Review of Activities at TASI
on S/C charging and Plasma Env. Monitoring

SPINE 1° meeting on 2011

January 17-19 2011

Presentation Summary

Active Charging control topics

- ACCS
- Plasma Contactors
- PlegPay results
- Surface Plasma Detector

Plasma Environment Monitoring

- EPDP Instrument

The Active Charging Compensator System (ACCS) is an instrument dedicated the **Active Control of the S/C Charging** level, by a **Controlled Emission of Electrons** generated and accelerated through a suitable electron generation device

The ACCS instrument is under development at TAS-I under **ESA ARTES 5 Contract** financed by **ASI**

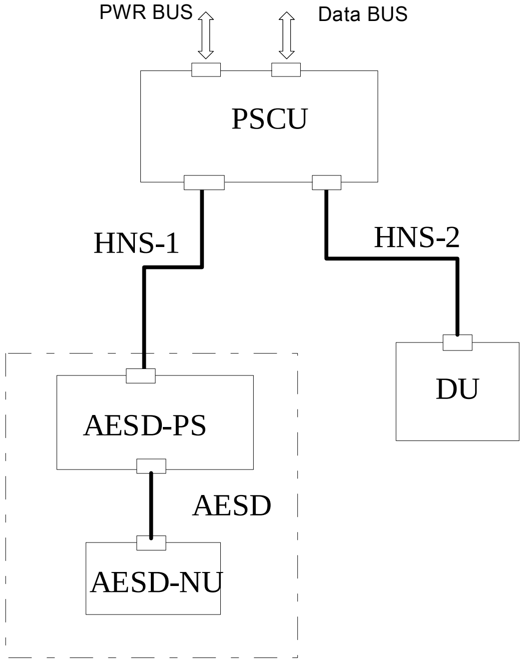
Within the current ARTES 5 contract the development and testing activity is focused on the **ACCS Electron Source Device** and relevant **power supply & conditioning electronics**

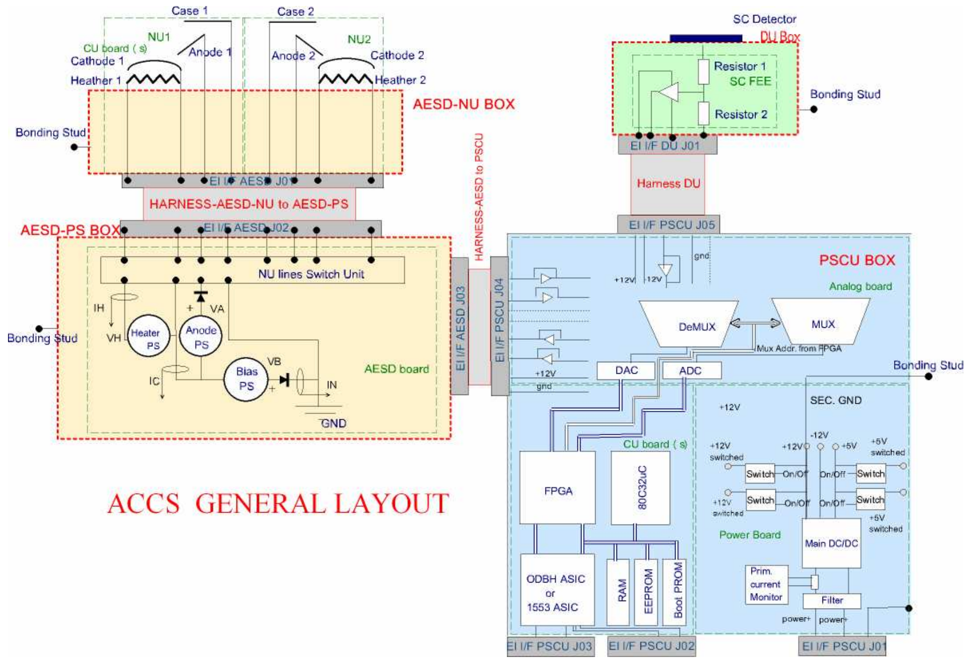
The **ACCS Electron Source Device (Neutralizer Unit)** is based the hardware successfully developed, tested and qualified within **LISA Pathfinder NA** for FEEPs & **MICROSCOPE** programs.
The EQM NU, under LISA PF program, has been successfully submitted to an operational Lifetime Test in excess of **6000h (with no aging evidence).**

ACCS configuration

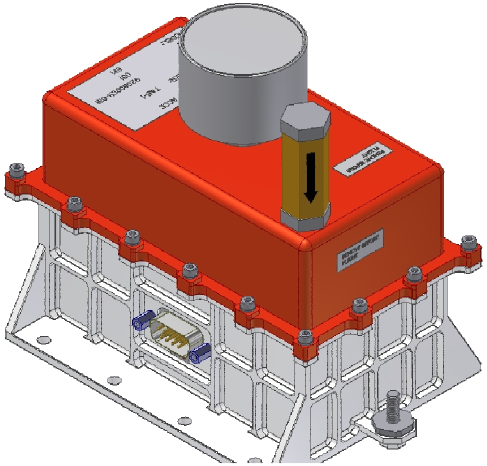
The **ACCS** architecture, in the complete instrument version includes :

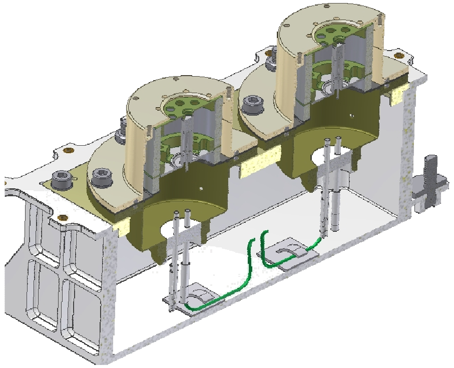
- The **AESD** assembly containing:
  - the **AESD- PS** box with the electronic board;
  - the **AESD - NU** box with the 2 neutralizers (1 nominal and 1 redundant);
- **A Diagnostic Unit (DU)** (currently to be developed and based on a Surface Potential Detector)
- A centralized **Power Supply & Control Unit (PSCU)**

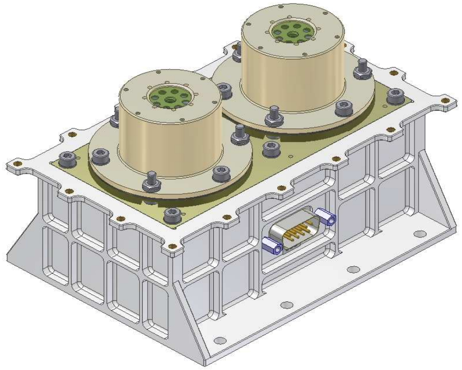


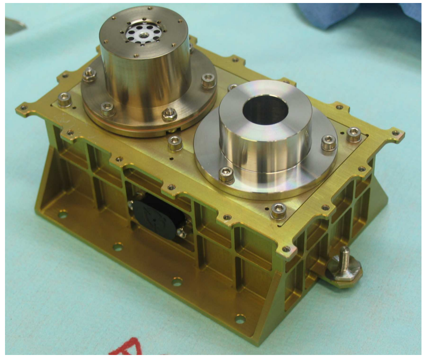


ACCS GENERAL LAYOUT

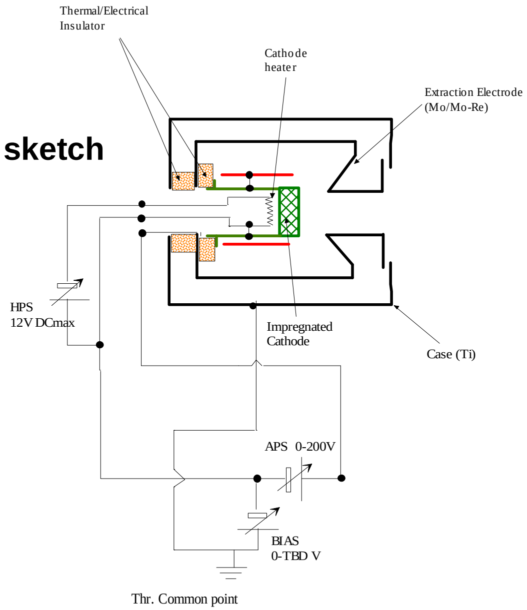






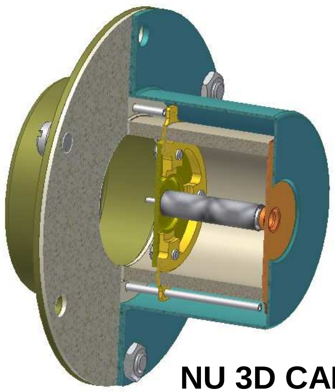


NU electric sketch

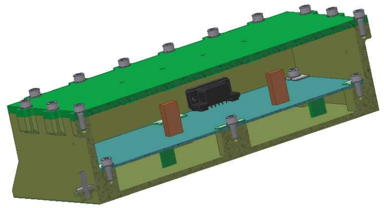


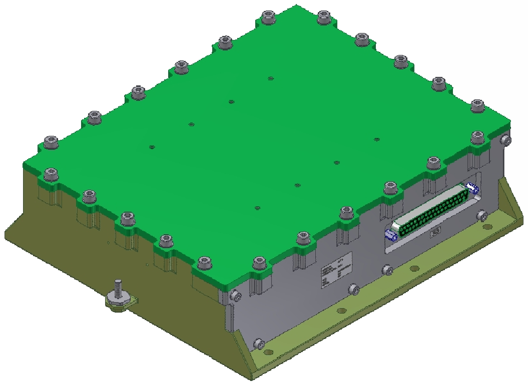
The AESD-NU Assembly contains: one box with two Neutralizer Units and a cover /removable) for on ground storage

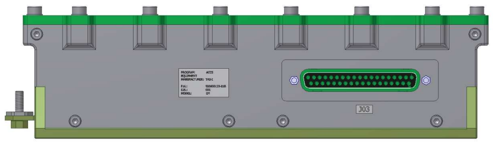
The Neutralizer Unit (NU) is based on the design developed under the LISA PF NA for FEEP program.

