Electric Propulsion Diagnostic Package for the FEEP thruster on Lisa Path Finder: Review of status of achievements at TAS-I

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Abstract: **A FEEP Micro Propulsion Subsystem (MPS) has been selected for the Lisa Path Finder mission as it can provide a finely controllable and repeatable thrust level in the thrust range below 1 mN, at a specific impulse higher than 6000 s. The use of the FEEP MPS on board Lisa Path Finder could eventually give rise to complex environmental interaction phenomena. An EPDP (Electric Propulsion Diagnostic Package) is therefore embarked on the spacecraft to allow the characterization of the FEEP MPS/spacecraft interactions. The FFEP EPDP manufactured by TAS-I includes Plasma and Mass deposition probes as well as an Electronic Unit for powering and control of the instrument. The paper presents a review of the EPDP Instrument architectural configuration, the achievable features/performances, the Plasma/Contamination probes, the Control Electronics providing also details on the manufacturing activities and test campaign currently underway at TAS-I Florence Laboratories**

Nomenclature

BSE	=	Bias & Sweep Electronics
CDA	=	Contamination & Deposition Assembly
EP	=	Electric Propulsion
EPDP	=	Electric Propulsion Diagnostic Package
ESA	=	European Space Agency
FEEP	=	Field Emission Electric Propulsion
HET	=	Hall Effect Thruster
LP	=	Langmuir Probe
LPF	=	Lisa Path Finder, as LISA (Laser Interferometer Space Antenna) precursor mission
MPS	=	Micro Propulsion Sub-system
PCB	=	Printed Circuit Board
PCU	=	Power & Control (electronic) Unit
PDA	=	Plasma Diagnostic Assembly
PSD	=	Power Spectral Density

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QCM = Quartz Crystal Microbalance
RPA = Retarding Potential Analyzer
SRS = Shock Response Spectrum
TAS-I FI = Thales Alenia Space Italia, Florence Site (former LABEN Proel Tecnologie Division)
TAS-I MI = Thales Alenia Space Italia, Milano Site (former LABEN)
TAS-I = Thales Alenia Space Italia
TLM/TLC = Telemetry/Telecommand

I. Introduction

FEEP (Field Emission Electric Propulsion) thrusters are assuming significant role in the near future European scientific missions, in that they are able to provide a very fine tuning of torques and forces for actuating the precise attitude and "drag-free" spacecraft control, during the operational phase. FEEP thrusters can provide a controlled and repeatable thrust level in the range of 1 to 100 μN, with a thrust noise below 0.1 μN and a specific impulse higher than 6000 s. Currently a FEEP MPS is baselined on Microscope and Lisa Pathfinder missions.

As precursor of LISA, the LPF mission is required to place a spacecraft into an L1 orbit, compatible with the technology demonstration requirements. On LPF the FEEP Micro Propulsion System (MPS) will be used to compensate the solar radiation pressure incident on the spacecraft and ensure that the LPF experiment Test Flight Package is maintained in a "disturbance - free" inertial (free fall) environment.

In spite of the great flexibility and versatility of the FEEP technology, there are still some concerns that the use of these thrusters could give rise to complex interaction phenomena among the thruster plume, the ambient plasma and the spacecraft. In this context, it is envisaged and recommended to use an EPDP (Electric Propulsion Diagnostic Package) dedicated to the characterization of the FEEP MPS/spacecraft interactions with particular reference to the following aspects:

1. characterization of the plasma parameters, outside of the primary ion beam.
2. investigation on changes in the electric and plasma environment of the spacecraft during the MPS (Thrusters + neutralizers) operation;
3. investigation on contamination and erosion of spacecraft exposed surfaces resulting from the deposition of propellant (metallic particles) and eventually of other sputtered materials.
4. provide valuable data to validate modeling tools and allow better design of future systems

The LPF EPDP, currently under manufacturing at TAS-I Florence Site at Proto-Flight Model (PFM) level, is directly derived from a similar package, dedicated to the investigation of HET EP, and successfully operated in-flight on SMART-1 satellite for more than 1 year. SMART-1 mission results have been outstanding and the learned lessons for what concerns EP/ spacecraft interactions have resulted precious for future space missions based on EP.

For the EPDP on LPF modifications/upgradings have been introduced, with respect to the EPDP flown on SMART-1, in order to cope with the LPF specific mission requirements. These modifications are related to the following areas:

- current ranges of the plasma probes, due to different (much more rarefied plasma environment) plasma parameter ranges;
- TLC/TLM interface (bus standard change from CAN bus to MIL-1553);
- heating provisions for avoiding solidification of Cesium or Indium on the plasma probe electrodes;
- different nominal power bus voltage (28 V instead of 50 V);
- different types of orbit and space plasma conditions.

II. EPDP Configuration/architecture

In the framework of the FEEP MPS operational mission on board LPF, the EPDP is asked, in particular, to investigate both the plasma parameters and the contamination parameters. The information on the expected plasma characteristics outside the primary FEEP beam and on the mass deposition are reported in summary in Table 1:

Parameter	Min	Max	Unit
Ion Energy	0	450	eV
Electron Energy	0.1	5	eV
Plasma Density	10	10^3	mm^{-3}
Plasma Potential	-200	200	V
Mass Deposition	0	0.25	mg/cm^2

Tab.1 : Reference performances asked to the EPDP on LPF

As in the case of SMART-1 EPDP the Lisa PF EPDP is composed by the following assemblies, each self-contained in a separate box:

• Plasma Diagnostics Assembly (PDA), including:

- Retarding Potential Analyzer (RPA), for the characterization of ion energy distribution and current density
- Langmuir Probe (LP), for the measurement of plasma parameters
- Heaters for FEEP propellant (Cesium or Indium) evaporation
- LP/RPA front end electronics.

