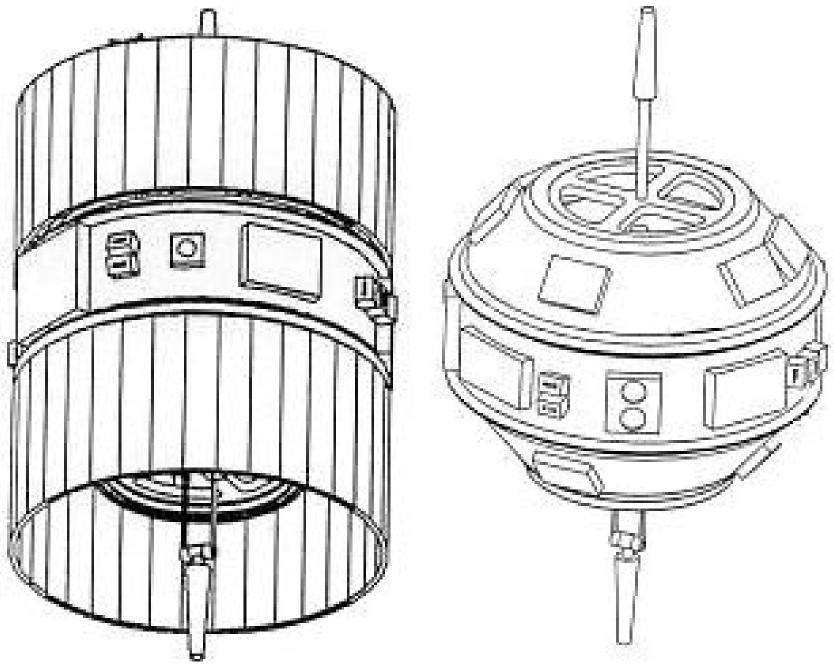

Fig. 2.1-1: The GG spacecraft with (left) and without (right) solar panels.
It is a “spinning top” with a rotation period of ½ sec.

A differential accelerometer for testing the Universality of Free Fall (UFF) is placed inside the “spinning top”. Actually, the accelerometer is mounted inside the so called Pico Gravity Box (PGB) which in turn is suspended inside the satellite, as shown on fig. 2.1-2.

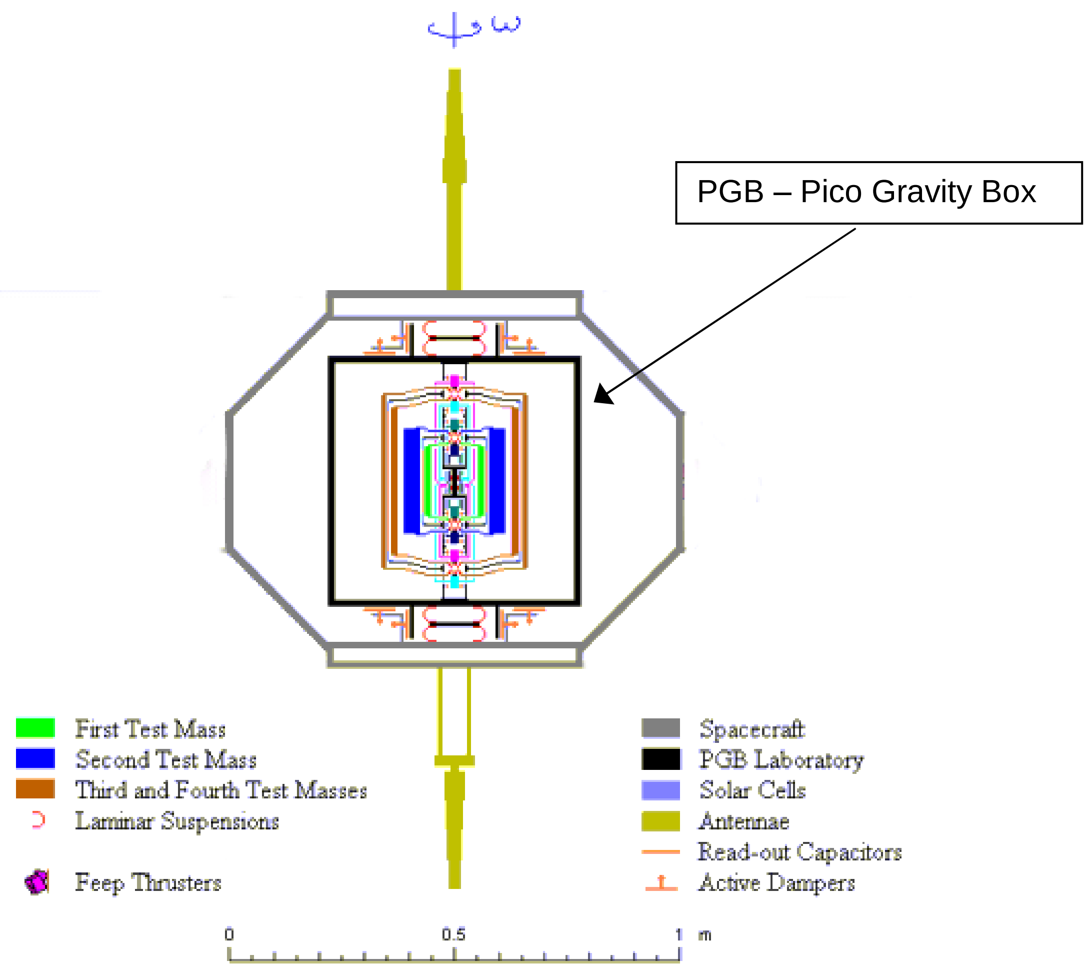

Fig. 2.1-2 Section through the spin axis of the GG satellite, a "spinning top". The accelerometer (green and blue test masses) is mounted inside the Pico Gravity Box (PGB) which in turn is suspended inside the satellite.

2.2 ACCELEROMETR KEY FEATURES

The accelerometer also has cylindrical symmetry about the rotation axis and is sensitive to differential accelerations in the plane perpendicular to the symmetry/rotation axis (see fig. 2.1-2). It will therefore sense an acceleration resulting from a breakdown of UFF in the gravitational field of the Earth, and thus test the Equivalence Principle (EP).

The challenging task of the GG mission is to reduce the level of differential disturbances between the test masses to 10^{-17} of the Earth gravitational acceleration at the satellite location.