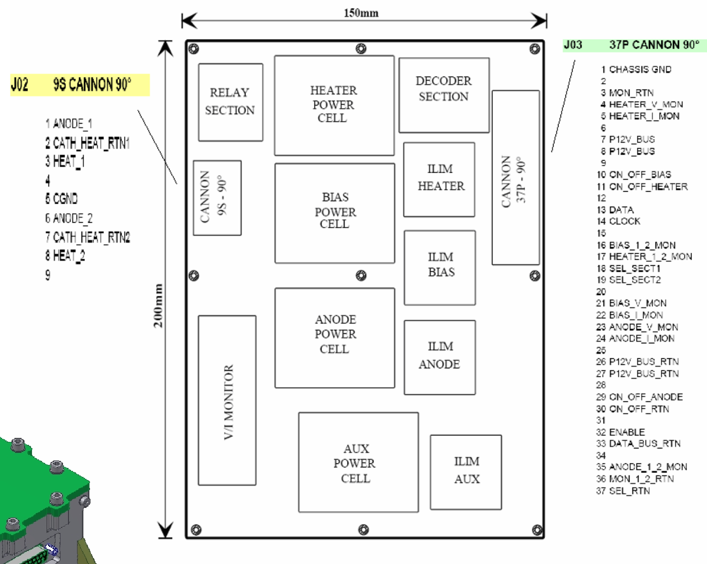


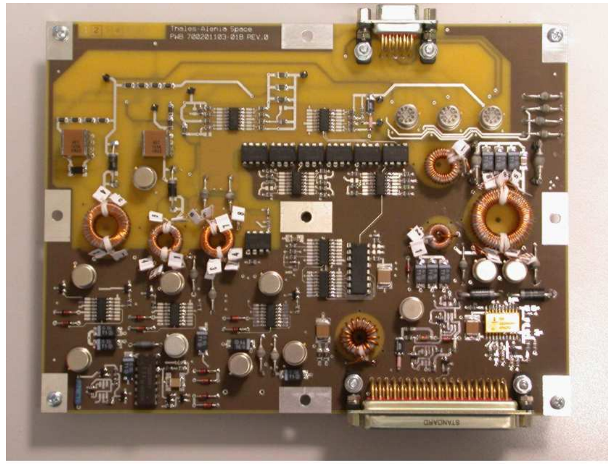
NU 3D CAD view







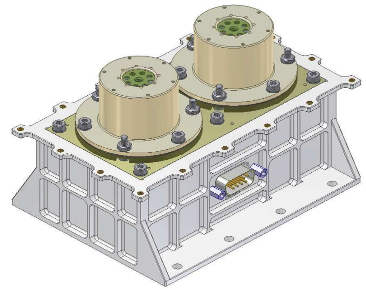




The AESD-PS Assembly contains:

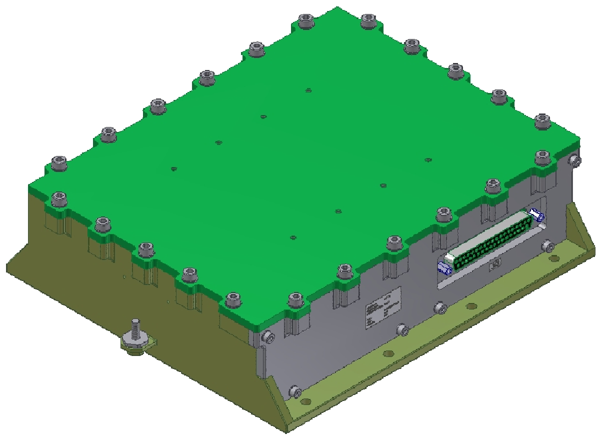
one box with the electronic board Inside. The box is realized with a single Alluminium box. The e-board implements all the necessary functions for the NU's conditioning & operation (anode, bias, heater, aux., power supplies, monitoring, relay and service sections)

AESD-NU Box



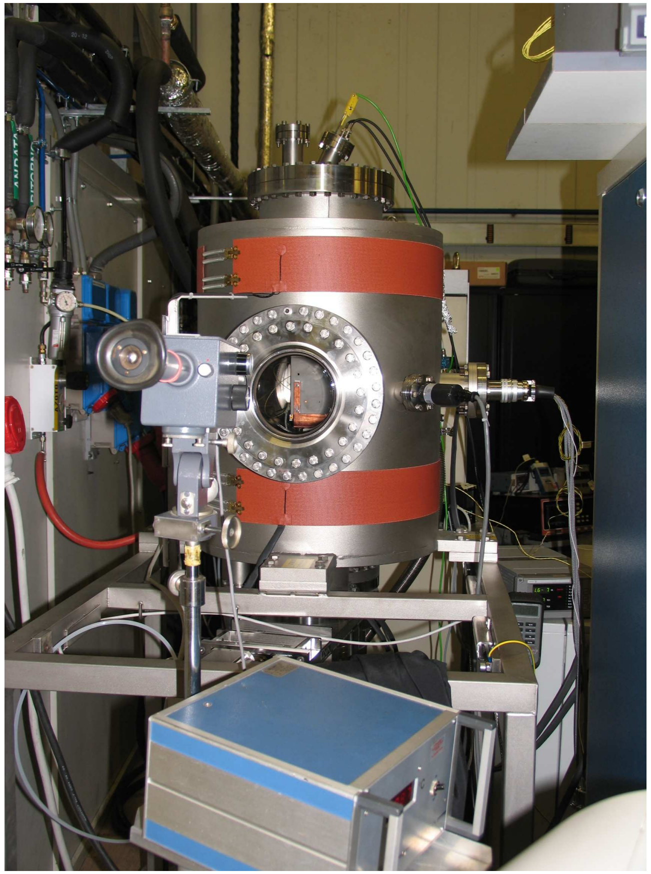
BOX	MASS	EST. ERROR
AESD-NU	465g	±10%
AESD-PS	1500gr (TBC)	±10%
PSCU	2300gr (TBC)	±20%
HARNESS	350gr (TBC)	±15%
DU	400g (TBC)	±20%

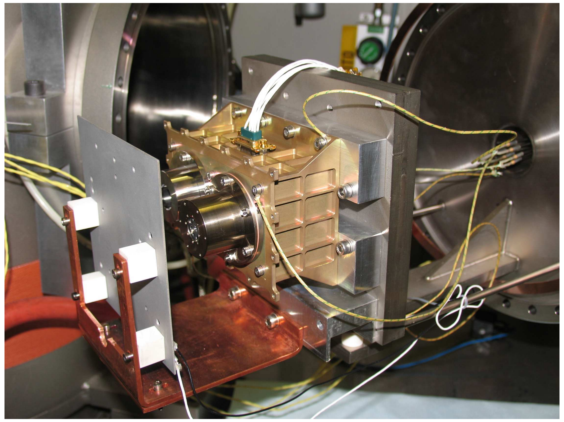
BOX	Max Adsorbed (W)	Max Dissipated (W)
AESD-NU	5±5%	5±5%
AESD-PS	9.5±10%(incl. AESD-NU)	4.5±10%
DU	2.5±1 (TBC)	2.5±1 (TBC)
PSCU	21.5/18.5 (TBC)	10 (TBC)
ACCS (overall)	~21.5÷18.5 (TBC)	~ 21.5÷18.5 (TBC)



AESD-PS Box

Note: some further optimization is possible





ACCS UNDER INTEGRATION in VC

ACCS EGSE Rack

ACCS High Vacuum Chamber facility

Foreground/Heritage

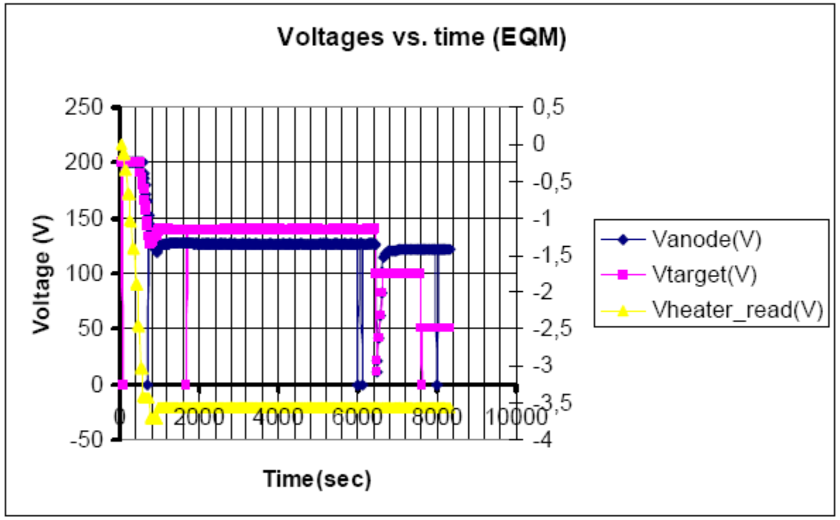
- The AESD-NU design derives from the Neutraliser Assembly (NA) for LISA PF
- Currently 4 NA FM boxes (very similar to the AESD-NU) with 8 Neutralisers have been already manufactured/assembled and the FMs concluded acceptance testing.