The PDA will allow in particular the collection/reconstruction of the information associated to the following parameters:

- Ion Energy (referred to secondary or charge-exchange ions)
- Ion Energy Distribution
- Electron Energy
- Plasma Density
- Plasma Potential
- Current Densities (both charge-exchange ions and electrons)

• Contamination & Deposition Assembly (CDA), including:

- Quartz Crystal Micro-Balances for mass deposition/erosion investigation

The CDA will allow in particular the collection of data referred to:

- Mass deposition of propellant and/or other sputtered material
- Mass deposition rate of the same material

• Power & Control Unit (PCU) including:

- Probes Conditioning
- Heaters control
- Power conversion and distribution
- TLM/TLC interface with the spacecraft
- Interface to the spacecraft power bus

Fig.1 below presents the general configuration sketch of the EPDP instrument on LPF.

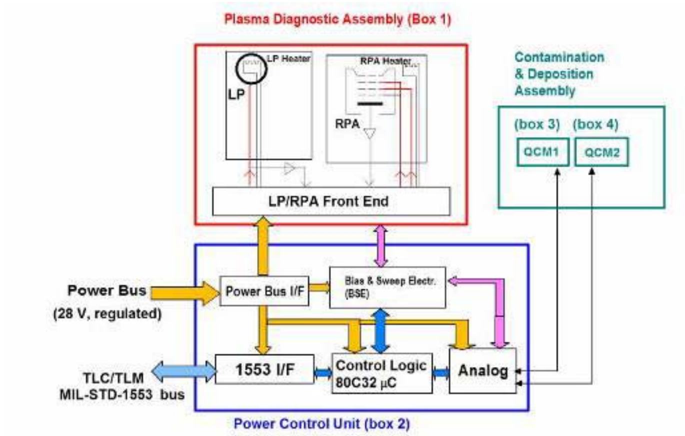


Fig. 1: EPDP for the FEEP on LPF functional Sketch

The mass and envelope budgets associated to the EPDP on LPF instrument are reported in table 2 below:

EPDP Box/Element	Dimensions	Mass
PDA box	125 x 65 x 150 mm	500 g
CDA (including 2 QCM Units	(21.7 x 21.7 x 26) mm x2	25g x 2
PCU	114 x 120 x 101 mm	1850 g
Total EPDP mass		2360 g
Electrical harness		300 g

Tab.2: Mass and envelope budgets for the EPDP on LPF assemblies

III. PDA (Plasma Diagnostic Assembly)

The PDA is the main sensor box including the two main plasma sensors, the LP and the RPA (see Fig. 2 and 3).

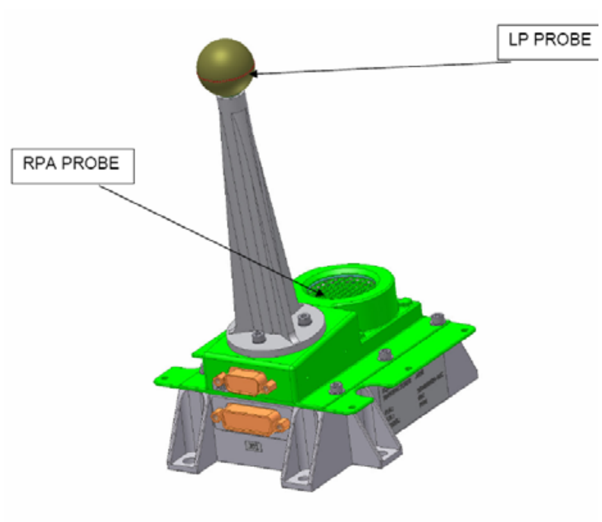


Fig. 2: PDA CAD 3D Modelization

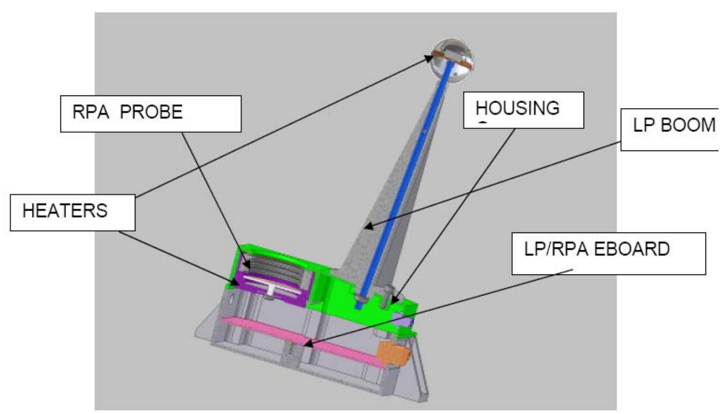


Fig. 3: PDA 3D model showing the interior of the box

The LP is basically a metallic sphere (25 mm diameter for the FEEP on LPF application), fully insulated from the PDA reference ground. The diameter of the sphere has been properly selected to allow the investigation of plasma parameters in the range of interest.

Fairly accurate information about plasma parameters like Plasma Potential (V_p), Electron temperature (T_e) and density (n) can be obtained by means of LP diagnostics. The method is based on the comparison between the experimentally acquired I (V) LP characteristic curve and a theoretical shape which is expressed through the plasma parameters.

A typical LP characteristic curve is acquired by sweeping (normally with a linear ramp) the potential of the probe between 2 extremes and measuring the corresponding current collected by the probe. Each LP voltage and current point of the ramp is acquired by averaging 10 successive samples.