This will be a tremendous improvement for the detection of an EP violation signal, and GG sets out to do it with a single, but symmetrical accelerometer.

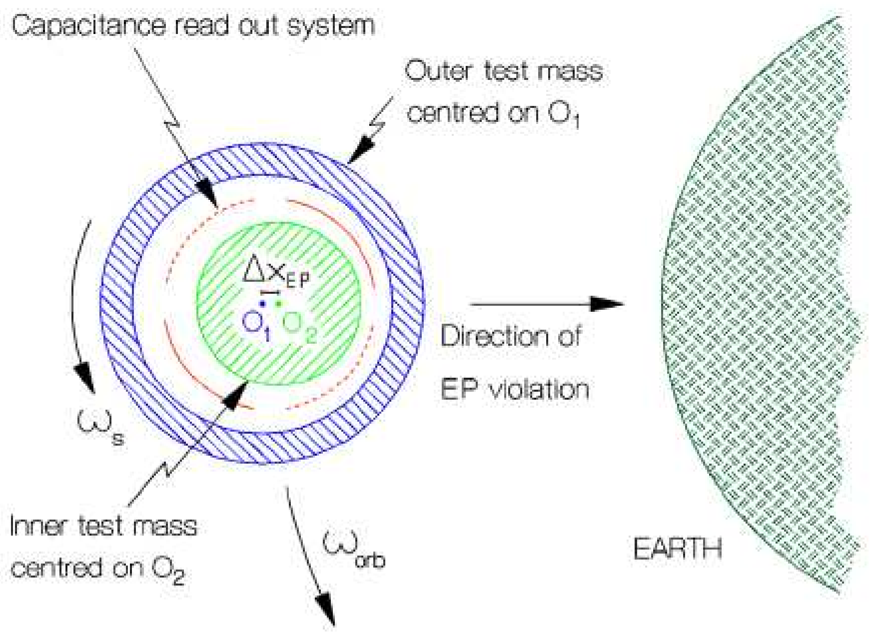

Fig. 2.2-1 Diagram of GG principle for detection of EP (Equivalence Principle) violation.

Here follows a summary of the accelerometer key features.

1. High spacecraft spin provides:
   - Higher Q for the mechanical suspension
   - Low electronic noise in the narrow bandwidth of the signal
   - Negligible radial radiometric effect
2. The PGB provides:
   - Passive attenuation of micro-vibrations (s/c vibrations, DFAC thruster noise, etc.) above its natural frequency
   - Mechanical/Thermal shield for the test masses
3. Suspension balance as accelerometer provides:
   - Self-centering suspended test masses
   - High CMRR (Common Mode Rejection Ratio) ≈ 10^5
   - Long differential motion period (≈ 500 s)

The only draw back of the GG accelerometer is the whirl motion, which is due to dissipation in its suspensions. The whirl motion happens at the natural frequency of the suspended test masses, a period of about 113 sec. However the whirl motion can be damped through active control by applying electrostatic forces on the two test masses.

2.3 PAYLOAD PRODUCT TREES

The overall product tree of the Payload is given in the figure.

For each colored box a detailed product tree is given on the following pages.

