Cold Gas Micro Thruster System for Galileo Galilei (GG) Spacecraft

- Technical Report -

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1. INTRODUCTION

The purpose of this document is to present an overview of the Cold Gas Microthruster Subsystem proposed to fulfill the GG Mission requirements related to the actuation of the drag-free S/C orbital control.

This document has to considered as the technical contribution to the GG mission/spacecraft Phase A Study, for what concerns the CGMTS. This subsystem is part of the GG bus subsystems and it is retained of fundamental importance for compensating the surface accelerations, firstly due to the residual drag forces at the spacecraft orbital attitude (in the 520 to 600 km range), acting on the GG spacecraft.

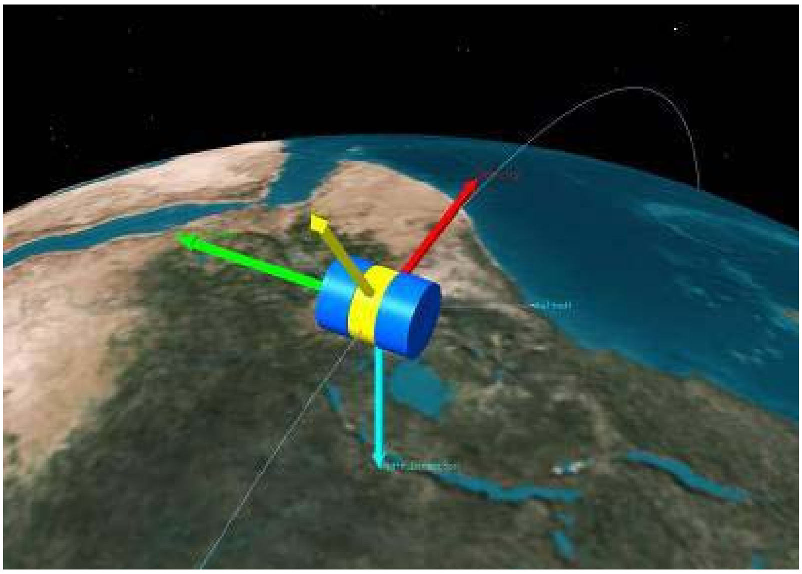
Drag compensation requires the spacecraft to be equipped with **proportional thrusters** and a control system to force the spacecraft to follow the motion of an undisturbed test mass inside it at (and close to) at the frequency of the signal.

The Phase a study activities related to the CGMTS are framed within the WP 1610 2C of the general WBS structure.

The study activity related to the CGMTS has been performed by TAS-I IUEL SI, PR.OEL Unit (TAS-I, Site of Campi Bisenzio, Firenze), under TAS-I Scientific Satellite BU (TAS-I Torino) supervision and coordination.

The main topics dealt in the present document are:

- CGMTS Technology Description
- Technology Heritage and related performances
- CGMTS requirements for GG application
- CGMTS preliminary Architecture and Design
- Design review to meet GG requirements
- CGMTS Interfaces
- Operational Constraints & Limitations
- Technology Readiness level and Development Plan
- Verification & Qualification Plan



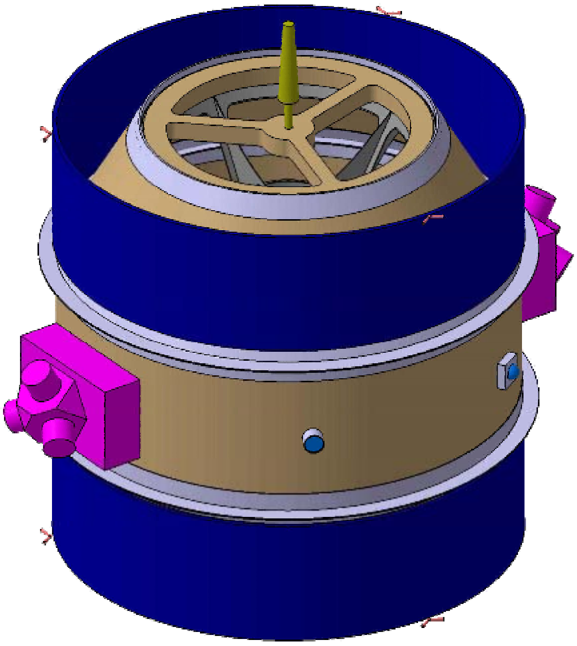


Fig. 1-1

2. THRUSTER TECHNOLOY DESCRIPTION

The CGMTS for GG will include the following major elements/units:

- Propellant tanks (not part of the TAS-I FI sub-system)
- *Pressure Regulation Stage (PRS)*
- *Micro-Thruster (proportional) Actuation Stage (MTAS)*
- *Micro Propulsion Electronics (MPE)*
- *CGMTS Harness*
- Pipework, standoffs & Brackets

2.1 Pressure Regulation Stage (PRS)

2.1.1 PRS general description

The functions main of the PRS module are :

- provide isolation from the N_2 high pressure tank during launch phase and during CGPS flight non operating time
- to reduce the N_2 tank pressure to a regulated nominal pressure level (P_{red}) for pressurisation of the MT's
- to distribute the N_2 propellant through outlet connections to MT's tubing
- to provide capability to insulate a thruster connection
- to provide the P_{red} monitor for insertion in the telemetry
- to provide means for switching over to redundant resources, and for shut down and isolation of malfunctioning parts
- to provide means for fill/drain/clean/test operations both of high and of low pressure sides with accessibility in the different mission phases

The PRS by TAS-I is an EPR based on a fluidic module driven by the MPE in charge to interface the high pressure (BOL, e.g. 300 bar) tank on one side and to provide a regulated “low pressure” (nominal 1-2 bar) at the MT’s inlet.

The PRS is configured with a “common” components set and 2 separated branches (main and redundant).

In each of the 2 PRS separated branches there is an On-Off HP RIV acting as an insulation valve and, downstream, by 2 HP RIVs arranged in series, one fully open and the other operating in closed loop control with a Low Pressure Transducer (LPT).

The two high pressure branches are arranged in parallel since it is required to cope with the failure on one pressure regulator branch. Then an on/off LP RIV has the function to isolate a single thruster pipe in case of pipe or thruster failure.

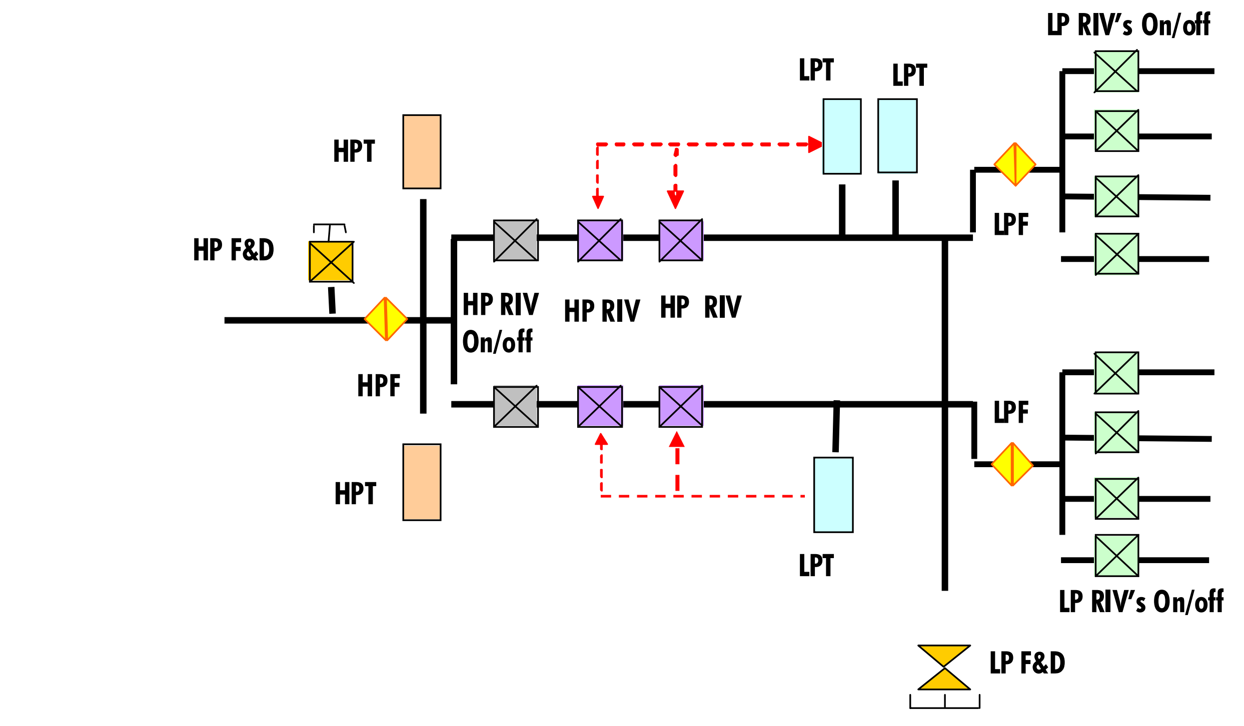


Fig. 2.1.1-1: PRS preliminary layout according to the EPR approach based on the HP and LP RIV's (TAS-I Product)

The main advantages of the EPR (proposed as the beseline solution for the PRS) based on regulation Piezo-valves as actuating elements are:

- Fully European Technology (Key components are TAS-I products)
- No ITAR Exportation/Importation Problems
- Extremely low leakage (at least one order of magnitude better than the MPR)
- Possibility to change the regulated pressure set point
- Very low ripple in the regulated low pressure
- High degree of flexibility (when the thrust is based on an on/off actuator, the change of the upstream regulated pressure can produce a thrust change)
- Contained Mass and Dimensions

2.1.2 HP/LP RIV's

The Key component of the PRS is the HP/LP RIV. The same design can be proposed for both the HP and LP RIV's. These Piezo valves can work either in an analog mode (as actuators of a closed loop control flow or pressure control) or in an off/on mode (for HP or LP pipeline insulation) .In principle the LP RIV could be made lighter as it has to withstand a low pressure (below 10 bar). As a first approach we propose to use exactly the same design/configuration for reducing the types of fluidic components. The HP/LP RIV is a normally closed device which provides leak tight capability when de-energized, and allows tiny – analogical and progressive - control of the pressure during operation (operation in a closed loop configuration for the reduction and regulation of the pressure).

The piezo actuator is a coaxial stack able to generate both the force to open the valve against the antagonist spring and the necessary stroke to fully open the orifice. When de-energized, the spring pushes the titanium plunger (or shutter) against the valve seat automatically closing the orifice.
The plunger tip is conical shaped so that when its movement is commanded along the valve axis the throat cross section is variable from zero to a maximum open area.

The piezo actuator steady state power consumption is very low (< 100 mW) and the design is compact and lightweight. The body is realized with a Titanium alloy.

The HP/LP RIV spring is very strong. This feature guarantees compliance with the ECSS-E-30 part 3A about actuator motorisation factors and safety margins compliance. The design is such that leakage figure is kept also during launch mechanical environment (launch vibrations does not jeopardize the valve sealing thanks to the high antagonist spring elastic constant).

Fig. below shows the HP/LP RIV piezo valve design.

Fig. 2.1.2-1: HP/LP RIV: view of the inlet side

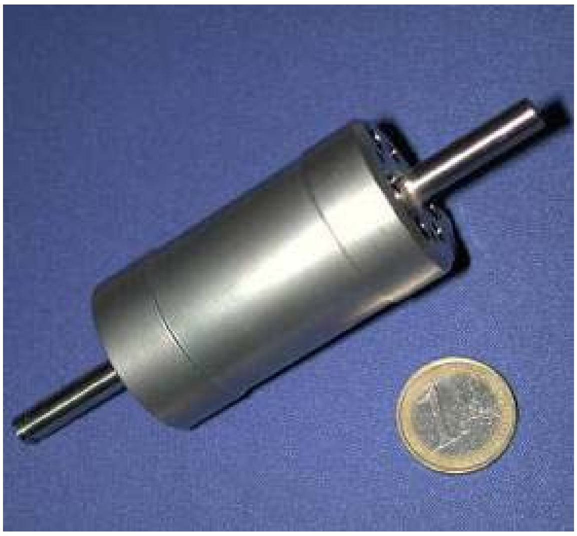


Fig. 2.1.2-2: HP/LP RIV: general view

2.1.3 PRS Auxiliary Components

The PRS design foresees 3 particle filters;

- 1 HPF placed at the high pressure inlet (for particle size of 10 microns),
- 2 LPF , one for each of the 2 low pressure outlets (for particle size ≤5 microns).