The LP is of relatively simple construction and allows a local measurement of plasma parameters, with a spatial resolution in the order of probe dimension. Inside the LP sphere a heater is accommodated and used for cleaning (by evaporation) the probe external surface in case of possible contamination due to metallic propellant deposition as a consequence of FEEP operation.

The LP is mounted within the EPDP PDA on the top of boom. This approach is recommended to in order to penetrate as much as possible inside the plasma sheath of the spacecraft even if as the local plasma Debye Length is expected in between few mm up to several cm. Typical sheath dimension are of 3÷5 Debye lengths and two sheaths have been considered: the one around the probe and the one around the PDA box. From the above it would result advisable to adopt a boom of 1 m of length in order to cover the low end side of the expected plasma density range. This length is unmanageable (in term of mass and envelope budgets received for the EPDP instrument). Nevertheless maximum effort to increase the LP boom has been performed within the actual box envelope. The LP boom length has been increased up to 120 mm against the 40 mm of the SMART-1 one. In summary the LP dimensioning has been made on the basis of a trade-off between implementation constraints and the need to get as much as possible accurate results.

The retarding field ion energy analyzer or Retarding Potential Analyzer (RPA) is a small, lightweight sensor unit (similar to the one flown on SMART-1) which measures the ion energy and the current density distribution versus energy. It is a flat gridded probe, made with a ceramic body housing a stack of 4 metallic grids (electrodes) standing over a metallic target which collects the ions. The RPA uses the electrodes, biased at suitable potentials, to selectively filter out the ions whose energy is lower than the potential energy barrier created by the 3rd grid (ion energy selector, swept from 0 to 450 V) yielding an ion current which varies as a function of the ion retarding energy. As a consequence the maximum observed ion current is observed with a grid bias of 0V. The first grid, tied to the reference ground, prevents the ambient plasma from entering inside. The second and fourth grids are electron repellers, for primary (coming from the external environment) and secondary (internally generated by collision) electrons, respectively. Both grids are connected to a negative potential (nominally – 80 V).

The cross section drawing of the RPA probe is sketched in Fig.4. Fig. 5 shows a particular of the RPA design

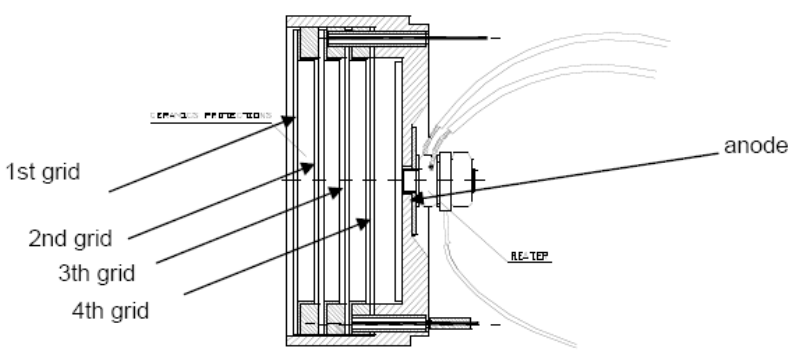


Fig. 4 RPA Cross section showing the grid and anode structures

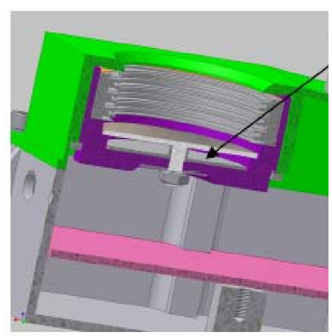


Fig. 5: Heater accommodation within the RPA body

Fig. 6 and 7, here below, show the current-voltage characteristic curves obtained respectively from a LP and a RPA

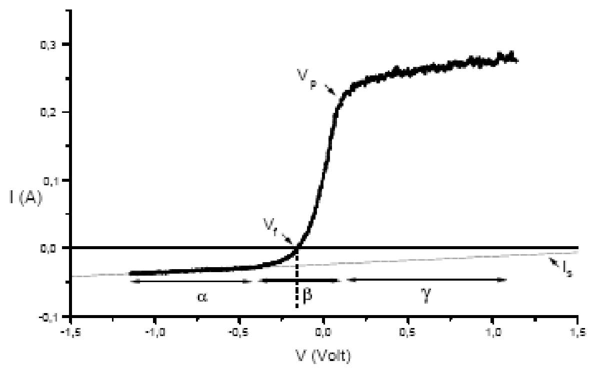


Fig. 6: Typical LP Curve

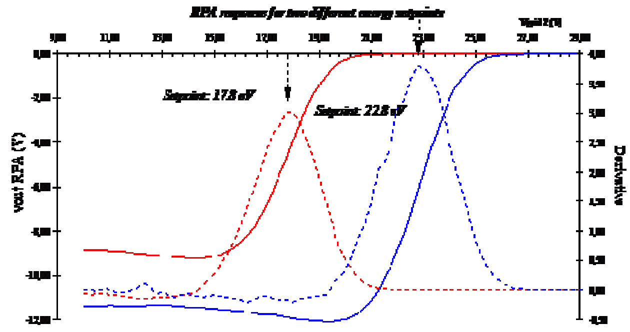


Fig. 7: Typical RPA curve

The LP and RPA operation parameters are reported in summary within Table 3 here below:

LP	RPA	Parameter
-1 µA to 1.0 mA	0 to 2 µA	Estimated expected Current Range
~ ±0.05nA	~ ±0.05 nA	Nominal Current measurement Accuracy
-210 to + 210 V	0 to 450 V	Control (sweep) Voltage Range
0.12 V	0.25	Voltage Step
±0.05V	±0.125V	Nominal Voltage measurement Accuracy
512	512	N. of points on sweep
Max 64	Max 64	No of samples for each measurement averaging
8ms to 2048ms	8 to 2048 ms	Delay between each acquisition

Tab. 3: LP and RPA operational parameters within the EPDP for LPF

Both the design of the LP and RPA has been tuned by using a numerical model set-up in house by TAS-I FI.