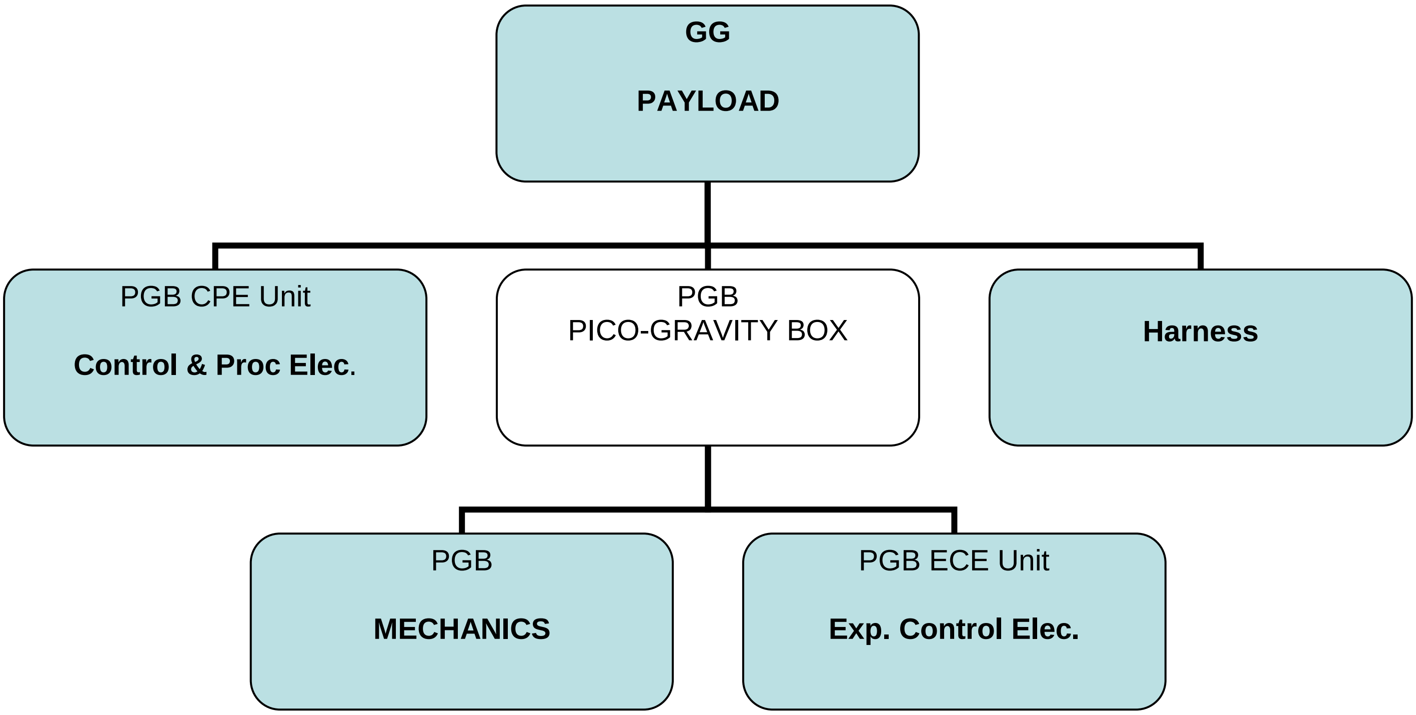

Fig. 2.3-1 Product tree of the GG payload

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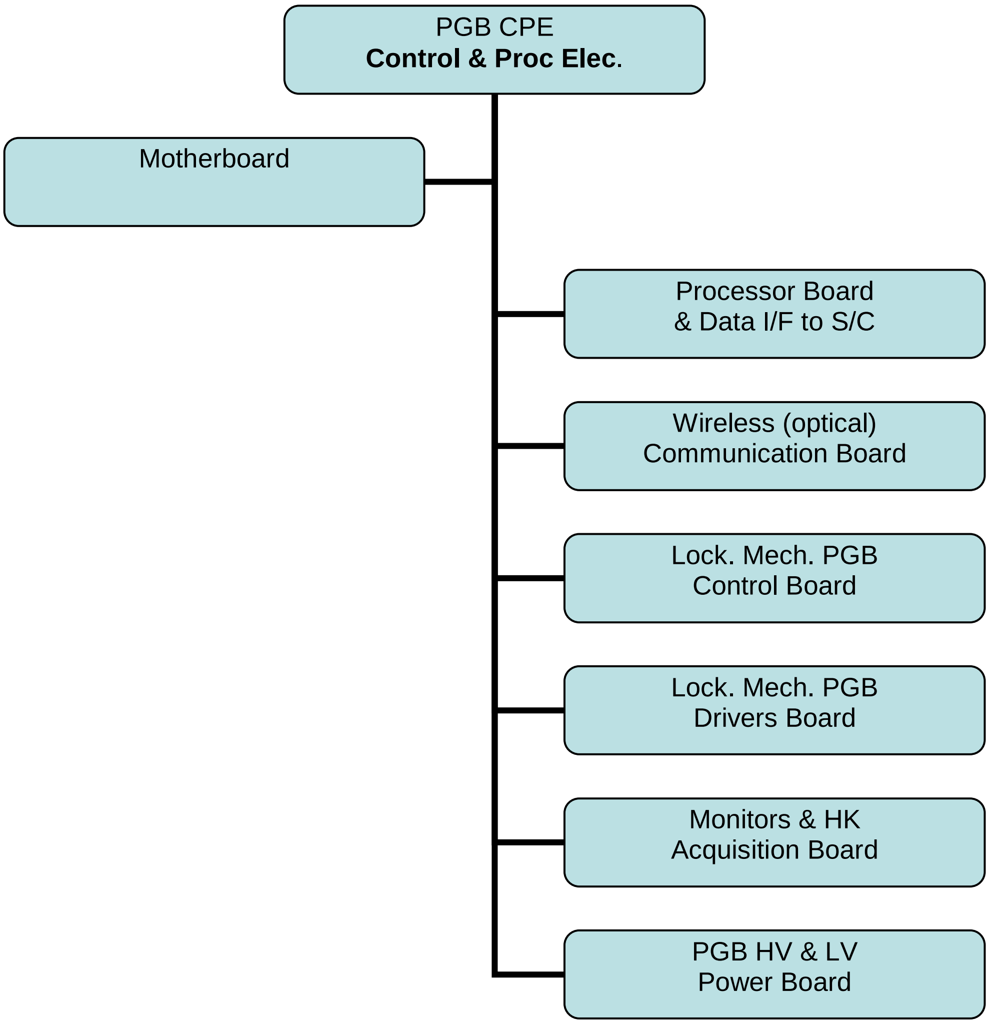

Fig. 2.3-2 Product tree of the C P E electronic unit. It is external to the PG-Box.