Their function is to filter Nitrogen propellant to prevent particle contamination to all downstream components. Because of the criticality of this component (and the complexity of this mission), only filters with long proved flight heritage will be considered. The HPF and LPF's will be procured from Qualified Suppliers (TBD)

The baseline pressure transducers (LPT and HPT) that could be proposed for the PRS equipment will be selected by qualified European Suppliers (TBD)

The same approach is proposed for the HP and LP F&D valves.

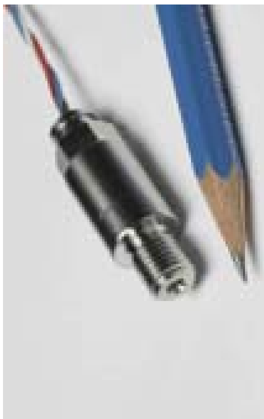
			
HP/LP Transducer (Presens)	HP/LP Transducer (Bradford)	HP F&D valve (Astrium GmbH)	LP Filter (RTG)

Fig. 2.1.3-1

2.2 Micro Thrust Actuation Stage (MTAS)

2.2.1 Micro Thruster general Description

For the GG applications a set of **MT's** are envisaged to perform the actuation of the drag-free S/C control. This section describes the MT (i. e. the single actuator).

The functions of the MT are:

- to provide isolation from the pressure inlet when de-energized
- to provide (together with the control electronics unit) a closed loop control of the propellant mass flow and thus of the thrust
- to provide temperature monitor of valve and nozzle, for in flight corrections of temperature effect of the I_s
- to provide the propellant mass flow monitor for insertion in the telemetry

Fig. below reports the MT schematic. The valve drivers and thrust control are actually located in the MPE unit.

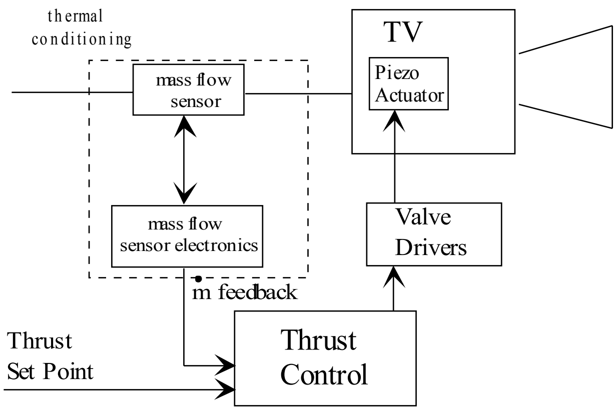


Fig. 2.2.1-1: MT closed loop principle of operation

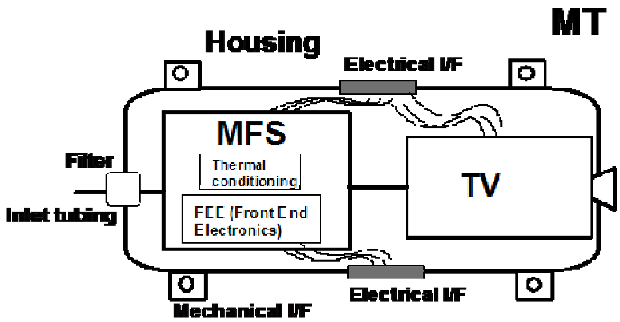


Fig. 2.2.1-2: MT physical arrangement

The MT configuration foresees the realization of a dedicated thruster package including:

- Mechanical Housing and inlet pipeline
- Inlet Low Pressure Filter
- MFS
- TV (equipped with an exit nozzle)
- MFS Front End electronics
- Outlet cable terminated with electrical connectors (this detail not shown in the fig. 2.2.1-4)
- Thermal Conditioning of the MFS and Front end electronics
- Internal Pipe work


Fig. 2.2.1-3: MT based on the GAIA configuration

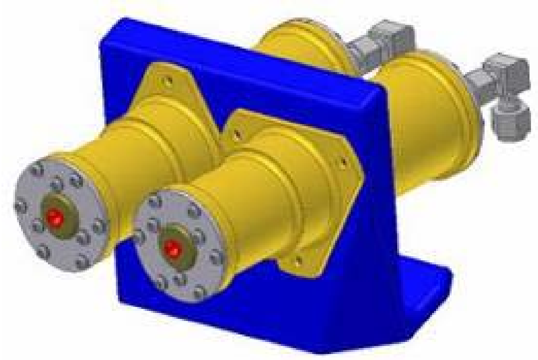


Fig. 2.2.1-4: MT couple (nominal+ redundant) accommodated on the L shaped mechanical support

Upstream the inlet of each MT a Low Pressure Filter (LPF) is inserted in the fluidic channel in order to protect the MT from particle contamination. The MFS detects the propellant mass flow and provides the MPE with such a feedback. The MFS is equipped with its FEE, both are located in a single package (the grey one in the above left picture) which is thermally stabilized at the max foreseen operating temperature (50 °C). The last device in the fluidic chain is the TV , a normally closed LP PV equipped with a nozzle. The housing features a flange for fastening/alignment to the S/C.

2.2.2 Thruster Valve (TV)

The TV is basically a LP RIV which provides isolation against low pressure (few bar) with low leakage, and allows tight – analog – control of the propellant flow during operation, taking advantage by piezo- technology actuation mechanism. The piezo-actuator power consumption is very low (< 100 mW) and the design is compact and lightweight.

In the TV a micro-nozzle is realized through an electro-erosion process and integrated in the valve body, downstream the exit orifice. This modification has the purpose of implementing a provision for allowing the propellant gas (nominally N_2) expansion in order to generate a thrust. The TV used as Thrust actuator within the MT operates in conjunction with a MFS (see after) placed upstream the TV itself.

CAD view of the TV Engineered Model for GAIA MPS	*TV EQM for GAIA MPS*	*TV Nozzle (cutaway) close up*

Fig. 2.2.2-1

The TV nozzle has been designed and validated also through a dedicated computer modelization and simulation The implemented numerical code is a DSMC code based on routines by G.A. Bird. The program employs collision and sampling cells which automatically adapt to the flow density in order to obtain near uniform numbers of molecules per cell. The flow profile into the TV has been obtained through the use of a rarefied-gas model in the nozzle expansion region.

2.2.3 Mass Flow Sensor (MFS)

The MFS is a fundamental component of a CG Thrust Actuator. It is used to measure/monitor the actual mass flow rate flowing through this device which can be correlated to the generated thrust level. The MFS device developed by TAS-I the mass flow information is obtained from the measurement of the “temperature unbalance” that manifests in presence of the mass flow, between two thermometers, while a constant amount of power is provided in between. Substantially, the new MFS device is a differential calorimetric flow sensor which detects the heat amount transported by the fluid.

The MFS has been implemented in a Si Chip. A heating element is positioned in between the upstream and downstream temperature sensing elements (thermo-resistors) which are located on cantilever beams for Δ**T** detection. In addition, within the Si chip, two other temperature sensors are realized:

- the intermediate sensor for monitoring of bulk surface temperature
- the external sensor for the monitoring of the gas temperature

These additional temperature sensors have been added in the new MFS design to control the gas temperature at the MFS input. This solution will avoid any drift in the device response, as a consequence to temperature stabilization

The MFS design (see Figs. below) aims at:

- Covering a dynamic range of up 3 order of magnitude in the mass flow level detection
- maximize the device sensitivity and minimize time response, by reducing the cross sectional area for the mass flow, which is concentrated on the small Si structure
- realizing a rugged and robust package able to withstand the environmental mechanical loads
- allowing operation with both N_2 and Xe gas.

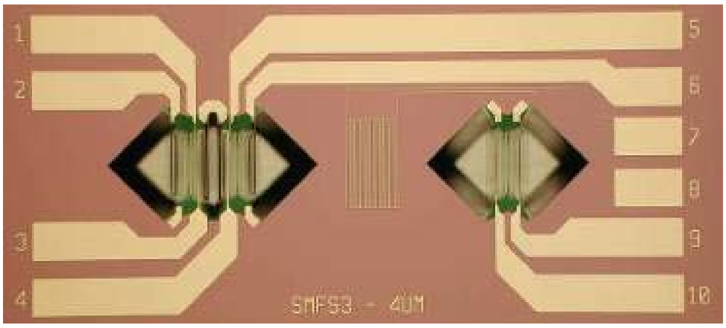


Fig. 2.2.3-1: MFS implemented in a Si Chip (new layout)

Fig. 2.2.3-2: Integration of the MFS elements inside the Mech. housing

When operated within a MT of the CGPS he MFS is placed just upstream the TV.

The performance of the "couple" TV + MFS (of course connected through a suitable closed loop control electronics and associated algorithms) directly affects and determines the performance of the Proportional Cold Gas Micro Thrust actuator.

2.3 Micro Propulsion Electronics (MPE)

The CGPS on Microscope Electronics is composed by 2 twin MPE units (1 nominal + 1 redundant) integrated in a single box
The general tasks associated to the MPE operation within the CGPS are:

- To manage the PRS Nom (Red) branch
- To control up to 4 thrusters according to the commanded thrust levels vs. time (provided by S/C by TC)
- To acquire monitors of MT's Nom (Red) and of PRS Nom (Red) for TM purpose
- To manage TM & TC interface to S/C
- To provide memory patch & dump functions

The MPE has to perform the above listed functions:

- Drive and commute 6+6 LP On/off insulation valves (based on TAS-I LP RIV)
- Drive and commute 2 On/Off insulation piezo valves for HP (based on TAS-I HP RIV)
- Acquire signals from 4 pressure transducers (2 HP + 2 LP)
- Drive 4 piezo-valves for pressure regulation.
- Act a control loop on one of these valves, while the second one is kept open (the remaining two in the redundant branch are un-powered)
- Acquire signals from 12 Mass Flow Sensors, 6 at a time
- Drive 12 piezo-valves for thrust control, 6 at a time
- Act a control loop on 6 of these valves (the remaining 6 are un-powered)
- Acquire auxiliary monitors (temperatures, voltages, …)

The MPE box is composed by 2 mechanical modules + 1 cover panel.

Each MPE module contains 2 boards and a board is attached to the cover panel. The total number of boards is hence 5:

- Power board
- Control + monitor board
- 3x Driver board (2 of them identical, the 3rd one probably different)

The proposed MPE is fully redundant for both Command and Telemetry interface as well as for the power interface. The MPE will be constituted by two independent and cold redundant units, hosted in the same electronic box. Each unit shall be able to monitor and control one branch of the PRS and four thrusters; moreover some functions shall be cross-strapped in order to provide redundancy and failure insulation.

The main task is to perform the control loops with a refresh time of few tens of ms, in order to guarantee accuracy and fast response to thrust commanded changes. The computational power of TAS-I standard design is able to perform the 7 required control loops (6 thrusters + 1 pressure regulator) with adequate margins.

The MPE shall operate in cold redundant whatever the design shall tolerate both nominal and redundant sections simultaneously powered ON without degradation of performances.

The tasks assigned to the MPE boards are below summarized:

Power Board:

- Power bus regulation
- EMI filters
- Secondary voltages generation
- Protections and power consumption monitor
- High Pressure Bi-stable valves driving/activation
- High Pressure Bi-stable valves position monitor

Control Board
- S/C data interface (MIL STD1553 Bus for GG, same I/F of GAIA)
- Microprocessor board
- SW hosting (TM/TC functions, Patch, Dump, control loops computation, …)
- External signals conditioning
- HK and monitors acquisition

Driver Board (x3)
- HP Piezo-valves ON/OFF
- Piezo-valves proportional control (high voltage drivers)
- Drivers readback
- Low Pressure Bi-stable valves driving/activation
- Low Pressure Bi-stable valves position monitor

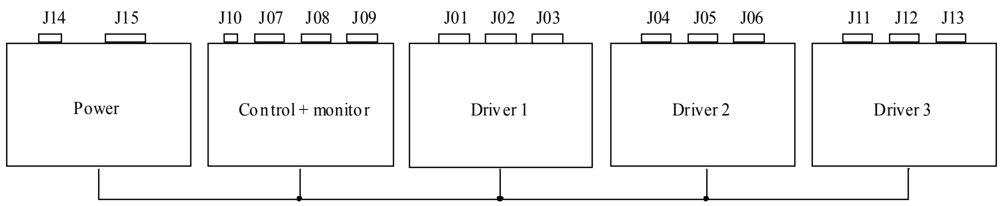


Fig. 2.3-1: Micro Propulsion Electronics architecture

Two identical modules, each one hosting up to 3 boards are stacked together. Internally each module is "I" shaped, with a rib in the middle, where two boards are mounted and screwed. The 5th board, is installed on the top cover. The most dissipating board (the power board) is the one placed on the top cover, which is the radiator to the external space.