The LP and RPA can be used in 2 different operating modes:

- RPA/LP controlled with a linear voltage ramp and collecting the I-V curve
- LP/RPA at a fixed voltage and collecting the current signal versus time

The EPDP PDA includes also a small electronic board named LP/RPA front end. This board includes part of the DC/DC devices that generate the voltages to power the LP and RPA sweep generators. In addition the LP/RPA board hosts the components for the necessary pre-amplification (very low noise amplifier to cope with the required sensitivity) of the current signals collected by the probes

IV. CDA (Contamination & Deposition Assembly)

The CDA package contains two Quartz Crystal Micro Balances (QCM). These 2 QCM's would be accommodated on the same panel of the S/C where the PDA is located. The QCM sensor (see Fig. 8 and 9) is designed for the accurate measurement of a small mass flux. The principal elements of this sensor are: the crystal assembly, the electronics hybrid chip, the case with a mounting flange and connector. The crystal pack consists of two matched quartz crystals: the "sensing" crystal and the "reference" crystal. The sensing crystal is exposed to the open space and thus to the mass flux and responds to a deposition of mass by shifting its oscillation frequency. The other crystal (reference) is accommodated inside the package and its vibration frequency is not affected by mass deposition. Using matched pairs, the two clean crystals beat at the same frequency over a large temperature range, with very small errors. The double crystal configuration renders the measurement almost independent of the temperature (differential measurement). In presence of mass deposition a "beat frequency" is generated and processed for obtaining the mass deposition information.

Fig. 8: QCM model MK 17 Procured from QCM Research

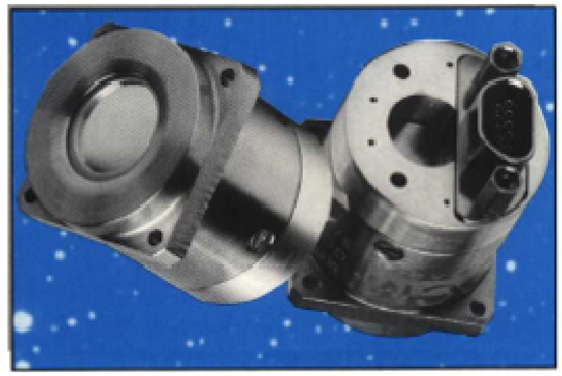


Fig. 9: Front and rear view of the MK 17 QCM Model

The QCM is equipped with a 1000 ohm PRT Temperature Sensor having the purpose of witnessing the device temperature. In fact, deposition phenomena are affected by the surface temperature and the type of contaminant

In addition a heater is present in the assembly in order to allow the outgassing and cleaning of the quartz exposed surfaces. The main parameters associated to the QCM operation are summarized in Table 4.

Nominal Frequency of each crystal	15 MHz
Beat signal frequency range	1kHz-135 kHz
Acquisition time delay for multiple readouts	10s÷100s
Mass Sensitivity	2.26 x10^8 Hz/(g/cm^2)
Number of repeated readings	1 to 100
Temperature range of thermocouple/thermistors	-50°C÷ +120°C
Accuracy of temperature readout	±3% reading
Beat signal frequency accuracy	0.1Hz
QCM Mass	25 g
QCM Envelope	21.7 x 21.7 x 26 mm
Power demand	0.15 W at steady state operation 2.5 W during the heating phase

Tab. 4: Main parameters associated to the QCM operation as mass deposition sensor

The QCM are used in flight by sampling versus time the temperature and beat frequency (QCM signals). The beat frequency throughout time provides also the information about mass deposition rate.

V. PCU (Power & Control Unit)

The PCU contains the I/F functions with the S/C and the other functions needed to drive, monitor and control the other EPDP instrument boxes. The PCU Design and manufacturing is carried out at TAS-I MI.

The major differences between SMART 1 and LISA EPDP PCU are related to the increased performances of the I/F electronics, the MIL STD 1553 Bus in place of the CAN bus, different voltage and current ranges for the LP and RPA probes (that now work in a much tenuous plasma environment), 28 V power bus instead of 50 V and implementation of probes heating function.

In the block diagram of Fig. 10, the physical functions allocations in board is depicted