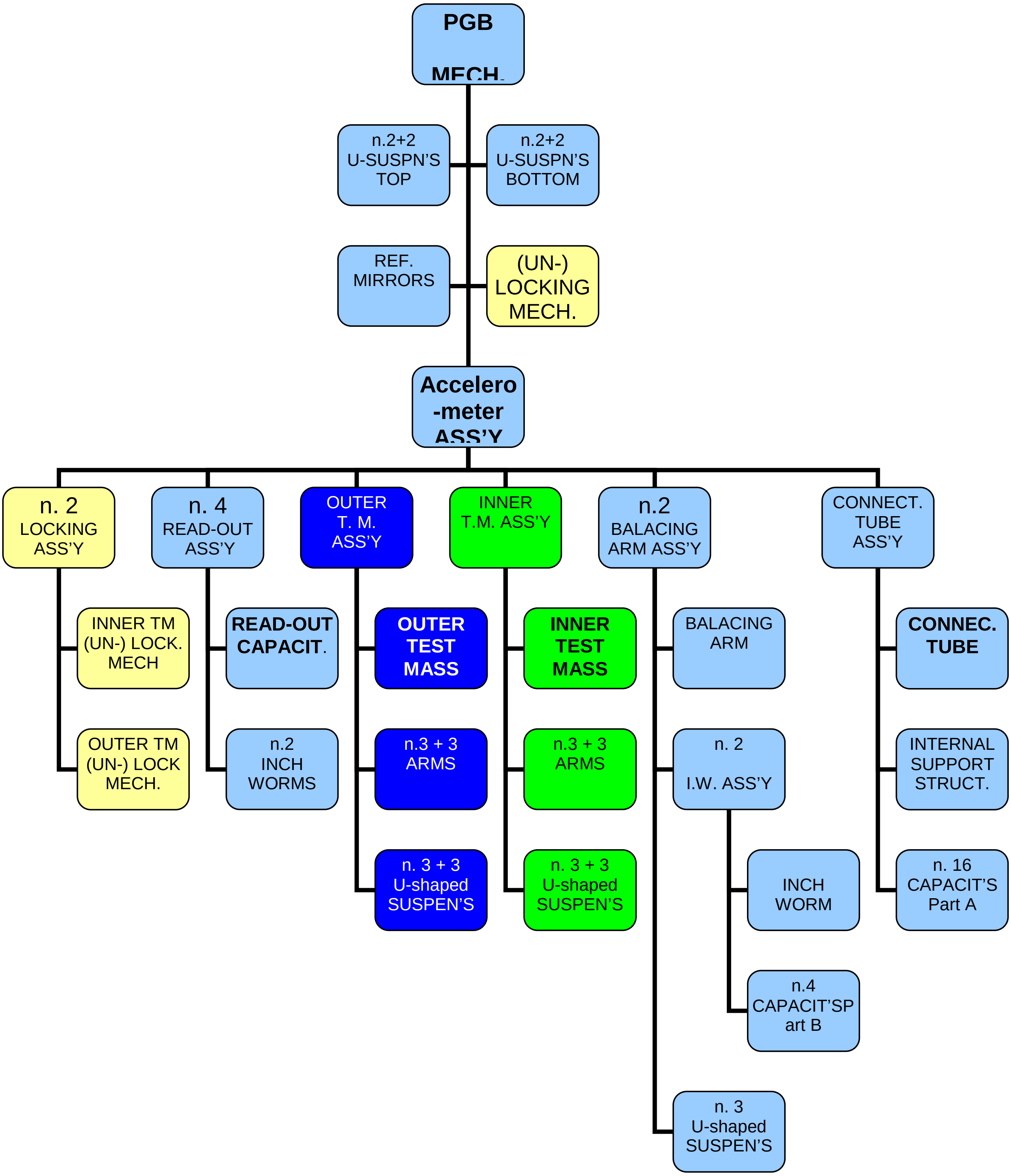

Fig. 2.3-3 Product tree of the PGB mechanics

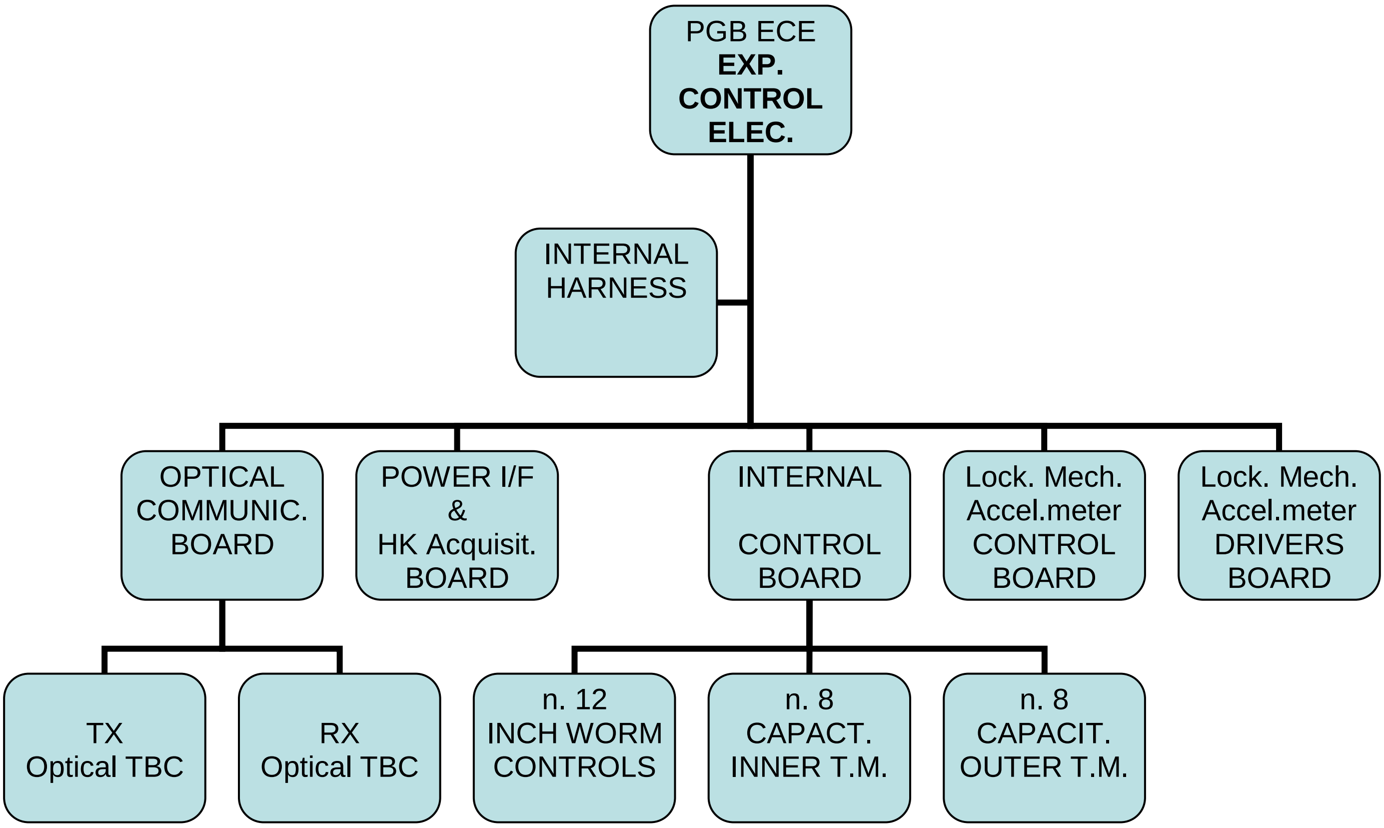

Fig. 2.3-4 Product tree of the PGB electronics, named Experiment Control Electronics (ECE). This is inside the PGB.

3. DEVELOPMENT

The design and development plan outlined in this chapter refers to the Payload as defined by the product tree in this report (para. 2.3). The main assembles / items are the Pico-Gravity-Box (PGB) and two electronic units: CPE and ECE. The later is inside the PGB. The overall product tree of the Payload is given in fig. 2.3-1, while the Payload Report (RD-3) gives more details on the design.

3.1 PAYLOAD SPECIFIC DEVELOPMENTS

Due to the GG mission peculiarities some Satellite requirements can be reached only using new or not completely developed technologies. In this section is described the areas/items that are in this category. The design and development activities for these items will be particularly accurate.

1) T.M. Accelerometer Assembly
This assembly is the core of the satellite, and the GG mission will be the first time such an instrument is flown in space. A similar instrument named GGG (Galileo Galilei on-Ground) is built in the INFN-Pisa laboratory. The GGG instrument is operating but has significantly reduced performances with respect to those foreseen/required for the space instrument GG, mainly due to the gravity on the Earth. However in engineering terms the GGG is an important validation / demonstrator model.
The development of the GG accelerometer will take much advantage of the GG instrument. Both in terms of specific design and test issues. In addition the GGG test system (test equipment) should be studied to assess its use and/or upgrading for functional testing of the GG space accelerometer.