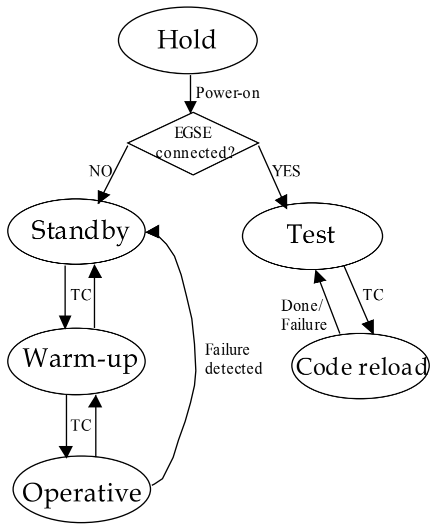


Fig. 2.3-2: Micro Propulsion Electronics Operating Modes

3. HERITAGE AND THRUSTER PERFORMANCES

3.1 Cold Gas Propulsion Ongoing activities at TAS-I

Program	Customer	Phase	Status	Notes
GAIA MPS	ESA/Astrium	C/D ongoing	EQM available; Qualification started; Mech. Pressure Regulator provided by Astrium ltd	Actuator: Proportional Micro Thruster in the 1-500 µN range (N_2); 6 nominal +6 redundant thrusters
Microscope CGPS	CNES/TAS-F	A completed B started	Preliminary Design; EPR based on TAS-I HP RIVs proposed in baseline	Actuator: Proportional Micro Thruster in the 1-500 µN range (N_2); 8+8 actuators
CGTA Small GEO	ESA/SCC	C/D ongoing	Detailed Design	Actuator : On/off 50 mN Thruster (Xe); 4+4 actuators

Table 3.1-1

3.2 GAIA key requirements

The key requirements which characterize the MT operation on GAIA are :

- The extremely wide thrust range to be covered (3 order of magnitude) starting from 1 µN up to 500 µN
- The thrust resolution (≤ 1µN), thrust bias (≤0.5 µN) , thrust noise (0.045 µN/√Hz above 1 Hz), thrust scale factor knowledge error (≤1%)
- The operational time in orbit of about 60,000 hrs (total impulse for each Micro Thruster of 10,000 Ns) and number of on/on cycles (102 millions)
- The quite fast thrust response time (<300 msec@63% of the new commanded thrust level)
- The minimum Specific Impulse (60 sec @20°C) to be achieved throughout the whole thrust range
- Assigned overall reliability figure :0.9787

3.3 Microscope key requirements

The CGPS for Microscope MT main requirements are here below summarized:

- Propellant Gas: Nitrogen
- CGPS based on a couple of independent "half-systems" , each allocated on a satellite panel;
- Accurate thrust throttling within the **1** to **500 μN** thrust range;
- Thrust resolution : **1 μN** or better
- Thrust bias error: **2 μN**
- Thrust scale factor error: 5 %
- I_s for each CGPS thruster: ≥ 45 s in the whole thrust range;
- thrust commanding frequency: up to 4 Hz
- Extremely low noise (≤ 1 μN/√Hz in the range 0.8 mHz to 20 Hz);
- High operational lifetime (1 year of continuous in-orbit operation);
- Total CGPS leakage ≤ 0.005 scc/min GHe;
- Leakage through one thruster valve ≤ 10^{-5} scc/min;
- Total impulse for each micro-thrust actuator: 1000 Ns
- Response Time:
  - < 100 ms for 30 μN step
  - < 300 ms for a thrust in the range 30-500 μN (<300 msec@63% of the commanded thrust level)
  -
- Stringent Mass, Power, leakage constraints;
- S/C Power Bus I/F (not regulated type from 22 to 37 V);
- S/C Data Bus I/F: RS422 type, with asynchronous link with full-duplex octets (UART);

3.4 Small GEO key requirements

Small GEO CGTA: TV requirements

- Propellant Gas: Xe
- Nominal thrust: 50 mN ±5%
- Nominal Inlet Pressure: 2.2 bar (Xe)
- Operating Temperature range: +5° to +60° (thruster interface temperatures)
- External leakage: ≤ 10^{-6} scc/s
- Internal leakage: ≤ 10^{-4} scc/s
- Total Impulse: > 1133 Ns
- Min. Impulse Bit: ≤ 2 mNs
- Thruster Rise and close time: ≤15 ms
- Specific Impulse: ≥ 25 s, for firing duration ≥100 ms
- Firing Pulse Duration: from 40ms to 2 hours
- Max. gas flow rate : 200 mg/s
- ON/OFF cycles (for qualification): > 850.000

3.5 Near future Cold Gas Propulsion applications

Possible near future missions using Cold Gas Propulsion

Program/Mission and Contractor	**Status**	**CGPS Operation**	**Notes**
Simbol-X (CNES/ASI)	Phase A study performed	Proportional Thrust 5-5000 mN (TBC) with N2 10+10 actuators;	Study performed under TAS-F coordination
Proba-3 (ESA/SSC)	Tech Info provided to ESA and SSC;	On/Off 10 mN, with N2 8+8 Actuators	GSTP4 technology contract expected in 2009 from ASI/ESA for a demo prototype
Nanoform (ASI)	Phase A study performed for ASI	Proportional Thrust up to > 20 mN on mother satellite 6+6 actuators Up to > 10 mN on child satellite 6 actuators	Study performed under TAS-I Turin coordination

Table 3.5-1

4. THRUSTER REQUIREMENT FOR GG APPLICATION

4.1 GG Micro thruster requirements

Specific Microthruster requirements are given in Table below. The deliverable shall consist of two branches with 6 thrusters each, without tanks.

Parameter	**Unit**	**Required value**	**Notes**	**Comments, also considering what is achievable for GAIA**
Maximum thrust	µN	≥150		Thrust levels up to 500 µN achievable
Max Thruster response time	msec	40	@ commanded step (up & down) ≥60 µN	about 100 ms: commanded thrust level below 50 µN: 100 to 200 ms: commanded thrust level in the 50 to 500 µN range
Resolution (quantization	µN	24	TBC, not critical	1 µN achievable with the current GAIA Design
Max noise	µN/√Hz	18	Around 1 Hz (Requirement associated to the static noise)	1 µN/√Hz from 0.01 Hz to 1 Hz <0.1 µN/√Hz from 1 Hz to 150 Hz achievable with GAIA design
Scale factor error	%	12	Peak	1 for GAIA
Command update rate	Hz	10	TBC	1 Hz for GAIA; Nice to have up to 8 Hz
Specific Impulse	s	≥60		In line with the Is provided by GAIA MT
Total impulse	Ns	4500	@150 µN total ton is about 8300 h;	a Total impulse figure twice higher is required for GAIA MT 700 million cycles at 10 Hz, in open loop, performed on the TV EM
Minimum thrust	µN	≤10	TBC	1 µN achievable with the current GAIA Design
Centrifugal Acceleration	g	< 4.4		Mechanical design of GAIA suitable for this requirement
Thruster Vector stability	rad	0.17	Peak at 60 µN	To be assessed
No. of thrusters in each assembly		6		2 assemblies

4.2 GG Auxiliary Propulsion requirements

This system will be used for:

- detumbling after separation from the launcher;
- satellite spinup.

It will consist of:

- 2 branches of 4 thrusters each one,
- all needed equipment (valves, filters, regulators, pipelines) without the tanks.

The required performances are provided in Table 4.2-1.

Parameter	Unit	Value	Comments also considering what is achievable for Small GEO
Max. Thrust	N	> 0.5	50 mN at about 2 bar inlet pressure; using an EPR with a regulated pressure set point of 10 bar would produce abot 0.25 N of thrust
MIB	Ns	< 0.005	
Specific Impulse	s	> 60	Small GEO uses Xe; the TV can operate also with N2 at the desired Is
Centrifugal Acceleration	g	< 4.4	Mechanical design os Small GEO suitable for this requirement
No. of Cycles		TBD	
No. of thrusters for each assembly		4	2 assemblies as from Small GEO architecture

Table 4.2-1

5. PROPULSION ARCHITECTURE AND DESIGN

The CGMTS shall include **6 nominal** proportional thrust actuators plus **6 redundant** thrust actuators (nominal and redundant MT's). As required by the input received at system level the drag-free control thrusters shall be accommodated in **two** clusters of 3 each, with orientations providing sufficient torque and force authority on all axes.

The preliminary redundancy requirements forces the adoption of 2 independent Pressure Regulation lines configured in a parallel arrangement, and of **3 x 2** micro thrusters (MT's) for each of the 2 thrusting locations (each of them corresponding to a Micro Thruster cluster). For each of the 3 thrust directions of a single cluster a **nominal** and a **redounded** thruster can be foreseen.
The Preliminary CGMTS architectural configuration is shown in fig. 5.1

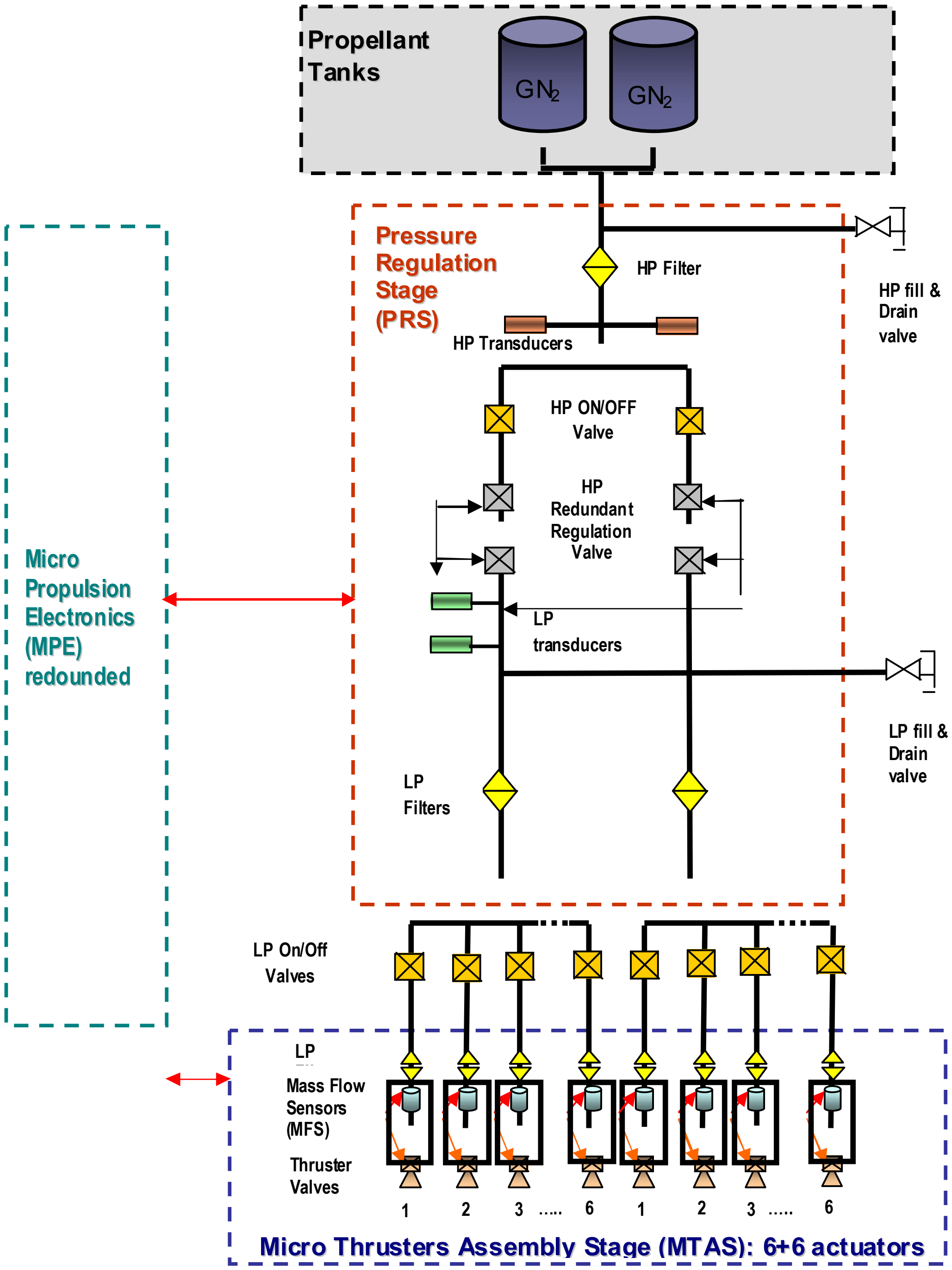


Fig. 5-1 CGMTS on GG preliminary architecture

6+6 MT's are connected to the same PRS reduced pressure node. Separate propellant ducts are foreseen for each thruster in order to prevent cross-talk effects. Each MT can be separately excluded by a dedicated LP On/off RIV. These components are accommodated inside the PRS.