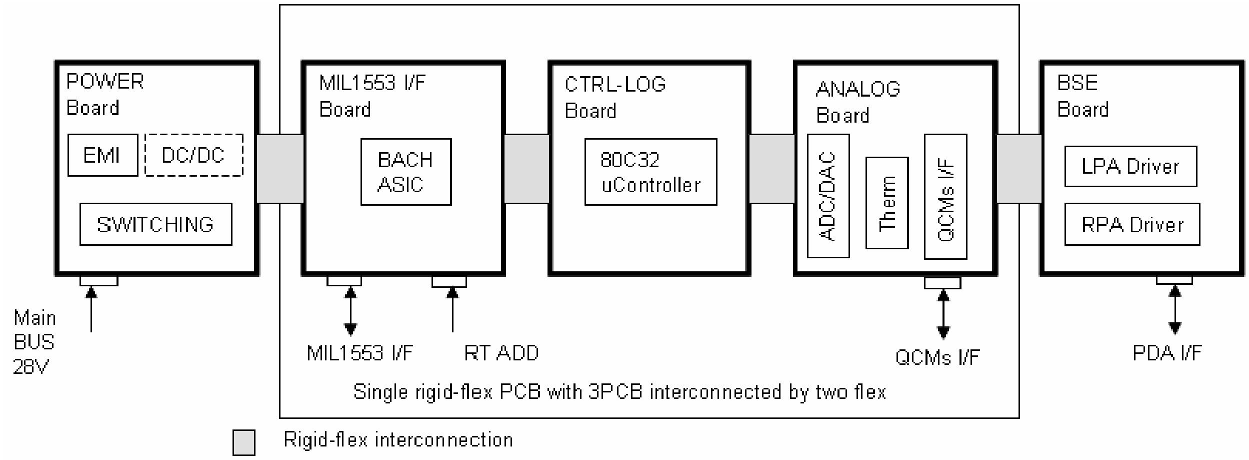


Fig. 10: Schematic of the various electronic PCB's in the EPDP instrument

The *Power Board* allocates the Interpoint main DC supply with its input EMI filter, the fuses to protect the +/-12V secondary lines, the solid state relays to switch ON/OFF the secondary +5V power line, used to supply the auxiliaries DC/DC converters used by the RPA and LPA probes, and the solid state Relays to switch ON/OFF the QCM1-2.

The *MIL1553 Bus Interface* is based on the BACH ASIC. The ASIC can work in several configurations. The Remote terminal implementation in multi message mode (with external memory) is chosen for maximum flexibility. The ASIC Telemetry interface is not used, since a faster and more powerful acquisition interface is implemented in the *CTRL&LOG board* FPGA. The CTRL_LOG board is based on the 80C32 microcontroller device

The CTRL-LOG board contains also the PCU memory composed by 8 K PROM for boot program section, 128 K EEPROM for program execution (EPDP software) and permanent data storage, 128 K RAM for temporary data storage.

The main functions of the *Analog Board* are:

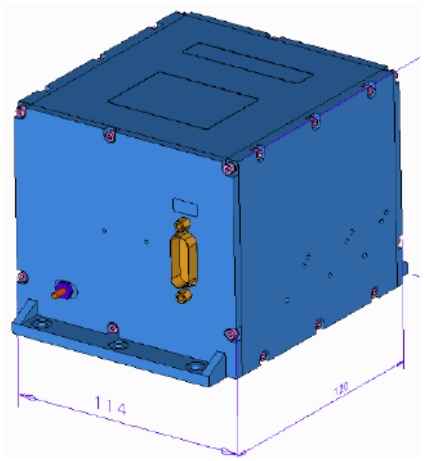
- to perform Analog to Digital conversion of the EPDP signals (RPA, LPA, Thermistors, Current Monitors)
- to perform Digital to Analog conversion for the control of the voltage of the RPD and LPA probes
- to provide the interface for the frequency signal of the QCM1 and QCM2
- to provide the an ON/OFF switch for QCM1 and QCM2 Heater control
- to provides the current source stimulus for thermistors conditioning
- to remove offset and to amplify the thermistor's signals
- to remove the common mode of LPA probe

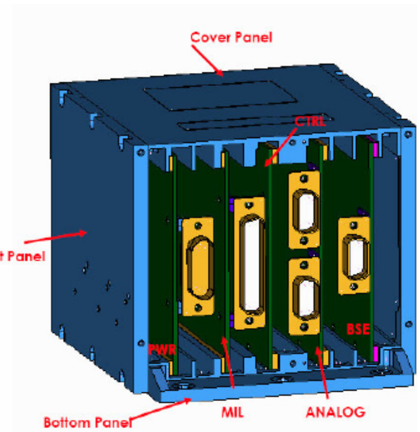
The main functions of the *BSE Board* are:

- to generate high voltage supply for the RPA and LPA probes by means of DC/DC converters
- to provide the programmable (+/-250V) voltage driver for LPA probe
- to provide the programmable(0 to 250V) first stage driver for RPA probe
- to provide the an ON/OFF switch for LPA and RPA Heater control

Heater drivers for the RPA and LP probes are also allocated on this board. Both consist of a switch that allows the heater supply with the 5 V power line under software control.

The Figs. 11, 12 and 13 below show the CAD modelization of the PCU box for the EPDP on LPF.