Status of ACCS Development

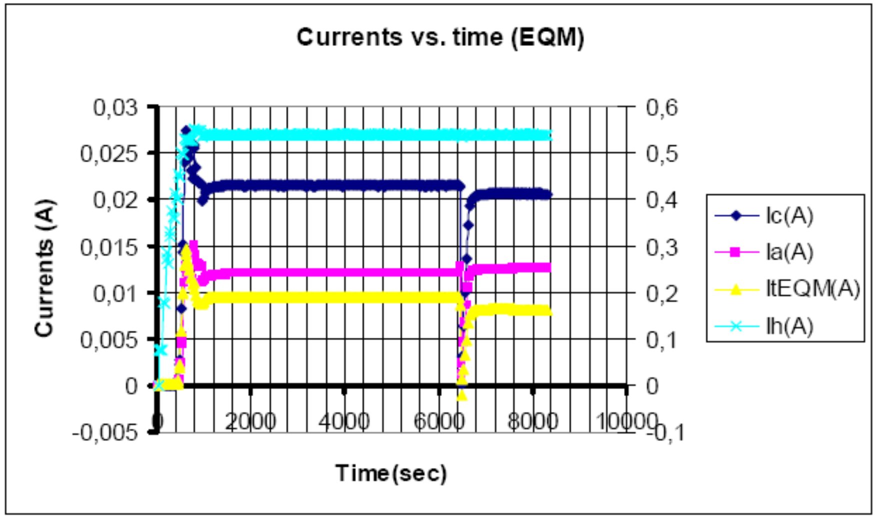
- TRR succesfully achieved with ESA
- EM HW (AESD-NU and AESD-PS e-board) and an EGSE simulating the PSCU) integrated
- integration tests succesfully performed
- Mechanical tests succesfully performed
- Preliminary functional check succesfully performed
- Neutraliser activated succesfully
- Functional tests are expected to start at the begin of 2011

Neutralisers Exp. Results

The experimental activities so far performed on the NU confirmed the capability to emit an electron current over 3mA for a target voltage of 50V with anode power of 1.5W and heater power <5W (about 2W).

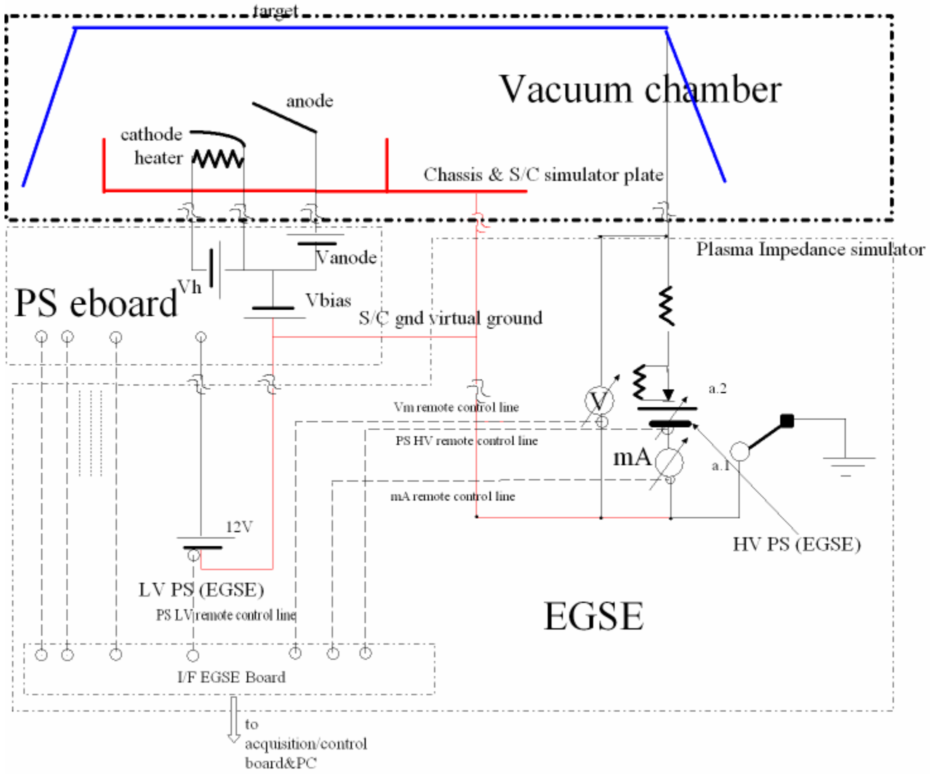


NU Voltage data from functional test performed under the LISA PF program



NU Current data from functional test performed under the LISA PF program

ACCS EGSE configuration



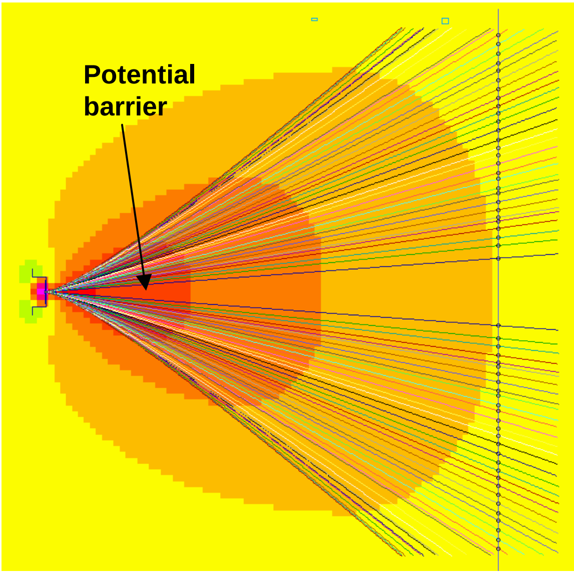
Functional characterisation

1. Activation test
2. Current emission against target at different bias and target potential

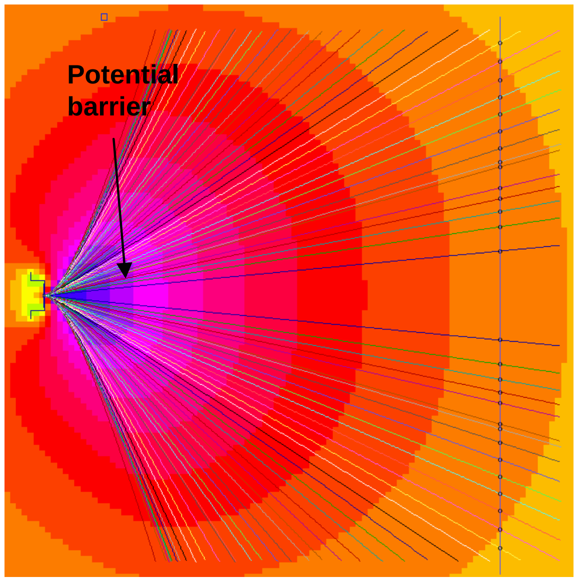
Functional schematic of the Test set-up for ACCS

ACCS Electron plume simulation

Simulations/modelization activities have been performed for the theoretical validation of the proposed Neutralizer Unit for performing the S/C charging process



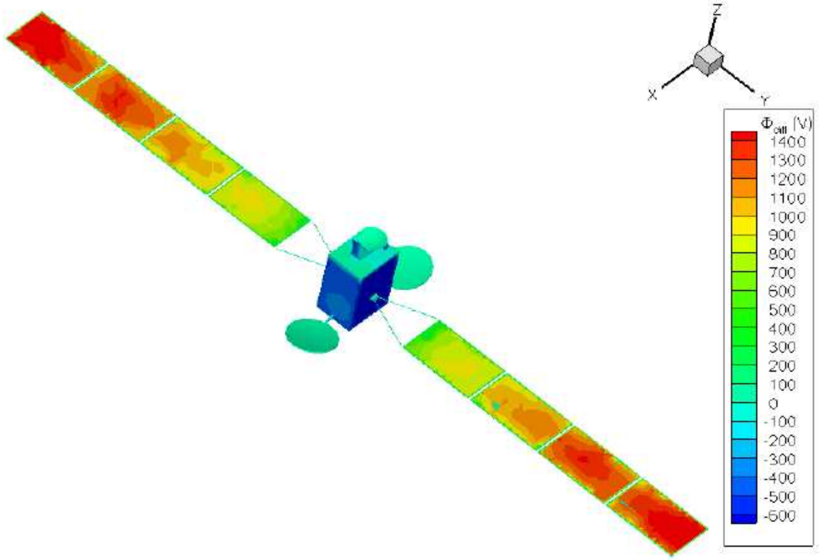
Far Vacuum simulation with open boundary conditions. Target at 1m.
Vbias=-200 Va=105 V;Vt=0V;
I emitted 6.7mA.