The PRS by TAS-I is an EPR based on a fluidic module driven by the MPE in charge to interface the high pressure (BOL up to 300 bar) tank on one side and to provide a regulated "low pressure" (e.g 1-2 bar) at the MT's inlet.

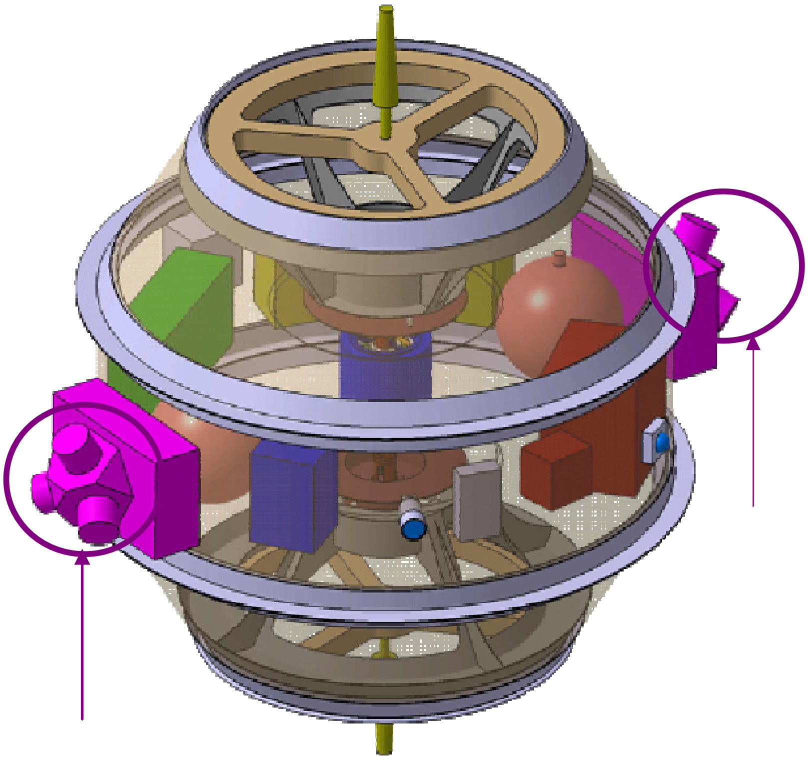


Fig. 5-2: GG Spacecraft Configuration showing the locations of the Micro Thrusters

A significant optimization of the GG Propulsion Architecture can be thought by making reference to an "integrated" CGPS. The integrated CGPS would have different actuators, namely:

- ***Micro Thrusters*** (6 nominal and 6 redundant) used for the actuation of the drag-free control
- ***Auxiliary Propulsion Thrusters*** (4 nominal and 4 redundant) used for the initial attitude stabilization and for the spin-up operation

TAS-I is available to offer the whole "integrated" CGPS. As said before the Micro Propulsion actuators for the drag-free control are directly derived from the GAIA MT and have been presented and described in par.

For what concerns the Auxiliary Propulsion Actuators TAS-I is ready to propose the TV baselined for the CGTA of the Small GEO Program.

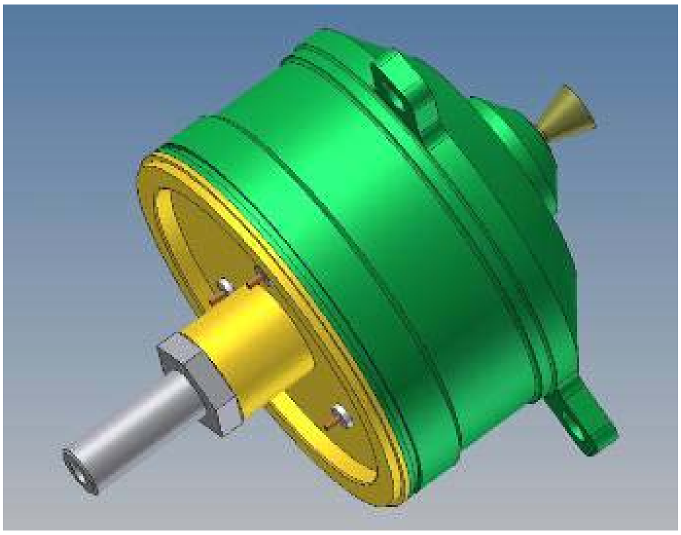


Fig. 5-3: TV CAD Model resulting from ongoing Small GEO program (prime contractor SSC)

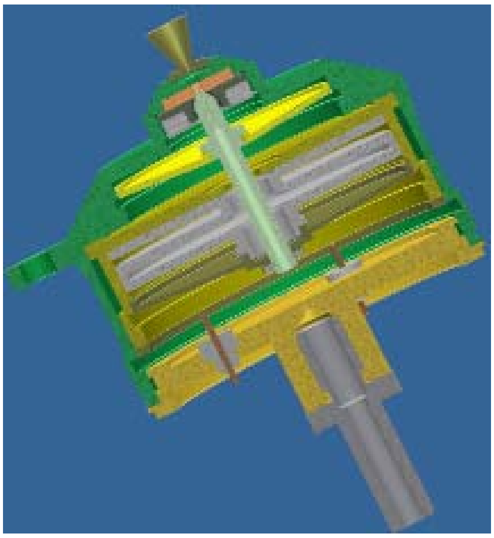


Fig. 5-4: Cutaway view of the Small GEO TV

The requirement specification of this Cold Gas On/off thruster are specified in par. 3.4.

The Thruster valve (TV) is a low pressure normally closed device which provides tight mass flow closure when not powered, and allows in the "fully open condition" a propellant flow determined by the exit orifice dimensioning.

It is equipped with a piezo actuator based on as a "stack" of ring benders which act against an antagonist spring. A plunger is connected to the piezo actuator. When a driving voltage is applied to the piezo actuator, it moves against the spring leading the plunger to open the valve throat (orifice). Therefore the throat (orifice) cross section is variable from zero to a maximum

For SGEO On-Off application the piezo drive voltage will not have to be modulated but simply switched between 0 and full opening voltage.

The inlet (low pressure) filter unit is integrated in the TV body.

- TV Overall dimensions (including the inlet filter): 72,15 x Φ66 mm
- TV Mass: 120 g

The SGEO TV design is derived from the already developed design of the GAIA TV (this latter in GAIA operates in conjunction with a Mass Flow sensor to realize a throttleable thruster). The SGEO TV is a scaling up of the GAIA design.

The design scaling up and finalization for the SGEO TV is currently ongoing, having TAS-I now signed the contract with SSC for developing and supply the whole CGTA (including Gas Conditioning and Electronics in addition to the Cold Gas thrust actuators)

The development and supply of a whole integrated CGPS for GG can provide significant benefit in term of flexibility, simplification and cost containment. Fig. 5.5 below presents a preliminary architectural layout for the integrated CGPS.

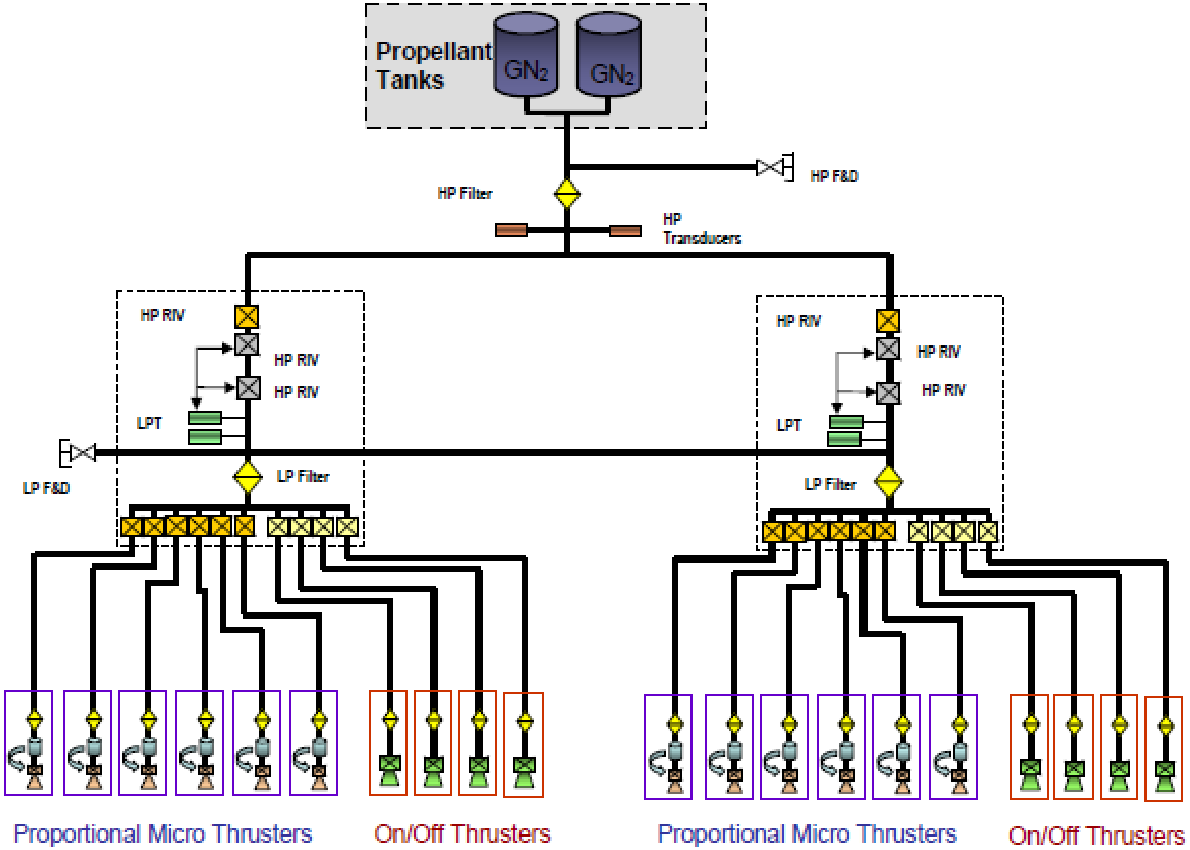


Fig. 5-5: Integrated CGPS proposed for managing the whole GG Propulsion Tasks

The main advantages associated to the proposed integrated CGPS are below highlighted:

- Use of a single PRS (with redounded branches) both to interface the Proportional Micro Thrusters and the On/off Thruster dedicated to the auxiliary propulsion
- A PRS based on the proposed EPR concept could allow to raise the regulated pressure set point e.g at 10 bar and thus increasing of a factor 5 the nominal thrust (50 mN) provided by the Small GEO actuators, in order to achieve a thrust level up to about 250 mN (this feature is possible if the operation of the proportional micropropulsion is not concomitant with the operation of the Auxiliary Propulsion)
- Use of a single MPE (with some design modification w.r.t. the baseline MPE dedicated only to the Micro Propulsion) both to interface the Proportional Micro Thrusters and the On/off Thruster dedicated to the auxiliary propulsion
- Simplification and optimization of the AIV activities for the Flight Hardware
- Procurement (TAS-I) from a single source of the integrated CGPS

6. DESIGN REVIEW TO MEET GG REQUIREMENT

6.1 Thruster Response Time

The only GG requirement that is significantly different w.r.t GAIA is the one referred to the thrust command update rate. In fact for GAIA this parameter is 1 Hz while for GG (due to the spinned Spacecraft) is 10 Hz (Thrust level to be updated every 100 ms).

With the current MT design as results from GAIA the updating of the commanded thrust level every 100 msec is possible only if the thrust transition is implemented on thrust levels different from 0 (valve completely closed). More clearly we can command a thrust level T_2 within 100 ms if the current thrust level T_1 is not zero thrust.

It is clear that changing the thrust from 0 to a nominal set point and vice versa requires a time that is related to the Delta Thrust level to be implemented. Changing the thrust from 0 to 150 μN would require a time higher than the one necessary to change the thrust level, for example, from 100 to 150 μN.

With the current MT design as results from GAIA it is possible to pass from Thrust = 0 (valve completely closed) to a thrust, of few hundreds μN within about 300 ms.