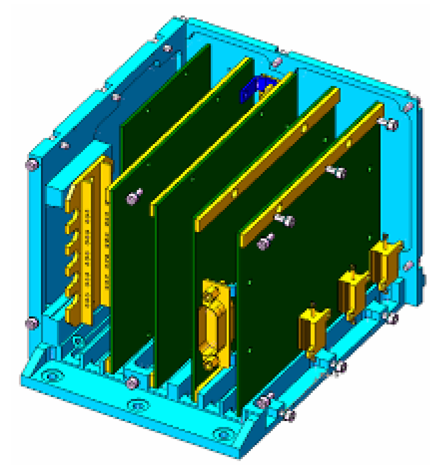


Fig. 11: 3D CAD View of the EPDP PCU Box

Fig. 12: PCU 3D CAD view showing the interior

Fig. 13: PCB accommodation within the PCU

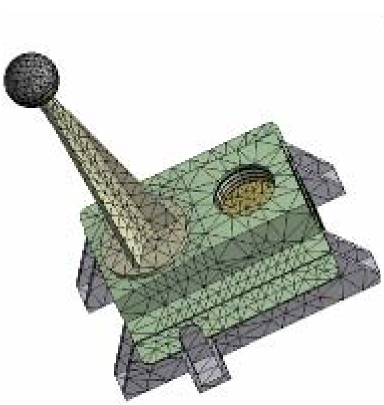
VI. EPDP Mechanical & Thermal analyses

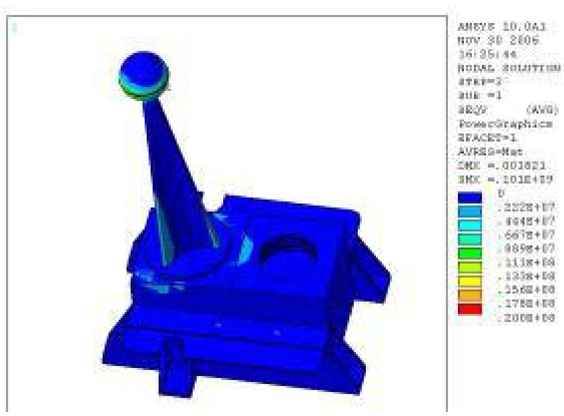
The mechanical and thermal analyses on the EPDP boxes have been performed to demonstrate by analysis that the Instrument is capable to withstand the mechanical and thermal environments foreseen throughout the LPF mission running. Both the PDA and PCU boxes have been analyzed against the LPF requirements, in particular for what concern mechanical environment the following analyses have been performed

1. Modal analysis
2. Equivalent worst case linear static analysis
3. 3 axis PSD analysis
4. SRS (shock) on each axis

The first analysis is used to investigate the Eigen-frequency of the unit and the others to evaluate the stress/strain on the box due to the various loads applied.

Figs. 14, 15 and 16 below respectively show the PDA FEM Model realized with Ansys environment, the power spectral density Stress distribution and the PDA box mapping of Eigen frequencies.





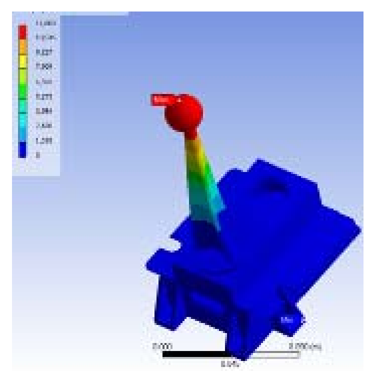
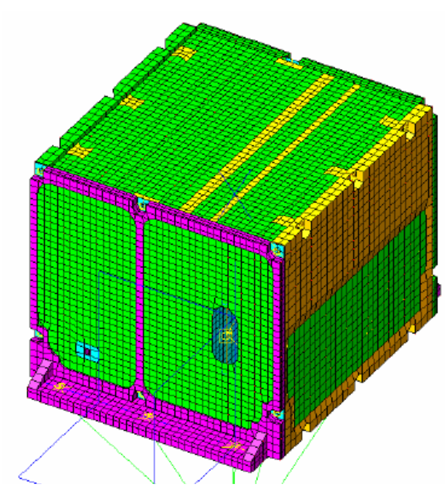


Fig. 14: PDA FEM Model

Fig. 15: PSD stress distribution on the PDA box

Fig. 16: PDA Eigen-frequency modes

Figs. 17 and 18 below respectively show the FEM of the PCU box and the PSD Stress Distribution on the PCU internal parts (PCB's)



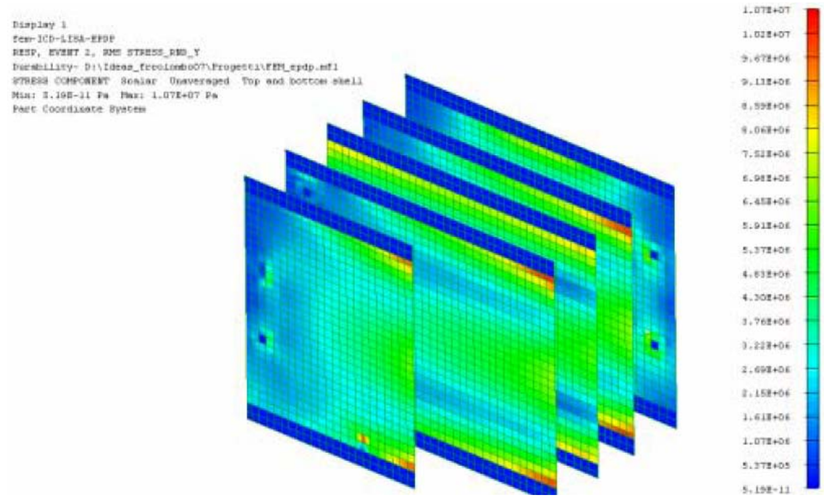


Fig. 17: PCU FEM Model **Fig. 18: PSD Stress Distribution (y direction) for the PCB parts**

There are three conditions that are of interest to be analyzed from the thermal point of view for the PDA; they refer to the following conditions: (1) LP heater ON; (2) RPA heater ON; (3) LP acquisition. In Figs. 19 and 20 here below, graphical representations of temperature distributions on the PDA elements are shown, in the worst case conditions