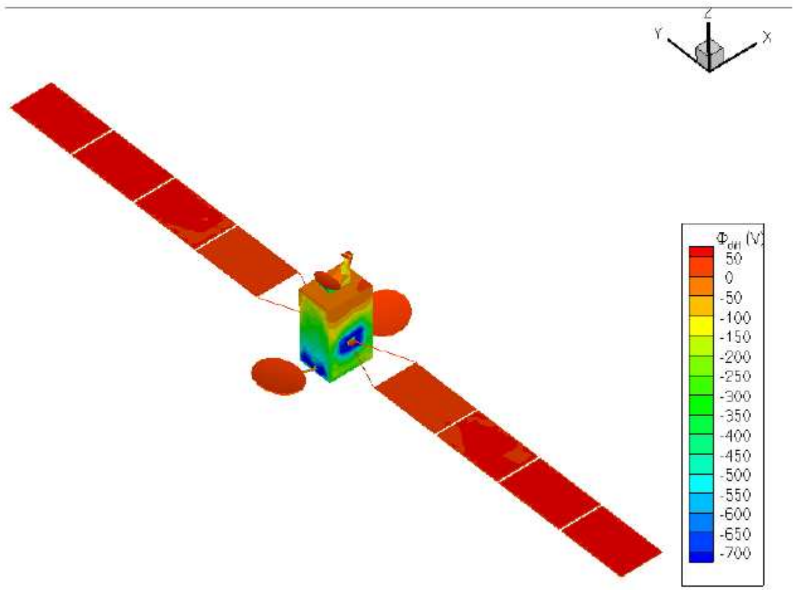


Far Vacuum simulation with open boundary conditions. Target at 1m.
Vbias=-100 Va=-05 V;Vt=0V;
I emitted 6.7mA.

Space charge effect results in a potential barrier in front of the cathode of about -40 Volts

ACCS S/C Charging analysis





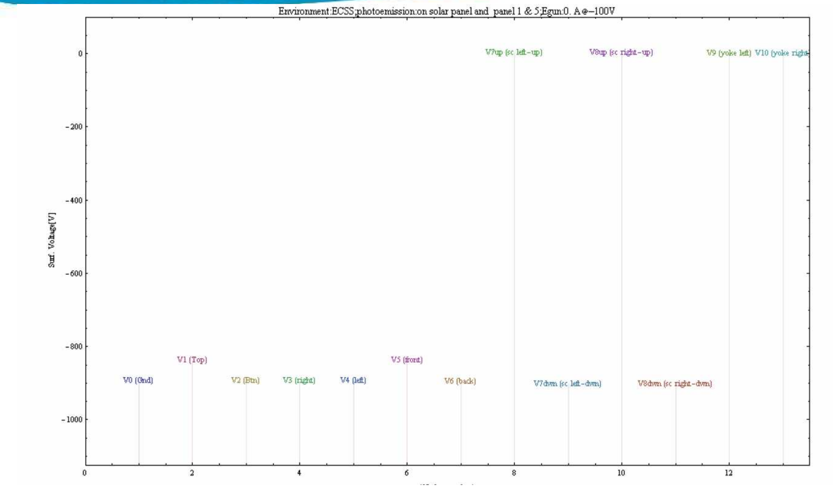
SPARCS simulations (preliminary) of a Galaxy S/C including ACCS in operation

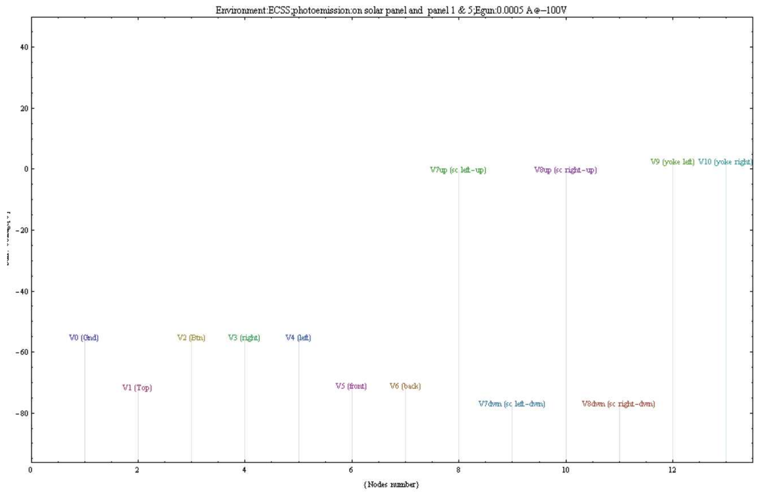
The benefits are shown:
differential charging is lowered in presence of electron emissions together with absolute charging

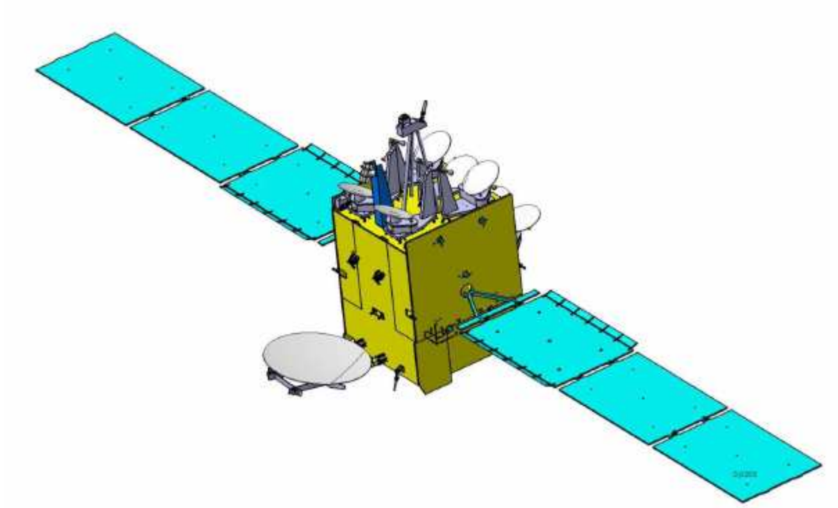
Courtesy of TAS France (Presentation of May 2007)

ACCS S/C Charging analysis II

Charging Nodal Model Analysis: ITALBUS Platform







- **A simple nodal modal of S/C has been developed at TAS-I**
- **Results supports SPARC Analyses.**
- **For S/C with 'suitable' internal grounding design , ACCS operation would allow the lowering of both Absolute and Differential Charging phenomena.**

INTERNAL THALES ALENIA SPACE
COMMERCIAL IN CONFIDENCE

ACCS S/C Charging summary

Further analyses with charging code such as SPARCS, SPIS (or NASCAP) would allow a more precise assessment of the operation of the ACCS within a specific GEO (or Polar LEO) Platform.

In order to optimise the design and the operation of the ACCS a detailed study should include:

- **a model of the AESD current emission (including space charge effects in front of its outlet): this would allow e.g. to identify the minimum BIAS voltage needed depending on the local environment and location onto the S/C**
- **transient analysis expecially during entering or exiting eclipse regions : this would give needed information to propose an "optimal" ACCS timeline operation.**
- **integration within the ACCS of a SPD (Surface Potential Detector) and simulation of ACCS operation triggered/commanded from the SPD (closed loop operation).**

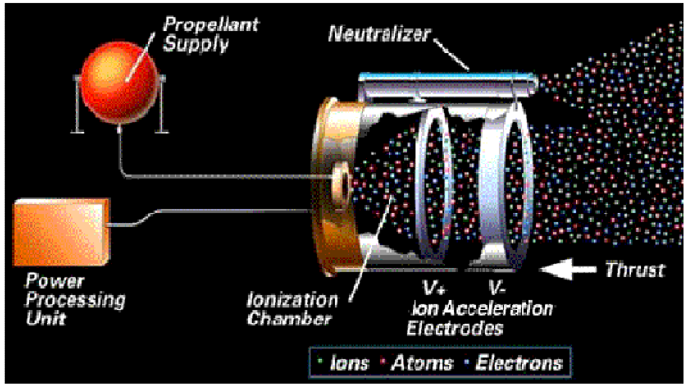
Concluding Remarks on ACCS

- An Active Charging Compensator System (ACCS) is currently under development at TAS-I for alleviating the ES surface charge accumulation on GEO and Polar LEO satellites.
- The active source for the Charge alleviation is based on the Neutralizer Unit (NU) already developed and successfully qualified for the ESA Lisa Pathfinder Program (dedicated to the FEEP propulsion)
- By begin of 2011 the ACCS units AESD-NU and AESD-PS, developed at EM level, will complete the functional on ground test
- The ACCS can be used and operated on board as a self consistent unit or as part of a wider Space Weather Instrument (Modular Space Weather Package, including eventually also an Environmental Particle Monitor, an Internal Discharge Monitor, a Plasma Diagnostic Package and a centralized Electronics Unit as shown on next page)