Possible means for increasing the command rate frequency with design modifications w.r.t GAIA (to be assessed during phase B) are below identified:
- Increase the computational power of the MPE (significant modification)
- Increase the cut-off frequency of the Low Pass Filter (a trade-off has to be performed as if this frequency is increased the noise is also increased)
- Modify the PID Closed loop Control Parameters/Strategy
- Eventually Introduce slight modifications to the TV actuation mechanism

Command rate frequency and Time response investigations can be performed within an eventual phase B of the GG project, such as:
- Joint simulation (Thrust closed loop control performance model) and experimental activities to characterize the thrust actuator dynamic behavior

For this task a Specific EGSE has to be prepared and configured

6.2 Thrust Vector Stability

Another issue to be assessed is the thrust vector stability requirement. The thrust vector stability can be affected by the presence of a thrust transversal component due to thrust parasitic noise. The experimental characterization of the thrust vector stability through the determination of the thrust transversal component is not feasible, currently, using the nanobalance facility located at TAS-I Turin. No experimental information is therefore available from GAIA program. A preliminary qualitative assessment has been done for GAIA by using a CFD modelization/simulation. The assessment performed within GAIA did not produce any significant concern about the thrust vector stability. A more exhaustive treatment of the issue could be tackled, in any case through CFD modelization, within a possible phase B of the GG program. It has to be pointed out that, in order to obtain reliable results for the transversal thrust noise, the computational times are extremely long.

The spectral analysis of the time evolution of thrust transversal component due to noise can provide the PSD: Due to the high computational times, only very high frequencies (> 10 kHz) can be reasonably analyzed.

6.3 Centrifugal acceleration

For what concerns the capability of the Micro Thruster (and also the auxiliary propulsion thruster) to withstand the centrifugal acceleration due to the S/C spin rate, we do not envisage problems or limitations, on the basis of considerations here below exposed.

It is understood that, most likely, the direction of the centrifugal acceleration acting on the thrust actuator is orthogonal to the thrust direction in any operational flight situation.

In this case the centrifugal acceleration is not retained to produce any remarkable effect on the thrust actuator correct operation.

Should, for some reasons or any particular flight condition, the centrifugal acceleration result directed in the same direction of the thrust, there could be a “side” effect to be taken into account and evaluated.

The resulting centrifugal force could act in the direction of forcing the opening of the Thruster valve orifice by acting in opposition to the mechanical force exerted by the spring that maintains the valve fully closed, when in the off condition (no voltage applied to the piezo actuator).

- Force exerted by the spring : about 10 N (corresponding to about 1 kg)
- mass of the valve actuator: 10 grams (0.01 kg)
- Centrifugal acceleration: 17.4 g
- Centrifugal force acting on the Valve actuator: about 0.174 kg

As the Centrifugal Force (0.174 kg) is << than the Spring strength (1 kg), no significant risk of valve opening due to the centrifugal force practically exists

6.4 Scale factor error

The factors of scale error ε in the thrust realization are in principle related to:

- ground calibrations uncertainties (accuracy of measurements, uncertainty about knowledge of calibration nominal operating conditions)
- deviation – in flight - from operating conditions in which ground calibration had been performed, uncertainty about knowledge of flight operating conditions
- accuracy/resolution of the models/equations/lookup tables implemented to calculate and perform correction factors
- s/w representation of variables , s/ w calculations

An assessment of the scale factor error has been performed for GAIA . The following error figures have been identified :

- Error due to the Thrust balance performance: 3-4%
- Errors due to calibration conditions, in flight different conditions, etc. : <1%
- Error due to quantization (measured thrust expressed with a 14 bit code): 0.06 µN
- Error related to the SW processing: ±0.1 µN

From the preliminary analysis carried on within GAIA we can conclude that the GG figure for the scale factor error is widely higher than the figure/s resulting from GAIA. So this is not a critical parameter for the CGMTS on GG.

6.5 Thrust Parasitic Noise

The contribute to the parasitic noise are due to:

- Coupling between the PRS and the MT (contribute above 1 Hz not expected and not analyzed)
- Propellant expansion processes in the nozzle (addressed with CFD analysis)
- Movements of the piezo actuator during the mass flow regulation operation
- Propellant mass flow variations due to the piezo actuator undesired movements

With Gaia Program a thrust noise characterization campaign has been performed at the nano balance facility in TAS-I Turin, with reference to the last 2 noise sources

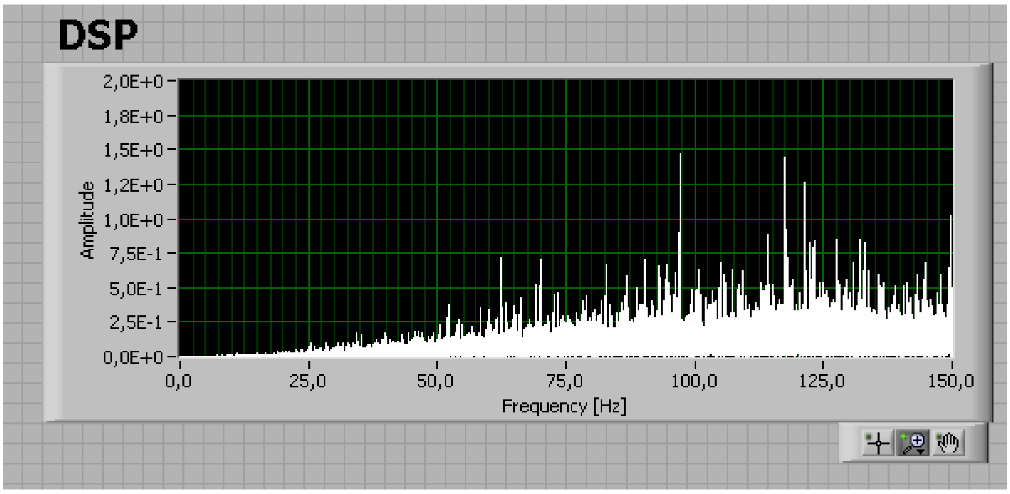


Fig. 6.5-1: PSD of force relevant to piezo actuator movement during regulation(vertical axis is µN/√Hz)

For the propellant mass flow variations due to piezo actuator movement the following noise figure has been obtained after the very preliminary test campaign: 0.075 μN/√Hz.
In the framework of the qualification Campaign of GAIA MT a formal noise characterization will be carried out for determining the actual Thrust Noise parameters

However from the very preliminary invstigation, resulting thrust noise data are not to be considered of concerns for the GG application.

7. BUDGETS AND INTERFACES

The CGMTS mass budget is reported in the following tables.

The mass budget includes the piping upstream the PRS (to the tanks) and downstream the PRS (to the MT's) including fluidic connections to the test bracket.

7.1 MT Preliminary Budget

Overall Dimensions	184,3 x 62 x 52,5 mm
Mass w/o cable	300 g + 10%
Mass with cable	370 g + 10%

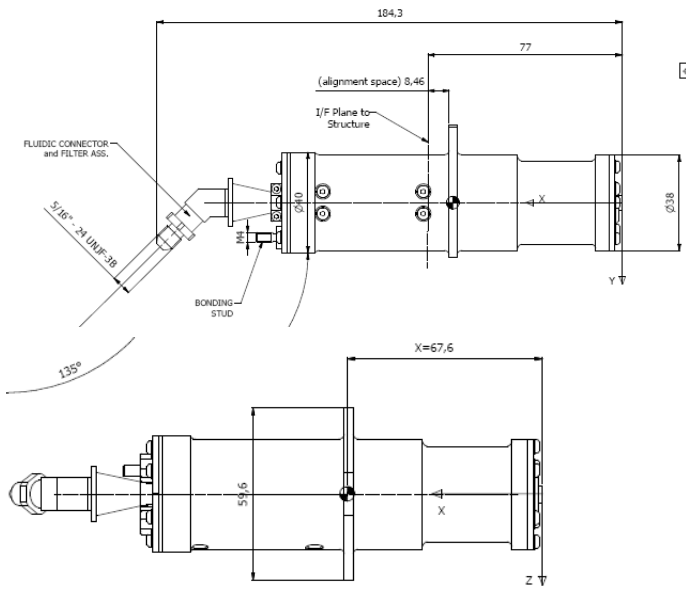
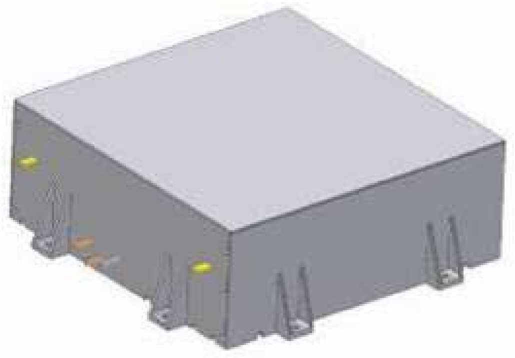