2) PGB wireless optical data transmission (ODT)
The ODT sub-system is specific for the GG payload. It transmits all data between the payload and the satellite via an optical bi-directional link. On the payload side the ODT is housed in the ECE unit, and on the platform side in the PCE unit.
In order to meet the specific design conditions of the ODT an engineering or functional model will be developed.
It is proposed to validate the functional conditions of the ODT system by implementing the EM model of the ODT on the GGG instrument.

3) Locking/un-locking mechanisms
These mechanisms provides important support functions keeping the sensitive and very delicate items of accelerometer blocked during launch. When the final orbit is reached these mechanisms are powered and the accelerometer can be operated.
Several sets of mechanisms are required to block all items in the accelerometer. At this preliminary stage of development it is suppose that all sets of mechanisms are identical.

It is proposed to develop a bread-board with one set of Locking/un-locking mechanism and related electronics (as necessary to control one mechanism).

3.2 PAYLOAD MODEL PHILOSOPHY

One complete Payload model, PFM (Proto Flight Model) will be built. Concerning the Payload, no recurrences are possible, but the existing GGG (Ground Galileo Galilei Experiment) at Pisa will become the demonstrator / development model for the PGB.

Some critical and/or new items will be built with the standard of an EM or Functional Model. The rationale for this choice is reported in the previous section (para. 3.1) and the list of payload assemblies and units to be developed is given in the table below.

BASELINE

The baseline for the Payload is to deliver to system level only the PFM PGB plus the developed EQM items, such ECE and the CPE unit. This latter ones will be refurbished and used as flight spares.

However the complete development program foresees the items and models as listed in the table.

Equipment	DM / STM	EQM	PFM
PGB Assembly	OPTION	---	1
Lock. Mech. PGB	---	---	N.A.
Lock. Mech. Accel.	1 DM	---	N.A.
Inner Test Mass	1 DM	---	N.A.
Outer Test Mass	1 DM	---	N.A.
Accel. Mechanics	GGG-Pisa	---	N.A.
ECE Unit	Dummy	1	Incl. in PGB
CPE Unit	Dummy	1	1
Payload EGSE	---	(1 PFM)	1

TABLE Payload development models

OPTION

As an option the development and testing of a PGB STM is possible.

A structural-thermal model (STM) of the PGB could be very useful to improve confidence of the design and test during the program development. However at the current preliminary state of design the PGB does not seem to be a stand-alone unit. Therefore it cannot be tested without additional structures from the satellite. This aspect should be investigated in the following development phase.

If the STM is approved, then the PGB STM qualification test campaign shall be completed at the system CDR (or before).

4. VERIFICATION

4.1 GENERAL CONDITIONS

4.1.1 Personnel

The PAYLOAD I&V activities shall involve TAS-Milano and the scientific institutes of the GG consortium involved in the development of the ACCELEROMETER System. If any verification facility not present in TAS-Milano is used, personnel from the company providing the facility shall support the activities.

The activities shall be conducted by TAS-Milano technicians and engineers assigned to the GG Payload program. The System Manager shall designate:

a) a *Test Engineer* which is a highly qualified engineer having good experience about scientific payload systems, that controls the operation of the camera system according to test requirements;

b) a *Test Conductor* which is a highly qualified technician able to operate hardware and software TE and to conduct tests.

c) contact subsystem at PA manager or system engineer for discussion.

TAS-Milano PA personnel will be involved according to TAS-Milano internal procedure.

Support of personnel from GG science team shall be required when the subassemblies are delivered to TAS-Milano in order to verify their functionality before system integration and in case of troubleshooting during integration phase.

4.1.2 Responsibilities

Responsibilities of each integration and verification phase shall be assigned before the beginning of the activities as follows.

TAS-Milano will be responsible of the AIV execution.

GG science team shall be supervisor of the Accelerometer I&V activities.

The Test Engineer is responsible for the integration and test procedures preparation, execution and analysis of the test results.

The Test Engineer ensures that the requirements of the integration and test procedures are followed, performances are verified and data are reviewed.

The Test Engineer has the final authority to start and stop test activities. If there is a non-conformance the following action will be taken:

a) integration or test of the System shall be stopped immediately;
b) the PA representative and the Test Engineer shall assess the anomaly and determine if testing is to continue or to identify what provisions are necessary for testing to continue.

The Test Conductor has the duty to supervise logbook updating and that integration and test procedures are filled in during the integration and test activities.
The Test Conductor is responsible for the correct working of the EGSE and TE provided by TAS-Milano.

GG science team is responsible for the availability of the scientific SW and analysis(interpretation of the science data from the accelerometer.

4.1.3 Environment

The I&V activities, where the subsystems are integrated to form the PAYLOAD, shall take place in TAS-Milano.

The integration and test environment will be based on clean rooms of class 100,000. The following environmental conditions shall apply:

PARAMETER	RANGE
Temperature	15℃ to 25℃
Pressure	STP Ambient Condition
Relative humidity	30% to 65%

TABLE Environmental conditions for integration and test

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4.1.4 EGSE / Test Equipment

PAYLOAD tests shall be performed using GG payload EGSE / Test equipment.
Detailed information is reported in the EGSE System documents (TBW).

A description of the EGSE /TE architecture, including a block diagram is given in chapter 7.

4.1.5 Facilities

The mechanical, electrical, functional and performance tests are carried out in TAS-Milano. The Vibration and EMC Tests are carried out off TAS-Milano premises.
The used test equipment and facilities shall be described in the relevant test procedures.

4.1.6 Handling

Handling of the single units will be kept to a minimum so that there is minimal risk for the flight hardware.

For short periods of inactivity during integration and testing, PAYLOAD Subassemblies units shall be bagged for contamination and moisture protection with single or double layers of clean polyethylene or nylon sheets and placed in a room with controlled temperature and humidity (clean room).

4.1.7 Safety

Safety of personnel and flight hardware are foremost in planning. The I&V activities shall be conducted in a manner to prevent personnel and flight units from potentially dangerous situations.

A specific safety procedure must be followed for handling and storage of the radioactive sources that will be used in the test activities.