Cathode/Neutralizers as Plasma Contactors

The **Cathode/Neutralizer** is a "key" component of an **Electric Propulsion (EP) System**, and can significantly affect the performances and reliability of the whole EP system,

TAS-I has accumulated a relevant heritage on Cathodes/Neutralizers for EP, since the successful development and in-flight operation of the **Neutralizer for the RIT-10 Ion Thruster on ARTEMIS satellite**



Ion Thruster operation sketch

2 main families of Neutralizer/cathodes products have been developed by TAS-I

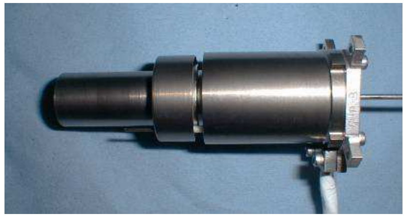
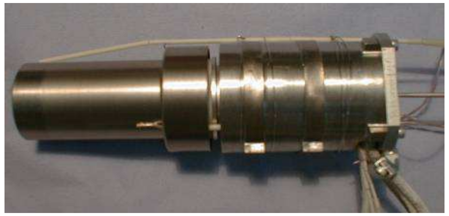
Hollow Cathode Assemblies (HCA) : usable for the **ion beam neutralization and plasma discharge ignition/sustain** in a variety of EP thrusters (Ion, HET) and, as stand alone components, as Plasma Contactor Device for "**grounding" of large space structures (ISS)**

Thermionic Neutralizer Unit/Assembly (NU/NA) usable for the **ion beam neutralization** of FEEP thrusters and very small Ion Thrusters and, as stand alone components, for avoiding negative **charging of GEO/polar LEO satellites**

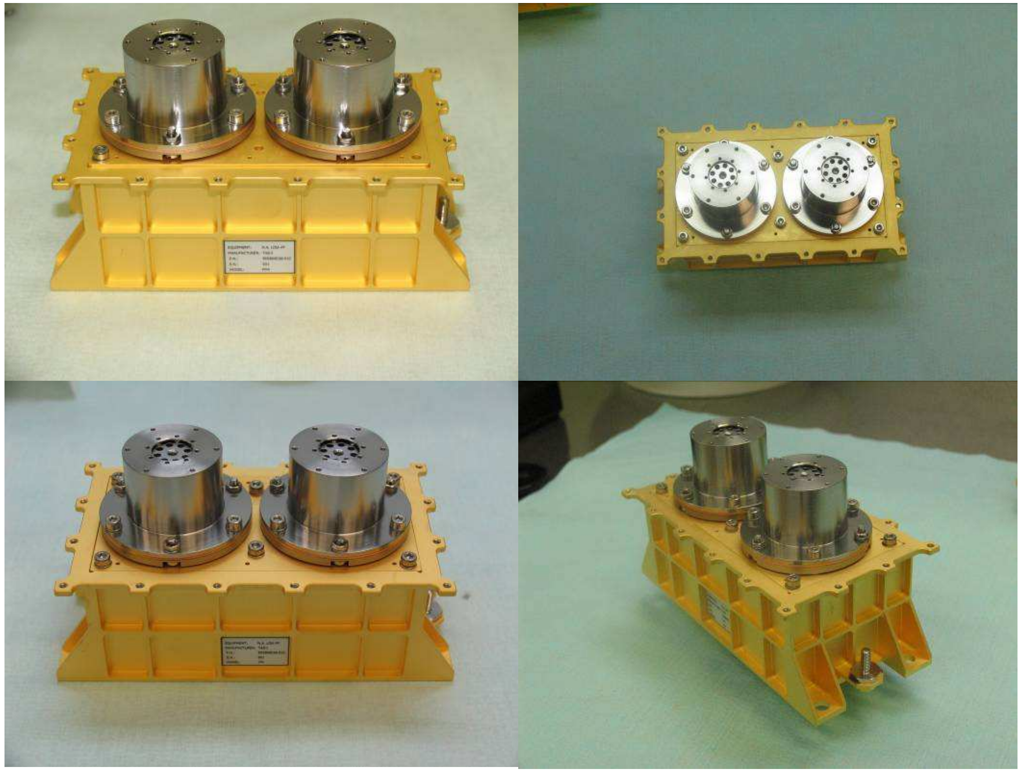
Artist's view of ARTEMIS satellite

Cathode/Neutralizers as Plasma Contactors

A family of HCA Devices has been developed by TAS-I over a time frame of about 20 years

NccA 1000 model	**NccA 5000 model**	**NccA 15000 model**	**Mini HET HCA**
RIT-10	**PPS 1350, SPT 100**	**PPS 5000, RIT XT**	**100-400 W HET**
Flown on ARTEMIS	**Flown on the ISS**	**Tested in Lab**	**Tested in Lab**
			
Heating power: < 20 W	Heating power: < 60 W	Heating power: < 100 W	Heating power: ≤ 25 W
Heating-up time: < 3 min	Heating-up time: < 6 min	Heating-up time: < 10 min	Heating-up time: ~5 min
Gas flow rate: 0.02-0.1 mg/s	Gas flow rate: 0.1-0.5 mg/s	Gas flow rate: 0.3-0.8 mg/s	Gas flow rate: 0.1-0.2 mg/s
Discharge curr.: 0.5 to 1 A Electron current: up to 0.8A	Discharge curr.: 2 to 5 A Electron current: up to 4 A	Discharge curr.: 5 to 20 A Electron current: up to 8 A	Discharge curr.: 0.3 to 2 A Electron current: up to 1.5A
Mass: 60 g	Mass: 110 g	Mass: 130 g	Mass: 90 g
Dimens.: 105x37x37 mm	Dimens.: 82x32x32mm	Dimens.: 90x42x42 mm	Dimens: 100x40x40 mm

NU HW for LISA And Microscope



PFM & FM01,FM02,FM03 Box for LISA PF

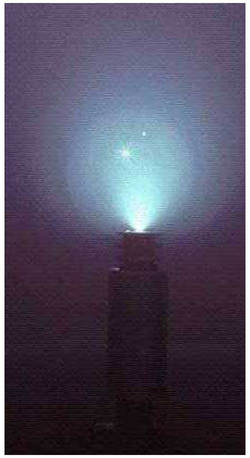
Microscope QM Neutralizers

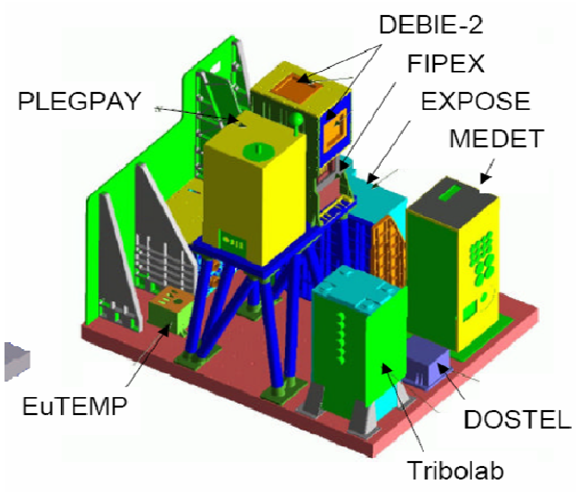
Several succesfull tests performed

- **Lifetimes test up to 6000h**
- **TVC tests and functional tests**
- **Humidity tests**
- **Vibration and Shock tests**

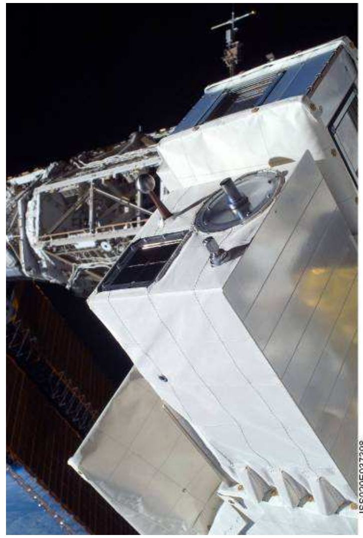
HC as Plasma Contactor in the PLEGPAY experiment on the ISS (flown)

PLEGPAY experiment on the EuTEF /ISS has been aimed at the validation of a European Plasma Contactor technology for future utilization on the European elements of the ISS