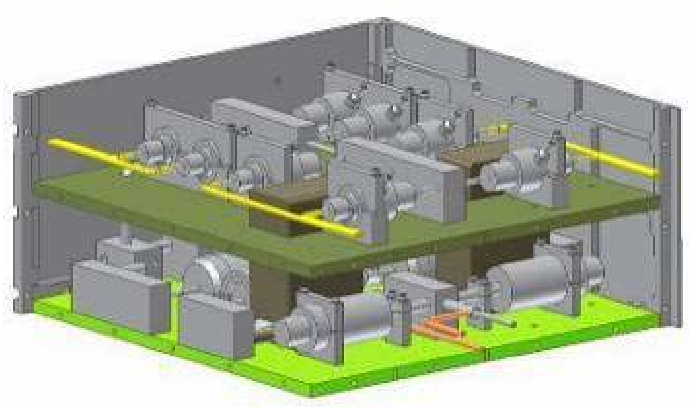
Fig. 7.1-1: MT Preliminary ICD

7.2 PRS (very) Preliminary Budget

Overall Dimensions	300 x 300 x 150 mm
Mass	4 kg+20%



7.2-1: PRS Box



7.2-2: View of PRS Internal fluidic Components

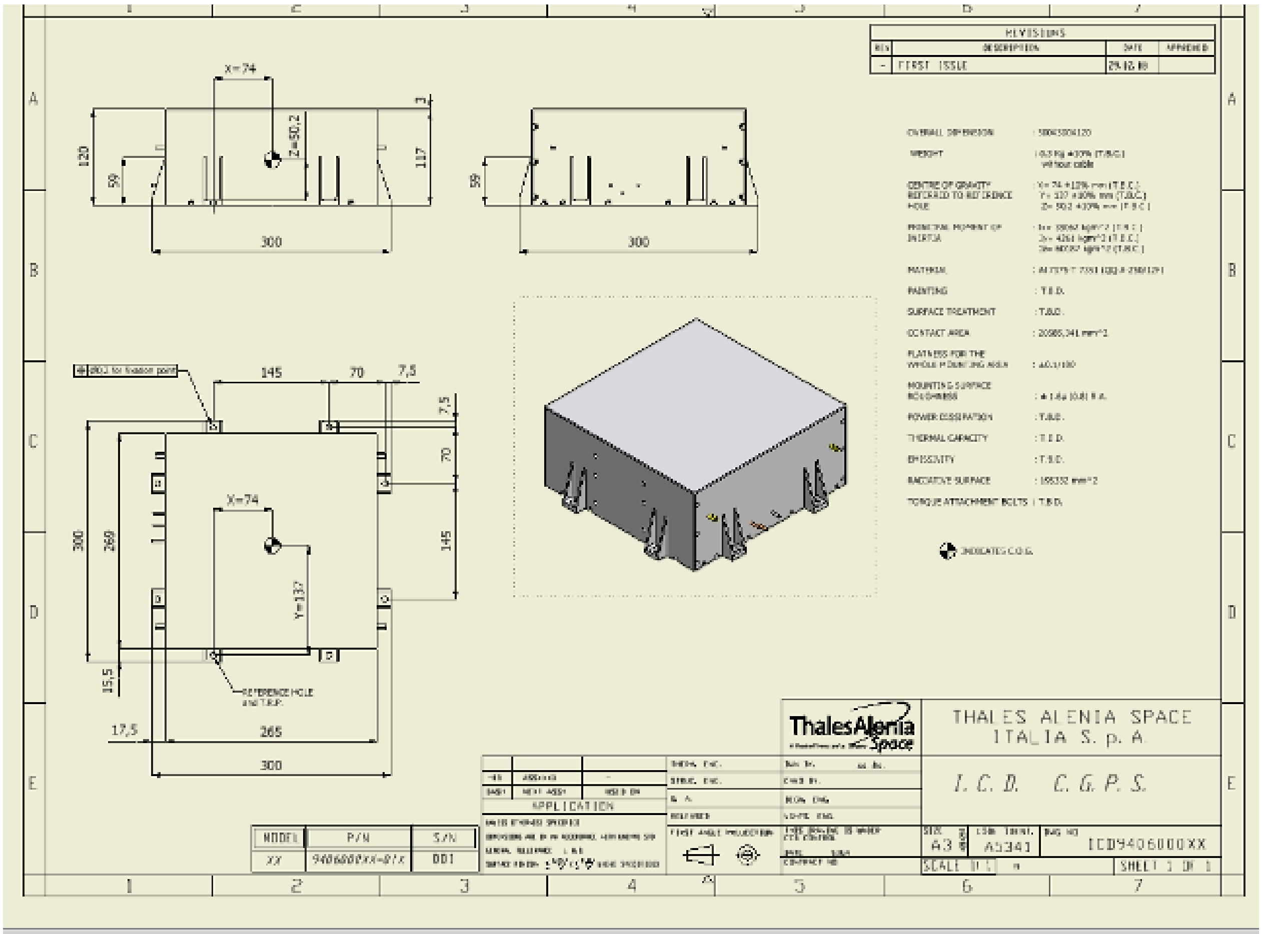


Fig. 7.2-3: PRS preliminary ICD

7.3 MPE (very) Preliminary Budget

Overall Dimensions	250 x 150 x 120 mm
Mass	3.5 kg+20%

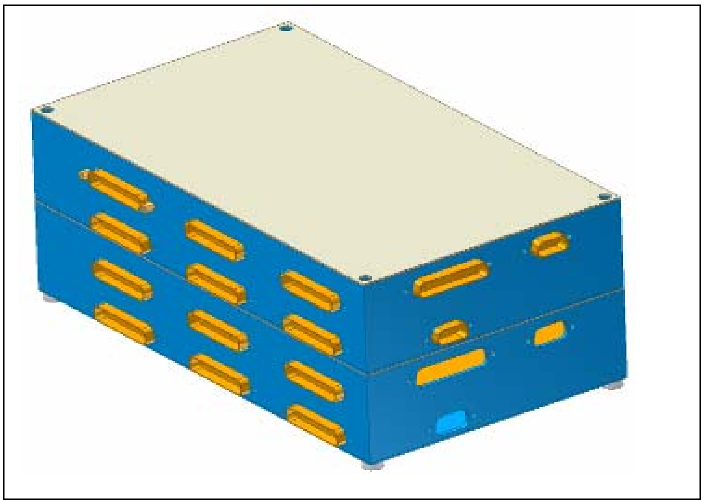


Fig. 7.3-1: 3D CAD View of the MPE(redunded) box

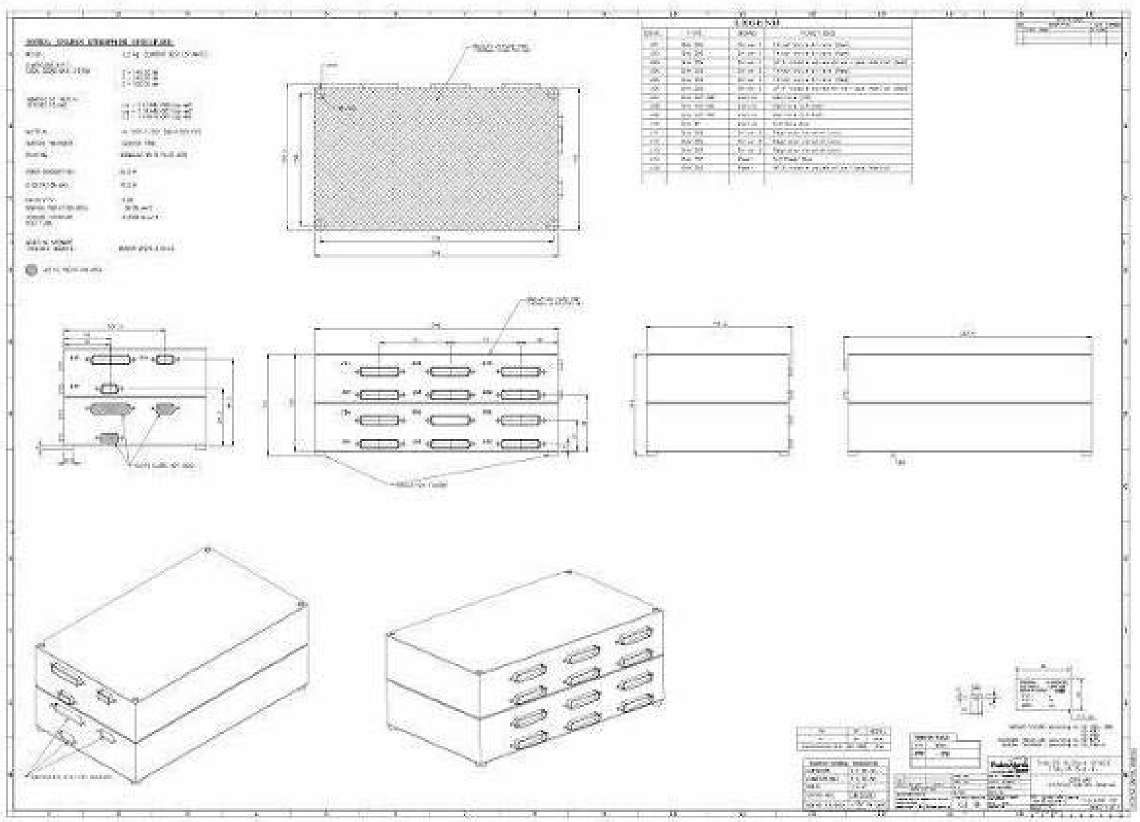


Fig. 7.3-2: MPE preliminary ICD

7.4 CGMTS preliminary overall mass budget (without tank and propellant)

Components	Provider	Number of item	Item Mass wt. contingency (Kg)	Contingency (Kg)	Total (Kg)
MT's	TAS-I	6+6	4,4	10% (0.44)	About 4.8
MT's brackets		6	0,600	20% (0.12)	About 0.7
MPE (nom+red.)	TAS-I	1 box	3,5	20% (0.7)	About 4.2
Electrical harness	TAS-I	1 set	0,5	20% (0.1)	0.6
PRS (2 branches)	TAS-I	1 box	4,0	20% (0.8)	4.8
Piping fittings and brackets	TBD	1 set	1,3	20% (0.26)	1.6
TOTAL Dry	TAS-I	CGPS	14,3		16.7

Table 7.4-1

7.5 CGMTS Preliminary Power Budget

Two reference cases are addressed:

- Stand-by status, when the system (just after boot) is working with all peripherals OFF and hence is taking the minimum absorption from the bus
- Operational status, with all peripherals ON and at maximum absorption from the bus.

In the tables here below the very preliminary power budget data for the 2 cases are summarized.

TOTAL + Contingency (20%)	**7.5 W**
Total dissipation of MPE	3.6 W

Power budget – Stand-by state

TOTAL + Contingency (20%)	**25 W**
Total dissipation of MPE	9.6 W

Power budget – Operational state

8. OPERATIONAL CONSTRAINS AND LIMITATIONS

8.1 EMC/ESD

No primary concern is presently identified for the CGMTS within this area. A dedicated EMC Campaign is scheduled within GAIA program.

8.2 Contamination

The CGMTS works with an inert gas, like N2. There are no energetic particles (like high voltage accelerated ions or charge exchange ions) involved that maight cause material deposition or sputtering erosion on sthe S/C exposed parts. Therefore No contamination issue is related to the CGMTS operation in space.

8.3 Arcing (FEEP)

The max. voltage involved in the MT actuator operation is about 200 Vdc. This voltage is applied to the Piezo actuator to fully open the valve orifice. At these voltage level no risk of arcing and/or electric discharges has to be considered.

9. TECHNOLOGY READINESS LEVEL AND DEVELOPMENT PLAN

9.1 Technology Readiness level

The table here below presents in a synthetic form the TRL status relevant to the CGPS major assemblies/units.

CGMP Units	Current TRL	Notes
PRS	4	For GAIA this module is called MPFM and is procured from Astrium UK and is a mechanical pressure regulator; The PRS here considered (and for which the TRL is identified) is an Electronic Pressure regulator based on TAS-I High Pressure Piezo Valve; Key components of the Electronic PRS are being developed and pre-qualified within an ARTES 8 contract with ESA
MPE	6	By begin of 2009 a MPE EQM for GAIA program will be ready for being submitted to the Qualification Test campaign at Unit level
MT	6	By begin of 2009 2 MT EQM's for GAIA program will be ready for being submitted to the Qualification Test campaign at Unit level

For what concerns the TRL relevant to the On/off Cold Gas TV proposed as thrust actuation element of the auxiliary propulsion, a figure of TRL=5 can be identified.

For this actuator TAS-I proposed the use of the TV currently under manufacturing for the Small GEO Program. Delta qualification activities are needed for confirming fully applicability to the GG program

The MPE, MT (Proportional Micro Thruster) and the TV (On/off Cold Gas Actuator for the auxiliary propulsion) will evolve to TRL 8 within year 2010.

For the PRS based on the EPR concept the evolution from to TRL 4 to TRL 6 is foreseen by year 2010 (development & technology consolidation sustained with internal R&D funding and ARTES contract expected by autumn 2009)

- TRL rispetto alla soluzione che si propone per GG
- Piano di sviluppo proposto alla luce di quanto previsto per GG
- Evoluzione del TRL nel corso dello sviluppo del programma

9.2 Proposed Development Plan for Phase B

The objective of the work is to define a Preliminary Design (phase B level) of the CGMTS Units, i.e. the MT(as single element of the MTAS), the PRS and the MPE in compliance with the GG performance and Interface Requirements.

The design development approach for the TAS-I sub-systems upon TAS-I responsibility is briefly outlined for the MT, PRS and MPE.

MT

The MT should, in principle, have the same design as per GAIA developments. However, due to some more stringent requirements associated to the MT on GG, in particular related to the increased thrust command frequency, slight modifications of the MT design could be necessary. Thus for the MT a DKP (Design Key Point) verification is proposed before the PDR. At the DKP the design modifications shall be fully identified and relevant impacts fully evaluated. A preliminary design description will be prepared. Downstream the DKP the MT Preliminary Design will be prepared, including identification of power, mass and envelope budgets and of I/Fs (thermal, mechanical and electrical). The preliminary design will be supported by preliminary mechanical, thermal and performance (thrust and plume modelizations). At the program PDR the MT Preliminary Design will be reviewed and updated Technical Specification will be ready.

PRS

The proposed module is an EPR not part of GAIA design which instead features a MPR. The reasons for switching from a MPR to an EPR have been presented and motivated in par. 5.2.1.
The PRS is therefore a new unit. However a remarkable design heritage and experience on this unit, has been accumulated indeed:
The key elements of the EPR PRS, dedicated to xenon, are being enginered in the framework of an ESA ARTES 8 Contract (Proportional Valve for High Power Electric Propulsion).
The functional demonstration of a PRS EM hardware versus Alphabus requirements has been successfully carried out at TAS-I Labs in Florence.
A qualification phase within this contract is started at beginning of year 2009.

The PRS auxiliary fluidic components (e.g. F&D Valves, HPT and LPT, Filters etc.) have been identified for the CGCS of Small GEO (this unit is simpler than the PRS but presents a certain degree of communalities for wht concerns the fluidic components)

In preparing and delivering the Technical Proposal for the BepiColombo High Pressure Regulator the issue relevant to the architectural definition on EPR (based on TAS-I HP Regulation Valve) has been addressed and analyzed, with detailed identification and definition of performances, layout, components, and Interfaces. Design, analyses, tests, qualification, MAIT, AIV activities associated to the development of a complete PRS unit, have been as well identified. Associated risks carefully addressed and examined (concluding the absolute feasibility of this unit in a reasonable timeframe).

All the accumulated heritage will be exploited for the proposed PRS associated to the Microscope CGPS. In any case the PRS has to be considered a new unit and therefore for this unit a complete design definition and consolidation phase has to be foreseen. At the DKP the guidelines and the proposed solutions for PRS design will be clearly identified and presented together with a low level equipment Specification.

Downstream the DKP the PRS Preliminary Design will be prepared, including identification of power, mass and envelope budgets and of I/Fs (thermal, mechanical and electrical). The preliminary design (encompassing the detailed identification of the fluidic parts/components composing the unit) will be defined. The definition of this design will be supported by preliminary mechanical, thermal and performance (fluidic modelization). At the program Delta-PDR the PRS Preliminary Design will be reviewed and Technical Specification will be ready.

MPE

The MPE circuitry and control s/w is the same as per GAIA for what concerns the most challenging functions (thrust actuation/control). Design variants are however needed in terms of different S/C interfaces (TM/TC bus, Power bus, Unit mechanical shape) and implementation of the Pressure Regulation closed loop Control. Most likely also the thrust actuation closed loop control strategy/parameters shell be reviewed for coping with the required fast response in terms of thrust actuation. Notwithstanding these variants are retained not critical an MPE design consolidation/refurbishment will be necessary.