4.1.8 MGSE

Specific MGSE (TBC) will be used to lift and position the PAYLOAD /Accelerometer during the integration and test activities.

4.1.9 Test Software

In order to perform the test activity a specific test S/W will be developed. This S/W will run on the CCOE and will include the following:

1. Data Base;
2. Test sequences;
3. Synoptic dedicated to GG Payload;
4. Test result evaluation application (OFF Line analysis).

The database will include all the TCs, the TMs, the variables and the parameter relevant to the PAYLOAD: The GG science consortium will participate in this development.

The test sequences will be able to send (and eventually generate) the TCs and to manage the TM received in order to perform the tests in automatic mode.

The Synoptic will be a S/W tool used to visually represent the most significant control parameters received by the instrument. It will be compounded by some fields, each of which will show a parameter.

The Test result evaluation application will be a procedure to analyse and validate the test's results.

The S/W that will run has the following capabilities:

1. Science data processing;
2. Test results storage (Archive functional an Log File);
3. Evaluation tools;

4.2 VERIFICATION APPROACH

4.2.1 Verification Approach

The task of the verification process is to demonstrate conformance to applicable requirements. The verification objectives are primarily:
to qualify the design;
to ensure that the product is in agreement with the qualified design, is free from workmanship defects and acceptable for use in flight.

The verification process activities shall be incrementally performed at different levels and in different stages, applying a coherent bottom-up building-block concept and using a suitable combination of different verification methods.

The verification process flow applied to GG Payload is detailed in para.4.3.

To reach the verification objectives, a verification approach is defined in an early phase of the project by analysing the requirements to be verified taking into account:

- design peculiarities;
- qualification status of candidate solution;
- availability and maturity of verification tools;
- verification and test methodologies;
- programmatic constraints;
- cost and schedule.

The verification process is considered completed when it is agreed with the customer that, on the basis of proper documented evidence, the identified requirements have been verified and the verification objectives are fully reached.

Those requirements that will result to be not fully verified at a certain level shall be identified and resolved with the customer.

4.2.2 Verification Methods

Verification will be accomplished by one or more of the following verification methods:

- Test
- Analysis
- Review-of-design
- Inspection

4.2.2.1 Test

When requirements have to be verified by measuring performances and/or functions under various simulated environments, the method is referred to as "Test".

These measurements may require use of special equipment, instrumentation and simulation techniques. Test procedures will be prepared to determine conformance to requirements in accordance with ECSS-E-10-03. The analysis of data derived from a test will be considered an integral part of the test itself.

When relevant, a test may include also the demonstration of qualitative operational performance and requirements. The performance will be observed and recorded.

4.2.2.2 Analysis

When verification is achieved by performing theoretical or empirical evaluation by accepted techniques, the method is referred to as "Analysis".
The analytical techniques may be systematic, statistical, quantitative or qualitative design analyses and/or modelling and computational simulations.

Within the ECSS framework, verification by similarity is considered part of Analysis. It may be applied if it can be shown that the item under verification is similar to another item that was verified previously to equivalent or more stringent requirements. The verification activity consists of the assessment and review of prior test data, hardware configuration and applications.

4.2.2.3 Review-of-Design

When verification is achieved by validation of records or by evidence of validated design documents or when approved design reports, technical descriptions, engineering drawings show unambiguously that the requirement is met, the method is referred to as "Review-of-Design".

4.2.2.4 Inspection

When verification is achieved by visual determination of physical characteristics (such as construction features, hardware conformance to document drawing or workmanship requirements) the method is referred to as "Inspection".

4.2.3 Verification Control System

The basis of the verification control system is Verification Matrix will included in the Verification Control Document. Each and every requirement will be analysed and a suitably verification method will be identified for the different stages of development of GG Payload.
The following general aspects must be considered in establishing (and in implementing) the verification program:

- Verification has an impact on the design (e.g. modularity, testability, accessibility).
- Ensure a coherent approach to verification implementation throughout the various levels in order to achieve a verified product.
- Ensure early verification of critical items to reduce the risks of late failure identification.
- Optimize the design and use of ground support equipment, simulators and test software.
- Minimize cost and schedule by avoiding duplication of tasks.
- Optimize the use of test facilities.
- Plan for feedback to the verification activity.
- Ensure suitable coverage of the interface verification.
- Investigate innovative solutions that may reduce overall verification costs.
- Provide adequate visibility and objective evidence of verifications performed.

Clear responsibilities will be assigned for the implementation of the verification program. The verification personnel will be involved from the early project phases in order to follow a concurrent engineering approach that avoids separation between verification requirement definition and verification implementation.

The verification planning activity will take into account the following elements:

- product tree (starting from the lowest level);
- applicable models;
- estimated time effort for procurement/design/manufacturing of each model;
- utilisation of models (in line with the model philosophy);
- estimated time effort for integration of models;
- selected test programme and sequences at different levels with estimated time and resources;
- Analysis, Review-of-design and Inspection activities suitably combined on the basis of the verification strategies and estimated time and resources;
- the activities and time associated with the procurement of the required verification tools;
- the project milestones and the relevant verification output.

A board will assess and approve the status of the verification process. This includes the approval of the test procedures at Test Readiness Review (TRR) and the verification close-out at the Test Review Board (TRB). No verification process activity will start before the approval of the governing document.

4.3 PAYLOAD A I V PLAN

The proto-flight approach for qualification and acceptance applied at system level is also adopted at the "lower" levels. Therefore the proto-qualification of the PGB shall be performed at:

- Unit level
- Subsystem/assembly level
- PGB

Considering that the PGB is an integrated part of the satellite, actually the satellite is constructed around the PGB, the final qualification of the PGB will be performed at system level (see para. 4.3.3 for more details). However electrical tests will be performed at PGB level.

In addition, during the development functional tests will be performed with the Demonstrator items (see Table in para. 3.2) at the GGG-Pisa facility.