Experiments on EuTEF

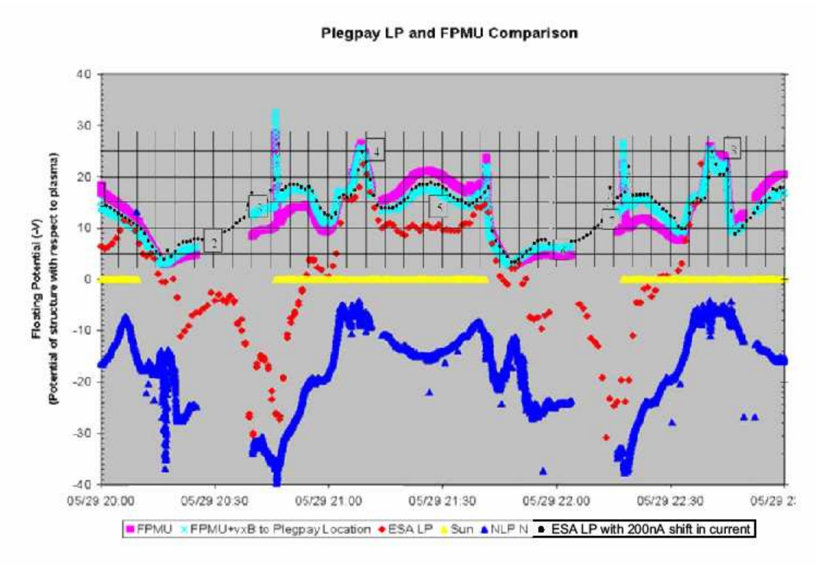


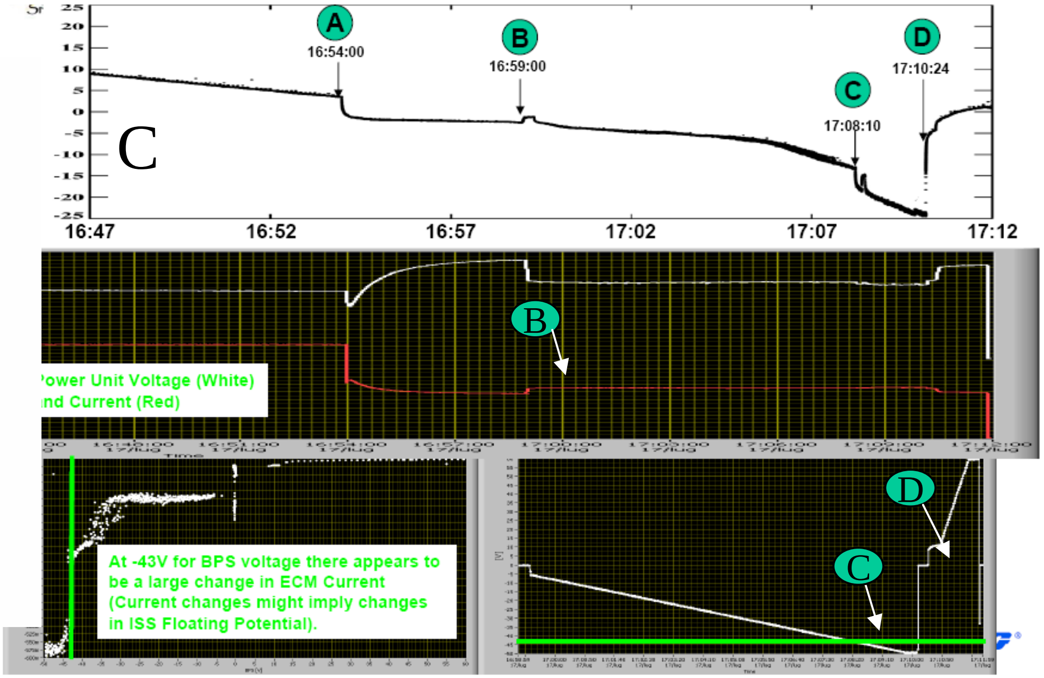
Main achievements of the PLEGPAY experiment

- Verification of the Plasma Contactor Technology for Large Space structure charging control/prevention
- Measurement of the parameters of the plasma environment in the vicinity of the plasma contactor
- In flight qualification of the plasma contactor technology through long term in flight operation (>800h)
- Detection of possible discharge events on a solar cell sample due to interactions with ambient plasma or with plasma contactor generated plasma
- Demonstrated the capability to control potential of large structures such as ISS through emission

PLEGPAY experiment on the ISS (flown)

PlegPay experiment demonstrates, more than expected ,the capability of Plasma Contactor to drive potential of very large structures. The effect was so evident that some concerns arose from NASA on safety issues in case of experiment failure; for instance the experiment was stopped for a period in which inspection adn discussion on the presence and the effectiveness of three independent safety switches internally to the instrument was carried on. After verification the instrument was switched ON again and additional tests performed again.





INTERNAL THALES ALENIA SPACE
COMMERCIAL IN CONFIDENCE

Surface Potential Detector

The build-up of electrostatic charge on exposed external surfaces of spacecraft most likely takes place in the GEO and Polar LEO environments

S/C charging (both absolute and differential) might give rise to "Electrostatic Discharges". These events can couple into the spacecraft electronics and cause upsets ranging from logic switching to complete system failure.

The measurement /characterization of S/C charging events is of fundamental importance to identify and figure out **Risky situations impacting the S/C health**

The proposed **Surface Potential detector (SPD)** is devoted to the measurement of the and characterization of charging phenomena on S/C surfaces
The SPD can be used in the "stand alone" configuration as a measurement instrument or within an **Active Charging Compensator System (ACCS)** within which the SPD is the "sensing" element that drives the ACCS closed loop control operation (see ACCS presentation)

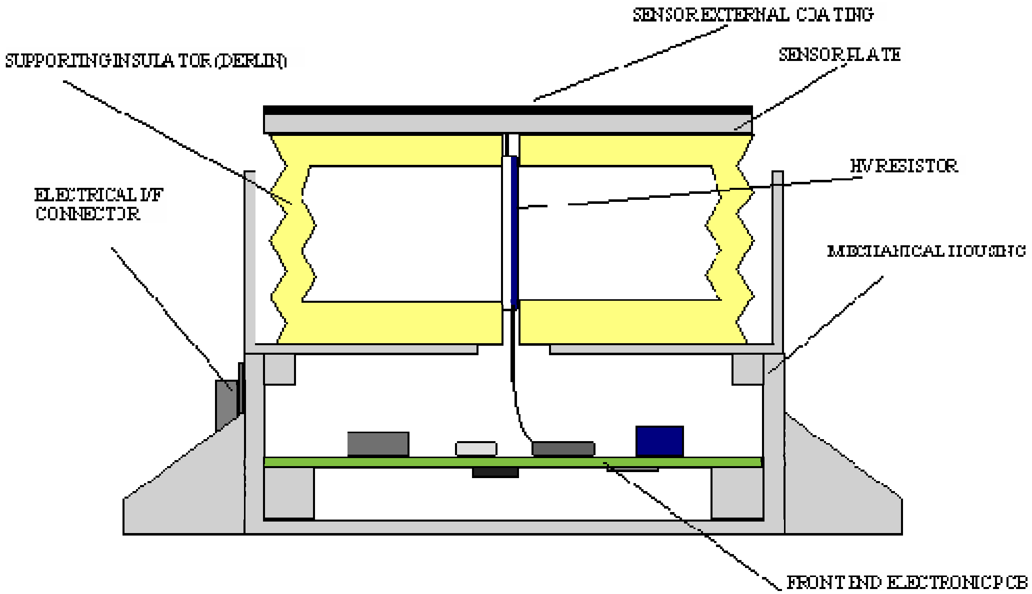
The SPD operates by sensing **the electrical potential acquired by reference sample material (layer deposed on a conductive plate) , exposed to the open space and adequately connected to the S/C GND to simulate/reproduce a critical configuration (for charging aspects) really experienced on satellite surfaces**

Practically the SPD detects and measures the current that manifests as a consequence of the sample charging. The charging current results in a "leakage" current. This latter (in general very low) is fed to a front-end electronics, based on an instrumentation amplifier, through a suitable partition network.

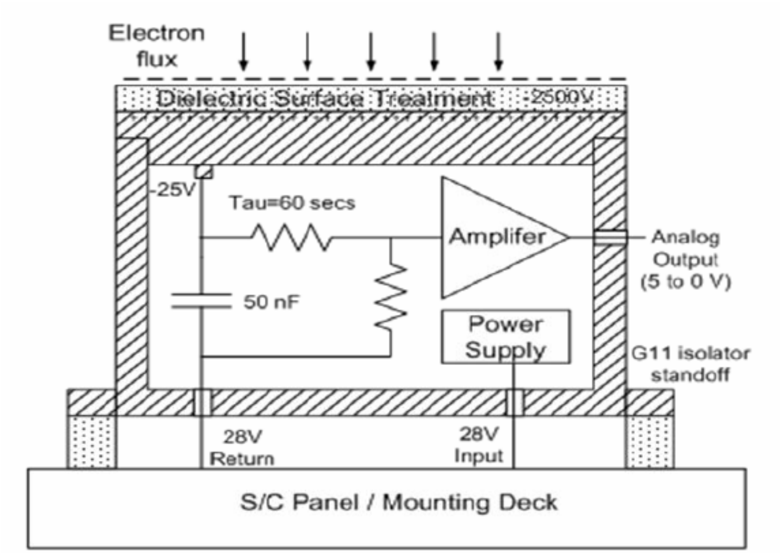
Materials deposed on the SPD conductive plate and connection to ground has to be chosen depending also on the implemented S/C grounding philosophy, with constraints related to the instrument dimension itself.