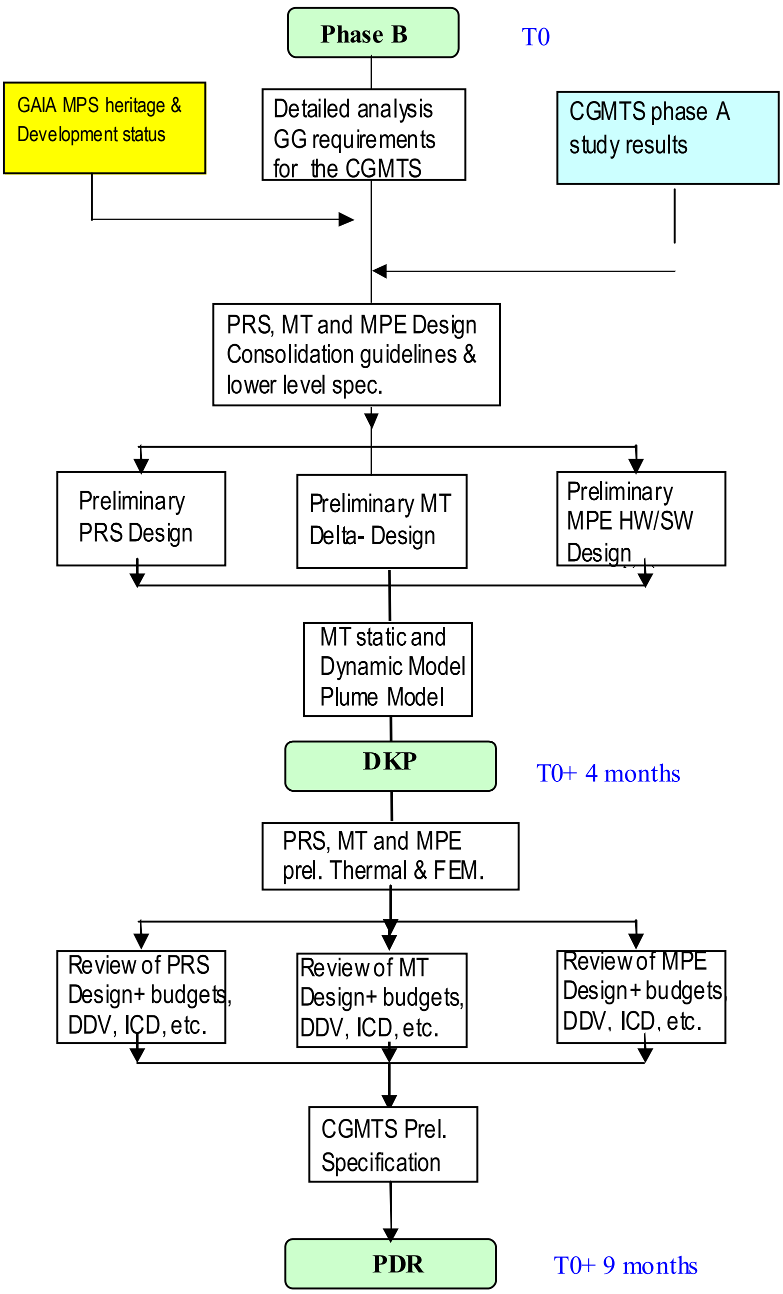
At the DKP the guidelines and the proposed solutions for MPE design consolidation will be clearly identified and presented together with a low level Equipment Specification

Downstream the DKP the MPE Preliminary Design will be prepared, including identification of preliminary power, mass and envelope budgets and of I/Fs (thermal, mechanical and electrical). The preliminary MPE design (encompassing the detailed identification of the most significant EEE parts composing the unit) will be then defined. The definition of this design will be supported by preliminary mechanical and thermal modelizations. At the program PDR the MPE Preliminary Design will be reviewed and Technical Specification will be ready.

An acceptance functional performance test at system level is foreseen with all the integrated modules.

9.3 CGMTS Development Flow Chart

The Phase B approach is also addressed with the following block diagram/flow chart.



9.3-1: Phase B Detailed Plan for the CGMTS

10. VERIFICATION AND QUALIFICATION PLAN

This Plan is referred in particular to the verification and qualification activities within expected phase C/D. The C/D activities related to the MAIT of the Flight HW are not here addressed.

10.1 MT EQM Qualification at component level

Downstream the PDR the Detailed MT Design and the relevant manufacturing Dossier for an EQM item will be prepared.
The detailed design documentation will be reviewed at the MRR. After the MRR the MT EQM fabrication will be released

It is envisaged to manufacture 2 MT EQM's. The QRR will certify the MT EQM (s) HW readiness and the availability of the MGSE/EGSE + test facilities to sustain the MT qualification tests.
A complete qualification is not foreseen since this is performed within GAIA and only delta qualification tests will be necessary to cover the GG functional and environmental requirements.

In this context the 2 MT EQM's will be dedicated to separate test sessions as below specified:

- 1 MT EQM (MT EQM 1) for:
  - Physical Properties
  - Electrical I/F
  - Functional/Performance (using suitable MGSE/EGSE/FGSE)
  - Leak, Proof
  - Mechanical (vibration + shock)
  - Thermal Vacuum
  - EMC conducted susceptibility

- 1 MT EQM (MT EQM 2) for:
  - Physical Properties
  - Electrical I/F
  - Functional/Performance (using suitable MGSE/EGSE/FGSE)
  - Leak, Proof
  - Thrust Actuation in answer to a thrust set point command frequency of 10 Hz
  - Thrust characterization (baselined on TAS-I Turin Nano balance)

The 2 MT EQM's will then both connected to a PRS branch and to the MPE , at EQM level, (see below) to verify (in the framework of CGPS EQM pre-integration and functional verification tests):

- The correct operation of the MT EQM's with the EQM PRS and EQM MPE
- Eventual "cross-talk" effects (if any) due to the PRS driving of more than 1 MT unit

The MT EQM test activity, including the integrated test at CGMTS level will be formally concluded and presented at the QRB/CDR.

After the CDR/QRB the MT Design will be frozen for the FM MT MAIT phase.

10.2 PRS EQM Qualification at unit level

For this module a complete qualification approach is proposed. Downstream the PDR the Detailed PRS Design and the relevant manufacturing Dossier for an EQM item will be prepared.
The detailed PRS design documentation will be reviewed at the MRR. After the MRR the PRS EQM fabrication will be released.

The proposed approach for the PRS EQM is to manufacture a single PRS branch, as we do not need a redundancy approach for the Qualification campaign. This solution allows in addition to contain the qualification costs. The sketch of the PRS EQM is below shown:

The QRR will certify the PRS EQM HW readiness and the availability of the MGSE/EGSE + test facilities to sustain the PRS qualification tests.

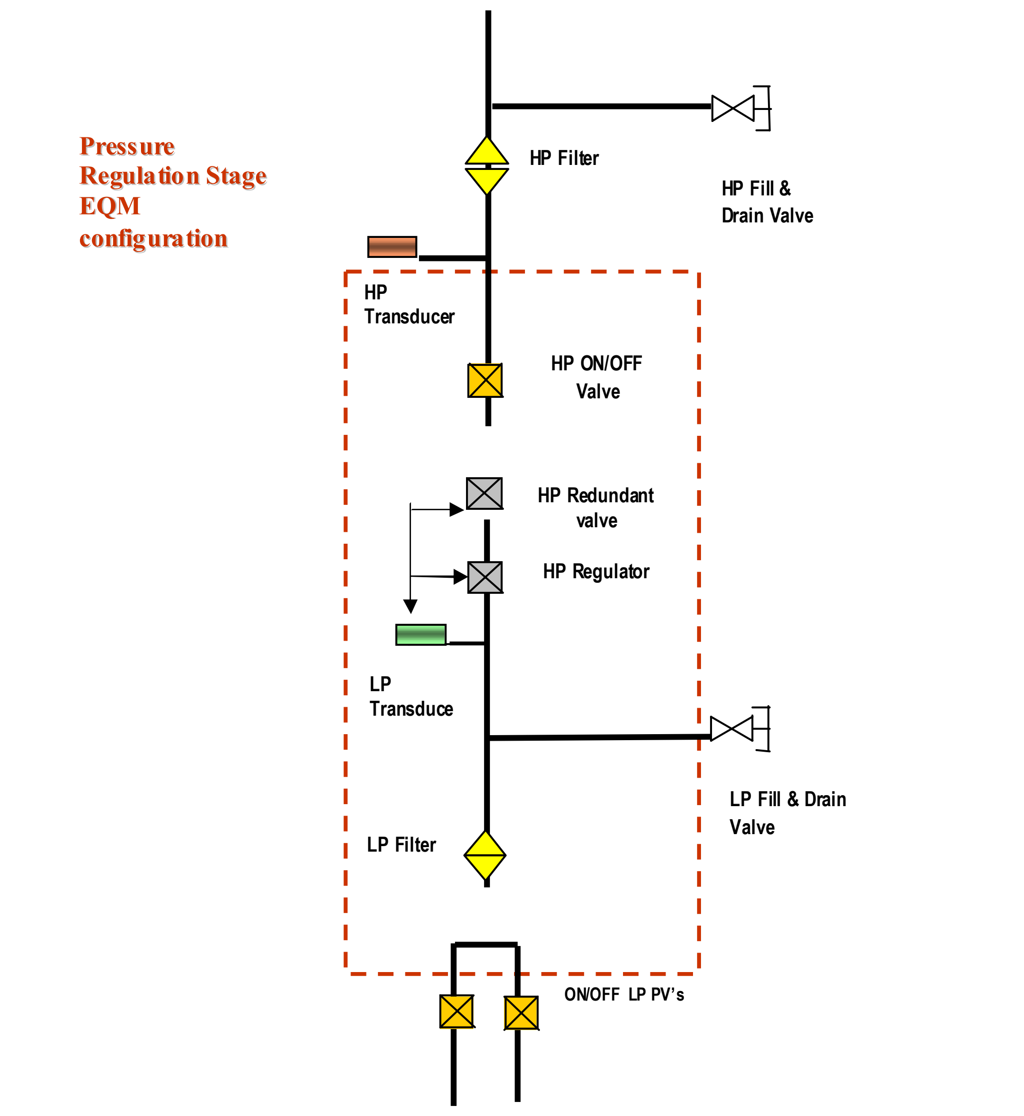


Fig. 10.2-1: PRS EQM Configuration

The PRS qualification approach will take also benefits and synergetic support from the TAS-I currently on-going EPR components (High Pressure Regulation & Insulation Valve) qualification program under ESA Artes 8 Contract.

The PRS EQM at unit level will undergo to:

- Physical properties
- Electrical I/F
- Leak, Proof
- Functional/performance tests (using suitable MGSE/EGSE/FGSE)
- Mechanical Tests (vibration + shock)
- Thermal vacuum test
- EMC conducted susceptibility

The PRS EQM shall then be integrated with the other EQM units to sustain the integrated CGPS qualification tests (including EMC)

The PRS EQM test activity, including the integrated test at CGPS level will be formally concluded and presented at the QRB/CDR

After the CDR the PRS Design will be frozen for the FM PRS MAIT phase.

10.3 MPE EQM Qualification at Unit level

For the MPE a qualification approach is proposed.

Downstream the PDR the Detailed MPE Design (HW and SW) and the relevant manufacturing Dossier for an EQM item will be prepared.
The detailed MPE design documentation will be reviewed at the MRR. After the MRR the MPE EQM fabrication will be released.

The proposed approach for the MPE EQM is to manufacture a single MPE section, as we do not need a redundancy approach for the Qualification campaign. This solution allows in addition to contain the qualification costs. An MPE EQM (non redounded) will be then manufactured and submitted to the qualification campaign at unit level including:

- Physical Properties
- Electrical I/F
- Functional/Performance (using suitable Test Equipment/EGSE)
- Mechanical (vibration + shock)
- Thermal vacuum
- Conducted EMC

The MPE EQM shall then be integrated with the other EQM units to sustain the integrated CGMTS EQM qualification tests

The MPE EQM test activity, including the integrated test at CGPS EQM level will be formally concluded and presented at the QRB/CDR

After the CDR the MPE Design will be frozen for the FM MPE MAIT phase.

10.4 Integrated CGMTS EQM qualification test campaign

After the qualification at unit level of the various CGMTS EQM units, namely

- PRS EQM (1 unit not redounded)
- MT EQM (2 units)
- MPE EQM (1 unit not redounded)

will be integrated for performing the following tests:

- First Coupling of Units
- Functional/Performance at ambient temperature
- Thruster "Cross-talk" effects characterization
- Reduced Functional/Performance at extreme temperatures
- Conducted and Radiated EMC
- ESD

The fluidic connections between the PRS and the 2 MT's during the integrated tests will be realized with laboratory pipe work and *swagelok* fittings. The length of the pipe work will be representative of the Flight arrangement on the S/C.