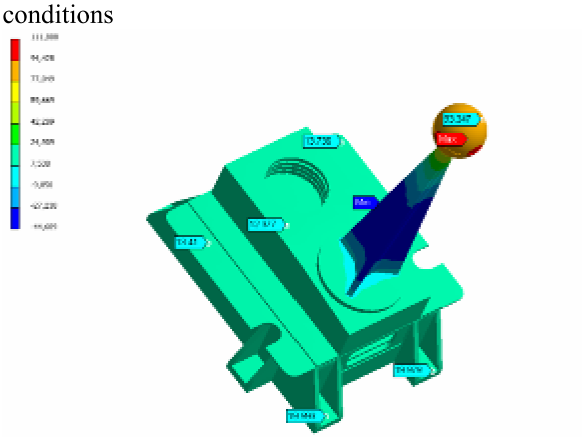


Fig. 19: LP heating mode with 1 W of power dissipation : Tb=20°C

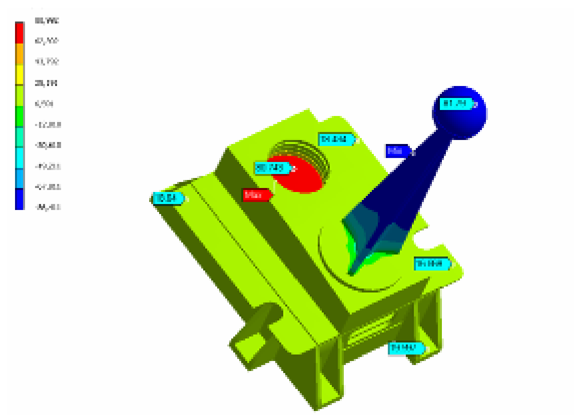


Fig. 20: RPA heating with 4.5 W of power dissipation : Tb=20°C

In summary the results obtained in terms of maximum and minimum temperatures of the PDA box and its components are compatible with the foreseen performances of the PDA provided that no operation (EPDP is switched OFF) is performed during the "Non Science Mode" at the highest temperature level (interface T >70°C).

The thermal analysis performed on the PCU revealed that in any operating mode and worst case boundary conditions the temperatures never rise above about the limits for PCBs. The maximum/ minimum EPDP PCU temperatures are therefore not critical. The thermal behavior and design of the EPDP PCU has been confirmed to be satisfactory. In any case, in order to improve thermal performance diffusive copper planes are foreseen to be implemented into the CTRL, 1553 I/F, ANALOG and Power Boards.

VII. EPDP operating modes and associated power consumption

Table 5 below presents, in summary, the EPDP operating modes and relevant associated power consumptions in the framework of the LPF mission.

Mode	Description	Power Consumption with 15% contingency
Off	The LISA EPDP is not powered	0
Boot	The boot module is executed from Prom (Probes and Heaters are switched OFF)	5.5 W
Stand-by	Initial State of application, the LISA EPDP is powered, TC and HK managed. On entering the standby mode, Probes and Heaters are switched OFF.	5.5 W
Reload	It Runs from PROM and perform the reload of Experiment Control SW in EEPROM. It manages only some TC and TM, no HK TLM is generated. To exit this state a power-off/power-on is required in order to repeat the boot check against the new SW	5.5 W
Acquisition	The LISA EPDP is powered, a probe is selected and an internal data acquisition/storage session is being performed	11.5 W (LP acquisition) 9.3 W (RPA acquisition) 5.7 W (QCM acquisition)
Heating	The LISA EPDP is powered, one heater is selected to generate science telemetry. Thermal control is activated.	16.1 W for RPA 9.3 W for LP 9 W for QCM
Download	The LISA EPDP is powered; probes are not powered; the internal sequence for memory dumping is being carried out.	5.5 W
Patch	The LISA EPDP is powered; probes are not powered; the internal sequence for data memory patching is being carried out.	5.5 W

Tab.5: EPDP operating modes and associated power consumptions

VIII. EPDP Test campaign

The validation of performances and environmental qualification, according to the proto-flight approach which has been chosen for the EPDP will be achieved directly on the flight hardware (proto-flight model, PFM) through the proto qualification campaign described in this paragraph. Fig. 21 below shows the sketch of the Test Equipment to be used for the EPDP Proto-qualification test campaign.

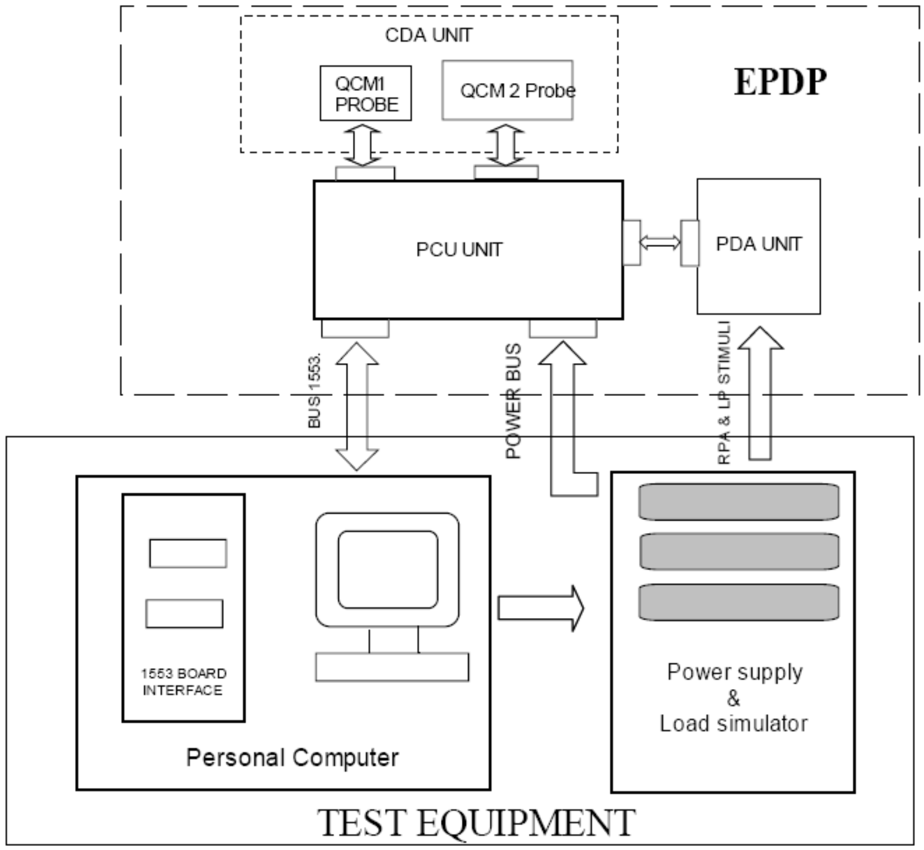


Fig. 21: EPDP & Test Equipment Block Diagram

The EPDP tests will be performed at proto-qualification level with the following objectives:

- to verify the absence of design and/or manufacturing deficiencies;
- to locate latent material and workmanship defects;
- to demonstrate that the equipment is viable to be flown in the expected conditions.