SPD configuration sketch

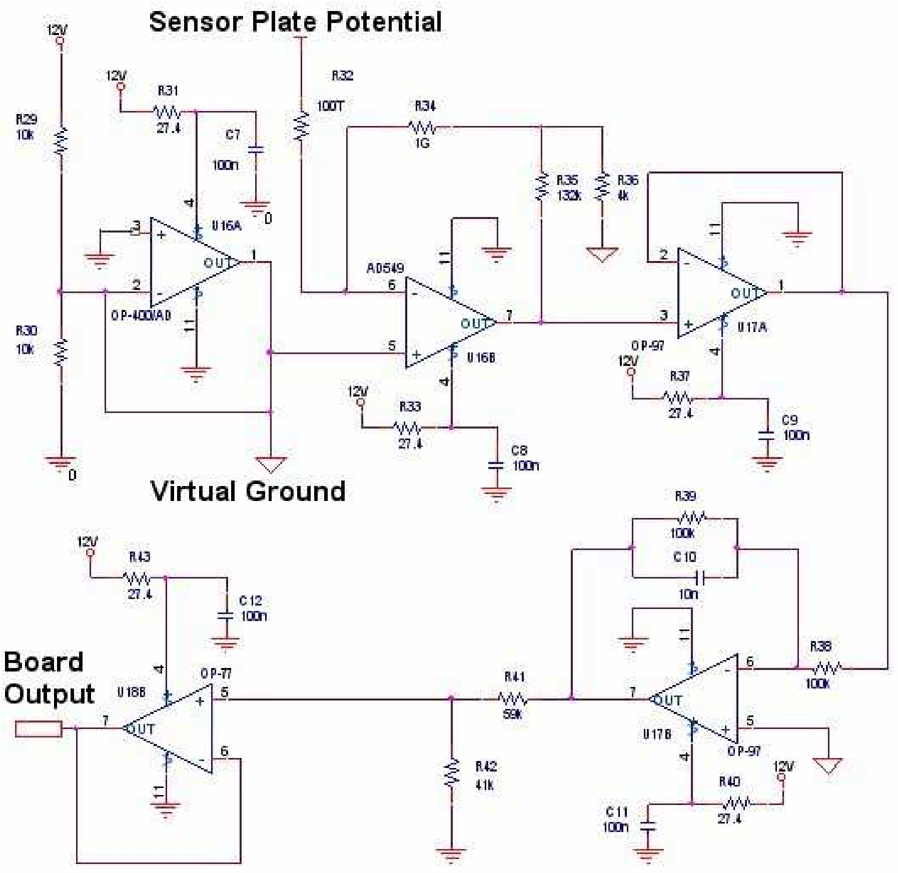
SPD Plate coating:
Can be Kapton, ITO, or other dielectric typical of S/C exposed materials



Proposed sketch for the SPD



Alternative sketch proposed by a US Company, based on a “capacitive” coupling

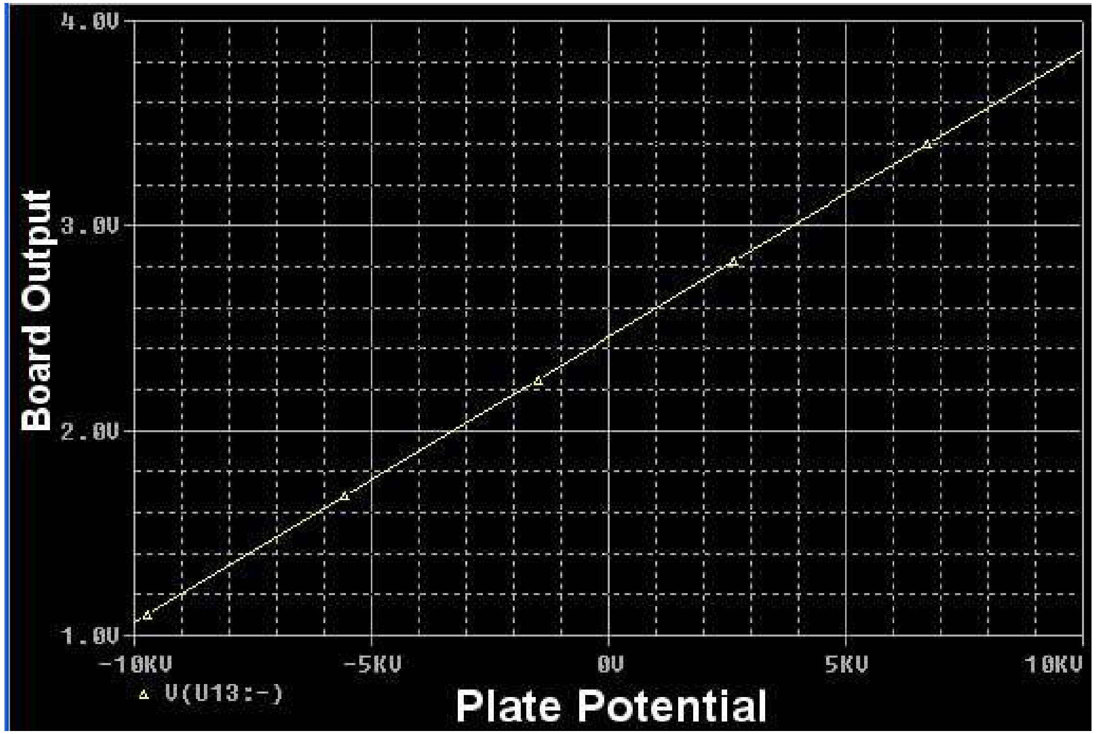


Electrical parameter parameters related to the SPD operation

In the GEO environment, a sensor plate area of 25 cm^2 may result in a collected electron current in the range of<~ nA.

The isolating resistor, for floating surface potential detection, would require a value of the order of some tens of TeraOhms in order to minimise leakage up to KV range

SPD Output signal



The instrument should be configured
To monitor:

- The potential of a “floating” sample of the S/C surface exposed to the environment
- The potential of a sample of the S/C surface connected to ground with a resistor representative of the typical actual resistance of the S/C surface material vs. the S/C gnd

Output signal from the SPD front End electronics as function of the plate potential

INTERNAL THALES ALENIA SPACE
COMMERCIAL IN CONFIDENCE

Concluding Remarks on the SPD

- A Surface Potential Detector is an instrument proposed for the characterization and monitoring (Static & Dynamic) of the S/C Surface charging phenomena that often manifest themselves In GEO and Polar LEO

- The SPD can be used as a stand alone instrument for the level of S/C charging monitoring/characterization or within an ACCS as sensing element of the Active Charging Compensator operation, according to a suitable closed loop control strategy

- In addition the SPD can be used as part of a wider Space Weather Instrument (Modular Space Weather Package, including eventually also an Active Charging Compensator,a Plasma Diagnostic Package, a Radiation Monitor, an Internal Discharge Monitor, and a centralized Electronics Unit

- Contacts with ESA ongoing to identify a possible scenario to sustain the instrument development (specific input provided in the framework of TRP call for ideas)

Heritage

Ion Propulsion Diagnostic Package (IPDS) for ARTEMIS

- Developed at PFM but not flown

Plasma Diagnostic Package (PDP) for HET on STENTOR

- Launched but destroyed with S/C due to ARIANE 5 failure

Electric Propulsion Diagnostic Package (EPDP) for HET on SMART-1

- Successfully flown and operated on board theS/C

Electric Propulsion Diagnostic Package (EPDP) for FEEP on LISA PF

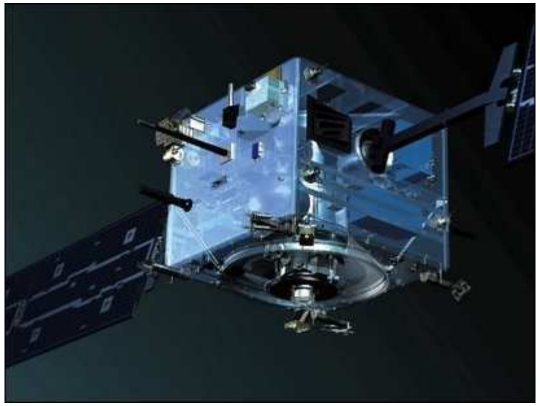
- PFM Delivered to ASU for integration at S/C level

Modular Multi Application El. Prop. Diagnostic Package (MM-EPDP)

- Under Development under ESA GSTP4 Contract funded by ASI

EPDP on SMART-1

SMART-1 satellite: in-flight test bed for the Solar Electric Primary Propulsion for deep space future missions



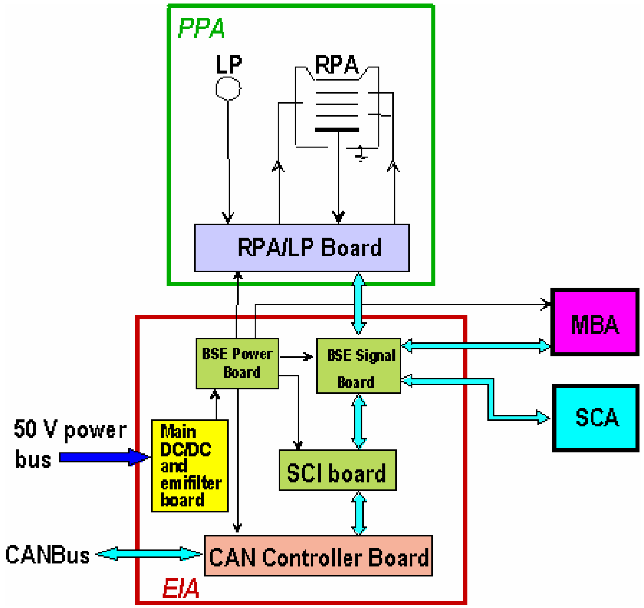
Artist's view of Smart-1 spacecraft

EPDP (Electric Propulsion Diagnostic package):
characterization of any possible influence of the plasma plume generated by a **Hall Effect Thruster (HET)** on spacecraft sub-systems and parts

The Smart-1 EPDP has been successfully operated on board Smart-1 in the time frame 2003-2006.