10.5 CGMTS Verification & Qualification Flow Chart

The CGMTS Verification & Qualification Flow Chart is shown in Fig. 10.5-1.

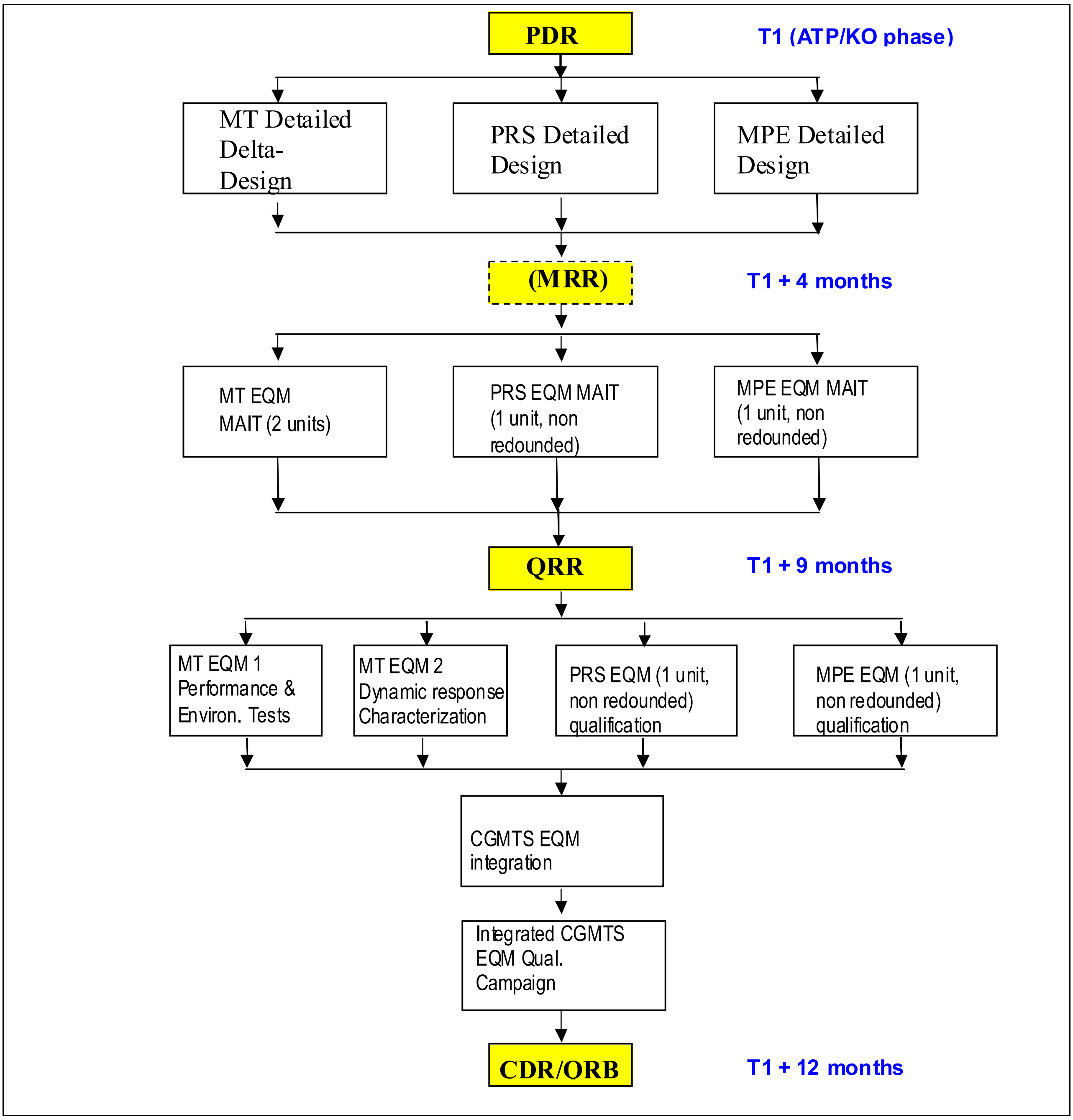

PDR
T1 (ATP/KO phase)
MT Detailed Delta-Design
PRS Detailed Design
MPE Detailed Design
(MRR)
T1 + 4 months
MT EQM MAIT (2 units)
PRS EQM MAIT (1 unit, non redounded)
MPE EQM MAIT (1 unit, non redounded)
QRR
T1 + 9 months
MT EQM 1 Performance & Environ. Tests
MT EQM 2 Dynamic response Characterization
PRS EQM (1 unit, non redounded) qualification
MPE EQM (1 unit, non redounded) qualification
CGMTS EQM integration
Integrated CGMTS EQM Qual. Campaign
CDR/ORB
T1 + 12 months

Fig. 10.5-1

11. DOCUMENTS

11.1 Applicable Documents

[AD 1] ASI, “Progetto Galileo Galilei-GG Fase A-2, Capitolato Tecnico”, DC-IPC-2007-082, Rev. B, October 2007 and applicable documents defined therein

[AD 2] “Galileo Galilei Mission Requirement Document”, SD-TN-AI-1167, Issue 1 draft, October 2008

[AD 3] Experiment Concept and Requirements Document (ERD), SD-TN-AI-1163, Issue 1 draft, October 2008

[AD 4] “Galileo Galilei System Technical Specification”, SD-SY-AI-0014, January 09, Issue Draft

[AD 5] “Thrusters requirements (preliminary)”, TAS-I , e-mail 29/02/09

11.2 Standards

[SD 1] ECSS-M-00-02A, Space Project Management – Tailoring of Space Standards, 25 April 2000

[SD 2] ECSS-E-10 Part 1, System engineering

[SD 3] ECSS-E-10-02A, Space Engineering – Verification

[SD 4] ECSS-E-30, Space Engineering - Mechanical - Part 1: Thermal

[SD 5] ECSS-E-30, Space Engineering - Mechanical - Part 2: Structural

[SD 6] ECSS-E-30, Space Engineering - Mechanical - Part 3: Mechanism

[SD 7] ECSS-E-30, Space Engineering - Mechanical - Part 5: Propulsion

[SD 8] ECSS-E-30, Space Engineering - Mechanical - Part 6: Pyrotechnics

[SD 9] ECSS-E-30, Space Engineering - Mechanical - Part 7: Mechanical Parts

[SD 10] ECSS-E-30, Space Engineering - Mechanical - Part 8: Materials

[SD 11] ECSS-E-40 Part 1, Software Engineering Standards

[SD 12] ECSS-E-ST-60-10C Control Performance

[SD 13] ECSS-Q-00A, Space Product Assurance - Policy and Principles, and related Level 2 standards.

[SD 14] ECSS-Q-ST-70-01C, Cleanliness and contamination control, 15 November 2008

11.3 Reference Documents

[RD 1] GG Phase A Study Report, Nov. 1998, revised Jan. 2000, available at: http://eotvos.dm.unipi.it/nobili/ggweb/phaseA/index.html

[RD 2] Supplement to GG Phase A Study (GG in sun-synchronous Orbit) "Galileo Galilei-GG": design, requirements, error budget and significance of the ground prototype", A.M. Nobili et al., Physics Letters A 318 (2003) 172–183, available at the following official website: http://eotvos.dm.unipi.it/nobili/documents/generalpapers/GG_PLA2003.pdf

12. LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition	Notes
AD	Applicable Document	
AIV	Assembly Integration Verification	
AOCS	Attitude and Control Subsystem	
ASI	Agenzia Spaziale Italiana	
ATP	Authorization to Proceed	
CCSDS	Consultative Committee for Space Data Systems	
CDR	Critical Design Review	
CGCS	Cold Gas Conditioning Subsystem	Here Referred to the unit under development for Small GEO Program
CGMTS	Cold Gas Micro Thruster System	Referred to Cold Gas Micro Propulsion on GG
CGPS	Cold Gas Propulsion System	Referred to the Cold Gas integrated Micro Propulsion + Auxiliary Propulsion for GG
CGTA	Cold Gas Thruster Assembly	System of On/off Cold Gas thruster developed by TAS-I for SGEO program
CNES	Centre National d'Etudes Spatiales	
CPE	Control and Processing Electronics	
DFACS	Drag Free Attitude and Control Subsystem	
DKP	Design Key Point	
DRB	Delivery Review Board	
ECSS	European Cooperation for Space Standardisation	
EEE	Electric, Electronic, Electro-mechanical	Referred to electrical parts/components
EGSE	Electrical Ground Support Equipment	
EOL	End Of Life	
EP	Equivalence Principle	
EPR	Electronic Pressure Regulator	It offers the possibility to program the regulated low pressure set-point
EQM	Engineering Qualification Model	
ESA	European Space Agency	
ESD	Electro Static Discharge	
EMC	Electro magnetic Compatibility	
FDV	Fill & Drain (Vent) Valve	
FEE	Front End Electronics	MFS conditioning Electronics embedded in the MT housing

Acronym	Definition	Notes
FEEP	Field Emission Electrical Propulsion	
FEM	Finite Element Model	
FGSE	Fluidic Ground Support Equipment	
FM	Flight Model	
FMECA	Failure Modes Effects & Criticality Analysis	
FOS	Factor of Safety	
FU	Filter Unit	Referred to the Filter positioned immediately upstream the MFS in the MT configuration
G/S	Ground Station	
GG	Galileo Galilei	Italian Equivalence Principle Mission
HK	Housekeeping	
HP F&D	High Pressure Fill & Drain Valve	
HP PV	High Pressure Piezo Valve	See also HP RIV
HP RIV	High Pressure Regulation & Insulation Valve	It can be used either in the on/off mode or in the analog regulation mode
HPF	High Pressure Filter	
HPT	High Pressure Transducer	
HW	Hardware	
ICD	Interface Control Document	
INFN	Istituto Nazionale di Fisica Nucleare	
IORF	Inertial Orbit Reference Frame	
I_S	Specific Impulse	Ratio between the generated thrust and propellant mass flow rate
ISV	Independent Software Validation	
ITAR	International Traffics in Arms Regulations	
KO	Kick Off	
LEOP	Launch and Early Orbit Phase	
LL	Limit Loads	
LP RIV	Low Pressure Regulation & Insulation Valve	It can be used either in the on/off mode or in the analog regulation mode
LP RVN	Low Pressure Regulation Valve with Nozzle	Other name for identifying the Thruster Valve (TV)
LPF	Low Pressure Filter	
LPT	Low Pressure Transducer	
MAIT	Manufacturing, Assembly, Integration & test	
MFS	Mass Flow Sensor	Operates in closed loop with the TV
MGSE	Mechanical Ground Support Equipment	

Acronym	Definition	Notes
MLI	Multi Layer Insulation	
MPE	Micro Propulsion Electronics	Also referred to the GAIA program
MPR	Mechanical Pressure Regulator	It provides a fixed value (non modifiable) of the regulated low pressure
MPS	Micro Propulsion System	Referred to GAIA Cold Gas Propulsion
MRD	Mission Requirement Document	
MRR	Manufacturing Readiness Review	
MT	Micro Thruster	It includes the TV, the MFS, the FEE and the FU
MTAS	Micro Thruster Actuation Stage	It is a set of MT's
OBCP	Onboard Control Procedure	
P/L	Payload	
PA	Product Assurance	
PCB	Pico Gravity Box	
PCU	Power Control Unit	
PDR	Preliminary Design Review	
PID	Proportional, Integrative, Derivative	Referred to the MT closed loop control strategy
PPRF	Payload Physical Reference Frame	
PRS	Pressure Reduction & Regulation Stage	
PSD	Power Spectral Density	Refferred to the thrust Noise issue
QL	Qualification Loads	
QM	Qualification Model	
QRB	Qualification Review Board	
QRR	Qualification Readiness Review	
RD S/C	Reference Document Spacecraft (or Satellite)	 Referred to the platform (Myriad) supporting the Microscope mission
S/S	Subsystem	
SD SEL	Standard Document Single Event Latch-Up	
SEU	Single Event Upset	
SGEO	Small GEO	ESA ARTES 11 Program within which TAS-I is providing the CGTA
SPoF	Single Point of Failures	
SPRF	Satellite Physical Reference Frame	
STB	Software Test Bed	
STS	System Technical Specification	
SVF	Software Validation Facility	
SW	Software	

Acronym	Definition	Notes
TAS-I	Thales Alenia Space Italia	
TBC	To Be Controlled	
TBD	To Be Defined	
TC	Telecommand	
TM	Telemetry	
TRL	Technology Readiness Level	
TV	Thruster Valve	Operates in closed loop with the MFS

END OF DOCUMENT