This qualification approach meets the following development constraints:

- The schedule of the PGB PFM production is too tight to allow repetition of environmental tests at all integration levels (unit/subassembly/assembly)
- Repetition of tests at the various levels could lead to over-stressing of the flight HW

4.3.1 CPE UNIT VERIFICATION

This unit is a “standard” electronic unit, and the PFM will follow a typical AIV flow as shown in the figure. At the unit level the following tests will be carried out as a minimum:

- Physical properties (verification against the ICD)
- Electrical tests at ambient temperature
- Functional tests at ambient temperature, which requires the “other half” of the optical link, i.e. the ECE module

In addition the following environmental tests will be performed:

- Random vibration test
- Thermal and vacuum cycling (TVT) test
- EMC conducted emission (CE) test

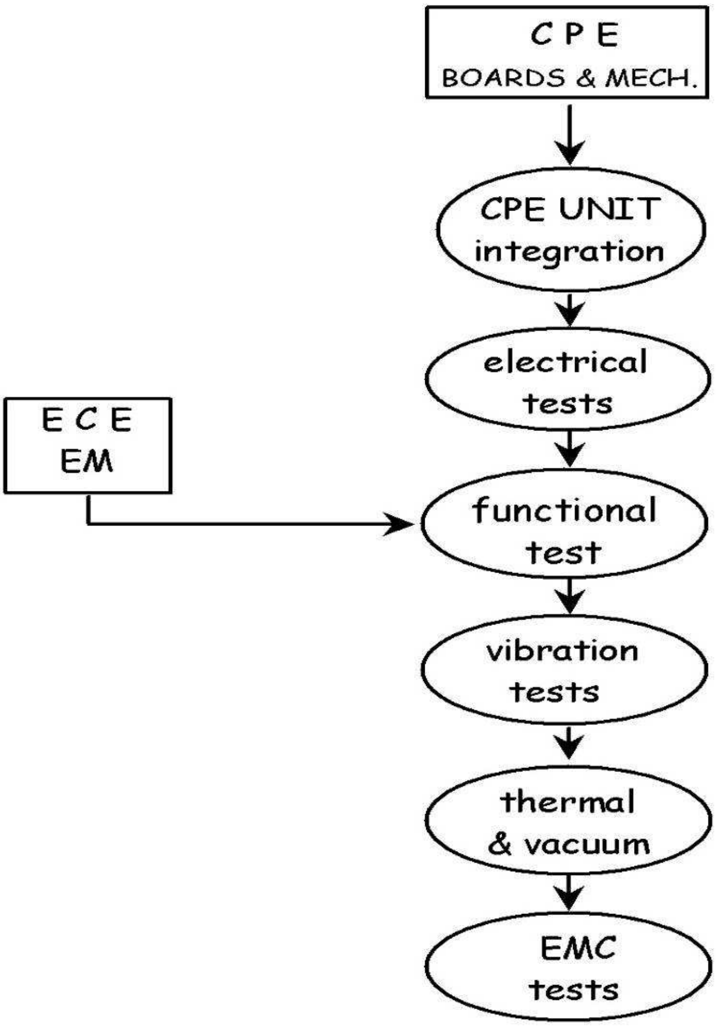

Fig. 4.3.1-1 AIV flow of the CPE unit

For all the above mentioned environmental tests, acceptance levels will be adopted as indicated in the table below, in order to avoid over-stress by repetition of these tests at higher integration levels.

Unit	Sine and Random Vibration	Therm & Vacuum Cycling	EMC
CPE	Qualification levels Acceptance duration	Qualification levels Acceptance cycles	CE

TABLE Test levels of the CPE unit

The CPE unit could require specific software development, although the preferred design approach is to handle experiment and housekeeping data in a FPGA. Details on this subject will be assessed in the next development phase.

4.3.2 TEST MASS ACCELEROMETER VERIFICATION

The Test Mass Accelerometer is a very particular instrument, and functional tests can only be performed on-ground in a proper custom-made facility or test bed (like GGG at INFN, Pisa). Full accelerometer performance (requiring an EP sensitivity of eta = 10^-17) cannot be verified due to a very low signal to noise ratio on the Earth. In fact this is the reason to do the GG experiment in-orbit on a satellite.

In few words the Accelerometer is not a stand-alone unit, but requires a very particular support structure. Such a structure will only be representative of the mechanical and thermal environment, if actual a copy of the PGB. However an additional PGB will become an excessive cost.

The suggested AIV flow of the PGB, starting from the Accelerometer is shown in fig. 4.3.2-1.

At the accelerometer (assembly) level the following tests will be carried out:

- Physical properties (verification against the ICD)
- Electrical and optical link tests at ambient temperature
- Functional tests at ambient temperature (requires the CPE)
- Reduced performance tests at ambient temperature
- EMC conducted emission (CE) tests (TBC)

Following these tests the Accelerometer Assembly will be integrated in the PGB structure.

The vibration and thermal-vacuum tests of the Accelerometer will be performed during the satellite acceptance test campaign.