The Test Matrix for the EPDP Proto flight tests is presented Table 6 here below:

Test area	*Test Description*	*Test facility Site*
Inspections & Electrical checks/ verifications	Visual inspection	Clean Room TAS-I FI
	Dimensional Verification	
	Mass Properties	
	Resistance & Insulation verification	
	Grounding verification	
	Continuity Check	
Functional & Performance	Power Consumption	Clean Room TAS-I FI
	1553 Bus Packet Protocol verification	
	Heater function	
	LP Measurement verification	
	RPA Measurement verification	
	QCM1 Measurement verification	
	QCM2 Measurement verification	
	QCM 1&2 Functional Test	QCM Research Inc. (USA)
	QCM1 &2 Calibration	

Test area	Test Description	Test facility Site
Mechanical environment	Searching of resonances	Selex GA FI
	Quasi static load	
	Sinusoidal Vibrations	
	Random Vibrations	
	Shock (TBC)	TUV
Electromagnetic Compatibility	Electrical Bonding	TAS-I Milano
	Primary & Power Insulation	
	Inrush current	CESI or Selex Roma
	Voltage transient	
	Conducted Emissivity on power leads, Frequency Domain	
	Conducted Emissivity on power leads, Time Domain	
	Conducted Susceptibility power line sine wave, differ. mode	
	Conducted Susceptibility power line sine wave, common mode	
	Conducted Susceptibility power line sine wave, Transient	
	Radiated Emission E-field	
	Radiated Emission H-field	
	Radiated Susceptibility E-field	
	Radiated Susceptibility H-field	
	DC Magnetic Moment	IABG facility
Thermal environment	EPDP Thermal vacuum Test	TV chamber TAS-I FI
	QCM Thermal vacuum Test	TV Chamber QCM Research

Tab.6: Summary of the set of tests to be carried out on the LPF EPDP within the Proto-qualification campaign

IX. Conclusions

An EPDP instrument dedicated to the characterization of plasma/contamination interactions on LPF spacecraft as a consequence of the operation on board of a FEEP MPS is presented. The LPF EPDP has been derived from the EPDP on SMART-1 (dedicated to the HET characterization) that was fully successfully tested throughout the SMART-1 mission. The EPDP on LPF is based on a PDA containing the plasma probes, on the PCU, for controlling and commanding the instrument correct operation and on the CDA, for the characterization of material deposition phenomena. Significant design modifications have been introduced on the LPF EPDP, mainly related to the different plasma environment induced by the FEEP and different spacecraft Power and Data bus interfaces. The new instrument configuration has been presented and reviewed in detail. Currently, the design for the PFM manufacturing/assembly has been frozen. Manufacturing activities for the PFM hardware are underway. The completion of the proto-qualification campaign (whose content ha been presented in the paper) and PFM hardware delivery is foreseen in the first quarter of year 2008.

References

G. Matticari, G. Noci, D. Estublier, J.Gonzales del Amo, A. Marini, M. Tajmar
"The SMART-1 Electric Propulsion Diagnostic Package" 3rd International Conference on Spacecraft Propulsion, Cannes, 10-13 October 2000

M. Capacci, G. Matticari, G. Noci, A.Severi, D. Borie
"An Electric Propulsion Diagnostic Package for the characterization of the Plasma Thruster/Spacecraft Interactions on STENTOR Satellite", JPC 1999, paper AIAA-99-2277

M.Capacci, G. Matticari, G.Noci, J. Gonzales
The EPDP experiment on board SMART-1, presented at LERICI Workshop 2006

M. Tajmar , W. Meissl, J. González, J., B. Foing, B., H. Laakso, G. Noci, M. Capacci, A. Mälkki, W.Schmidt, F. Darnon,
CEX Plasma Contamination on SMART-1:First Measurement and Model Verification
40th AIAA/ ASME/ SAE/ ASEE Joint Propulsion Conference and Exhibit, July 2004.

Hilgers, A., B. Thiébault, D. Estublier, E.Gengembre, J. Gonzalez, J.-F. Roussel, M. Tajmar, G. Markelov, J. Forest,
Modelling of SMART-1 Interaction with the Electric Thruster Plume, in Proceedings of
9th Spacecraft Charging Technology Conference, JAXA-SP-05-001E, Tsukuba, Japan, April 2005

Thiébault, A. Hilgers, M. Capacci , E. Gengembre, and J. Gonzalez,
Measurements of SMART-1 Plasma Environment with the EPDP Langmuir probe, in Proceedings of
9th Spacecraft Charging Technology Conference, JAXA-SP-05-001E, Tsukuba, Japan, April 2005

M. Capacci, S. Sassoli, G.Noci , J. Gonzales, D. Estublier, A. Hilgers, Anssi Mälkki
SMART-1 Spacecraft estimation from the EPDP experiment, presented at the 3th IAGA conference, July 2005

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