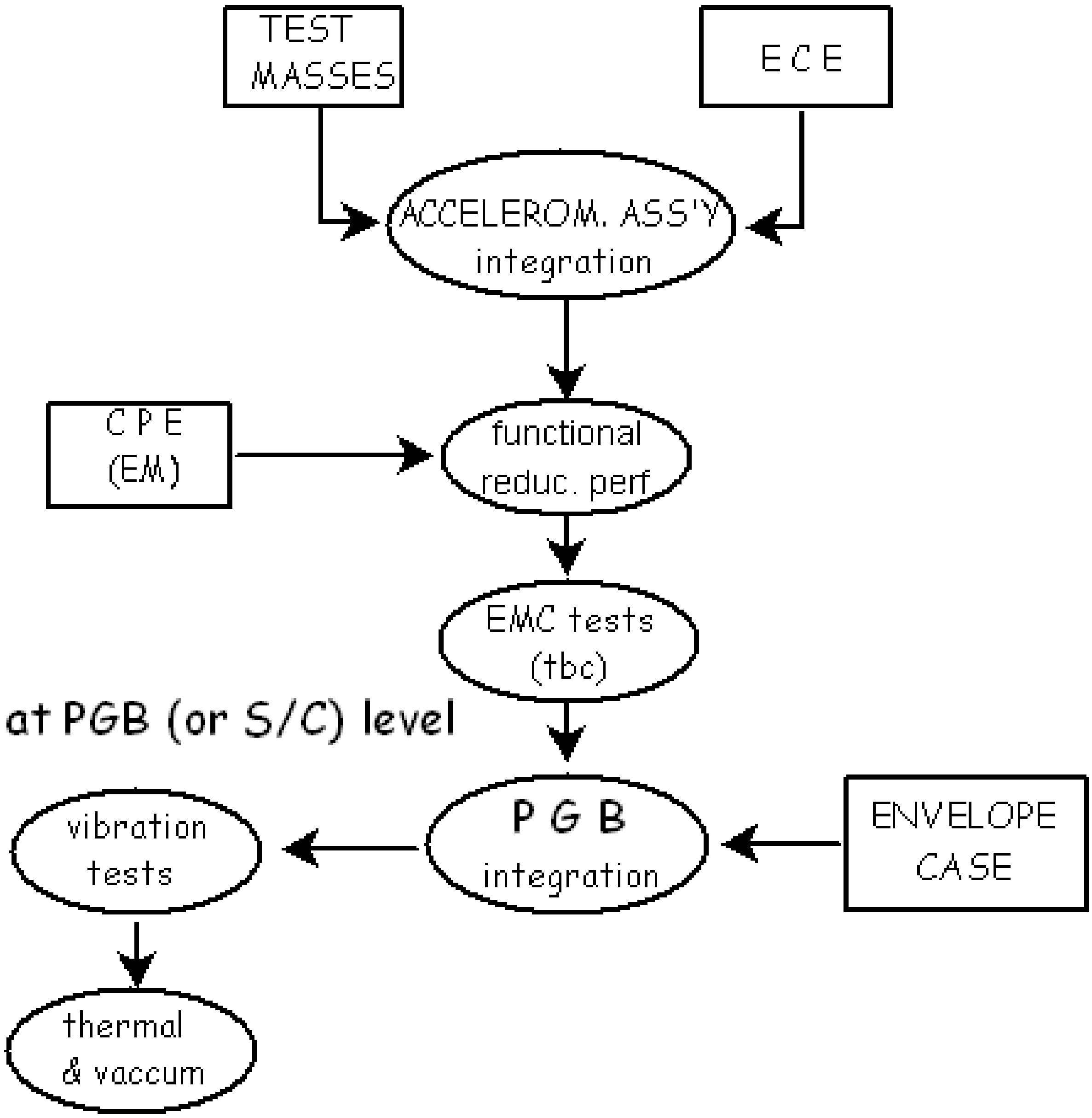

Fig. 4.3.2-1 General AIV flow of the PGB.

4.3.3 PGB VERIFICATION

As already mentioned the PGB is an integrated part of the satellite, and therefore its environmental tests are moved to the S/C level for cost and schedule reasons as explained above.

The following environmental tests are expected (TBC) at S/C level to complete the qualification of the PGB as well as the Accelerometer:

1- Vibration tests
2- Thermal tests
3- Radiated EMC

For details on the platform and system development see also the GG System Engineering Plan (ref. SD-PL-AI-0027).

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5. PAYLOAD EGSE ARCHITECTURE

FUNCTIONS OVERVIEW

The aim of the GG Payload EGSE is to support testing and operations on the GG payload, Accelerometer & ECE, CPE Unit.

The main functions performed by the GG Payload EGSE may be summarised as follows:

- UART RS422 Exercising, for Command & Control Interface
- Power generation
- Optical data simulation
- Sensor & Actuator simulation and acquisition

The Payload EGSE high level architecture is depicted in the figure:

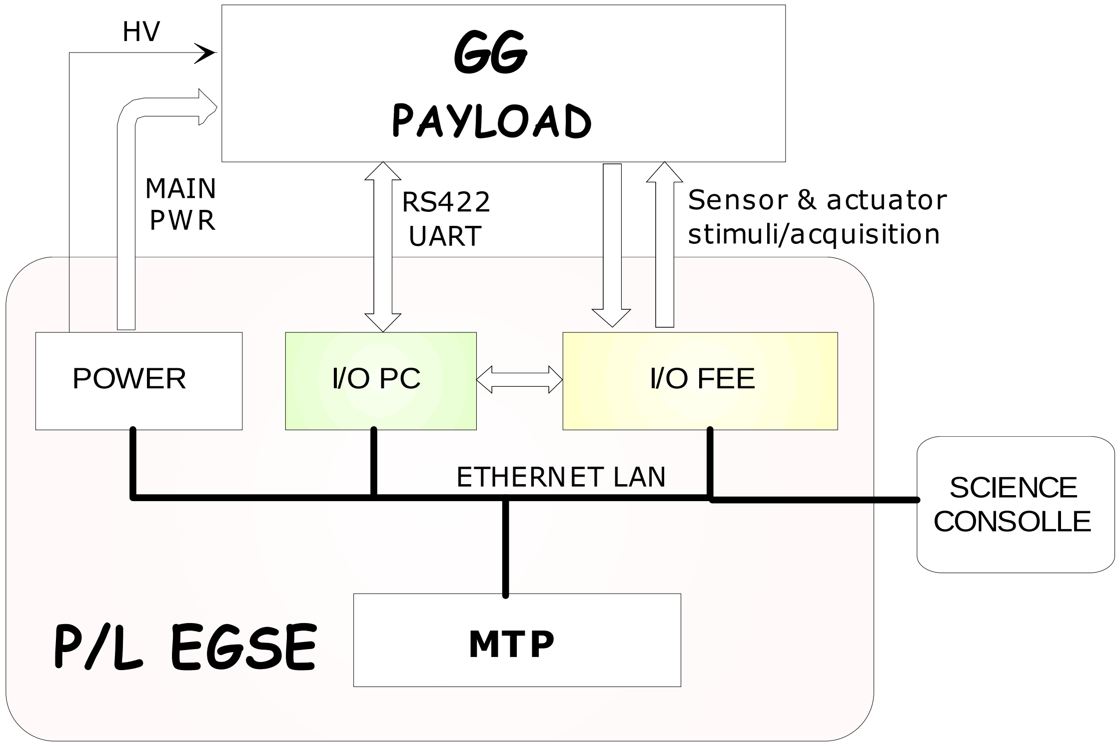

Fig. 5-1 - GG Payload EGSE Architecture block diagram

The GG Payload EGSE shall be supervised by the Master Test Processor (MTP).

The MTP main tasks are:

- System start-up and EGSE initialisation
- EGSE FEEs control
- Command processing
- Data acquisition & process
- Man-Machine Interface

An external workstation (science console) may be connected to the Ethernet LAN.

The science console and in particular the science SW is provided by the GG science team.

Annex 1:

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