Smart-1 EPDP operational features:

- energy/current distribution of plasma ions in the **0 -400 eV** range
- plasma electric parameters (e.g. density, potential and electron temperature)
- material erosion/deposition (through Quartz Crystal Microbalance
- Solar Cell performance degradation (V-I measurement)



Smart-1 EPDP Units

Smart-1 EPDP Units:

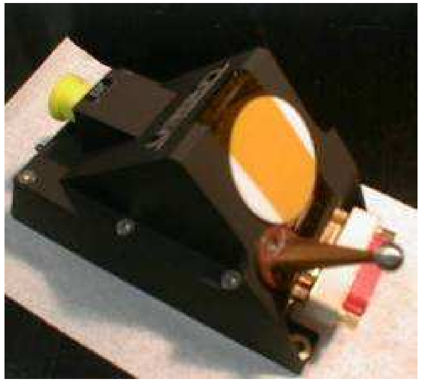
Plasma Probe Assembly (PPA), including:
- Retarding Potential Analyzer (RPA), for the characterization of ion energy distribution
- Langmuir Probe (LP), for the measurement of plasma parameters
- LP/RPA front end electronics

Micro-Balance Assembly (MBA), including:
- Quartz Crystal Micro-Balance for mass deposition/erosion investigation

Solar Cell Assembly (SCA), including:
- Solar Cell with support and connections

Interface Electronics Assembly (IEA), including:
- Sensors Conditioning
- Power conversion and distribution
- TLM/TLC interface with the spacecraft
- Interface to the spacecraft power bus

MBA based on QCM



PPA

SC assembly

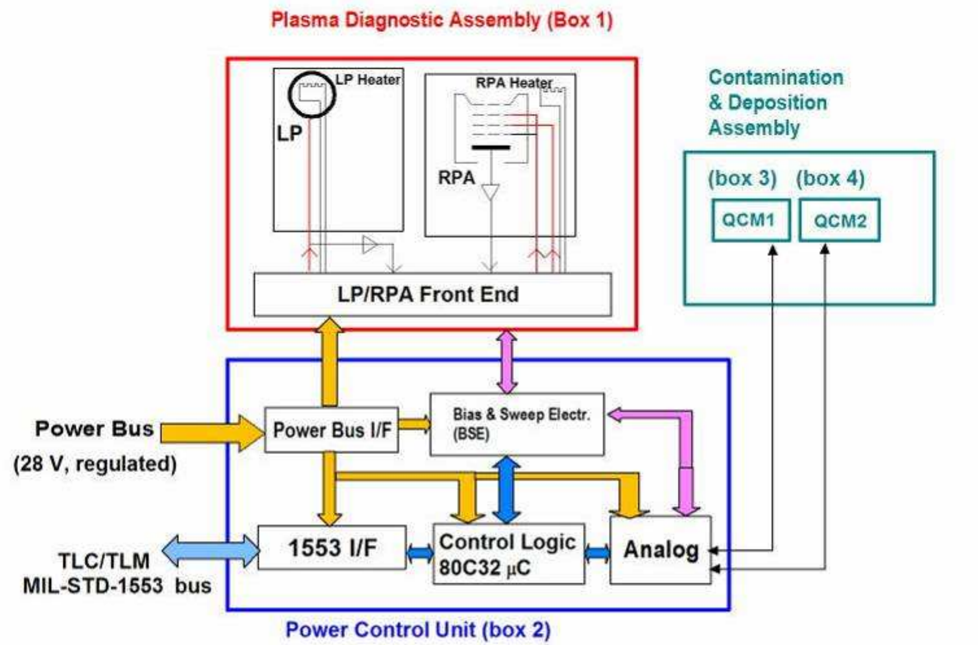
IEA

EPDP on Lisa Pathfinder

LISA Pathfinder: in flight test of the LISA key critical technologies (Lisa Technology Package and FEEP Propulsion)

EPDP tasks: characterization of any possible effects of the plasma plume generated by the **FEEP** operation on spacecraft sub-systems and parts

- energy/current distribution of plasma ions in the **0 -450 eV** range
- characterization of the plasma parameters and relevant changes during the FEEP operation;
- investigation on Ce contamination and erosion of spacecraft exposed surfaces
- provide valuable data to validate modeling tools



Lisa PF EPDP Units

Lisa PF EPDP is based on the following Units:

Plasma Diagnostic 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) evaporation
- LP/RPA **Front End Electronics (FEE)**

Micro-Balance Assembly (MBA), including:

- **Quartz Crystal Micro-Balance** for mass deposition/erosion investigation

Power & Control Unit (PCU) including:

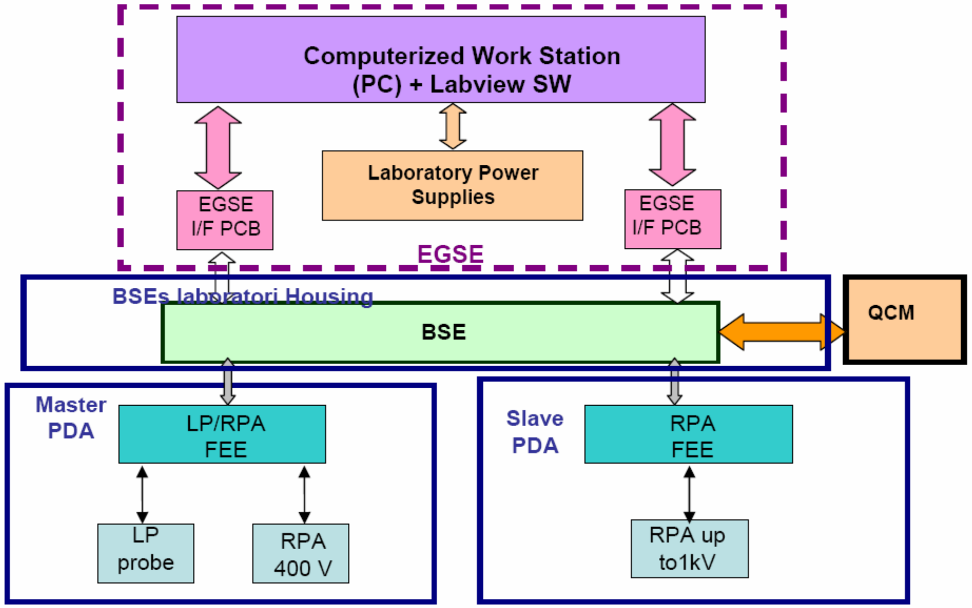
- Probes Conditioning
- Heaters control
- Power conversion and distribution
- TLM/TLC interface with the spacecraft
- Interface to the spacecraft power bus

PPA

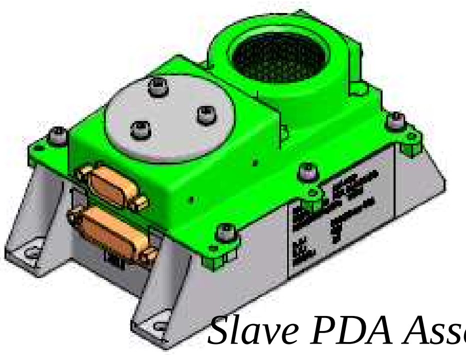
MBA(QCM)

PCU

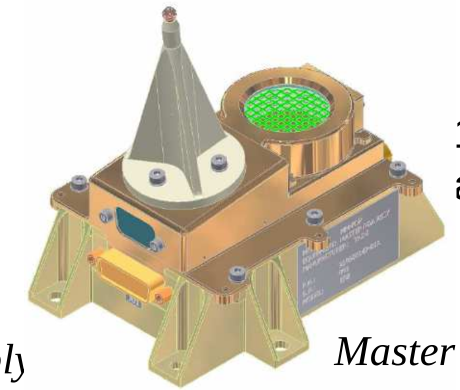
MM-EPDP PDA Module laboratory Prototype



PDA + Laboratory Electronics sketch



Slave PDA Assembly



Master PDA Assembly

1 **Master Plasma Diagnostic Assembly (m-PDA)** unit equipped with:

- 1 LP
- 1 RPA suitable to characterize secondary (backflow) ions (up to **400 V**)
- 1 LP/RPA FEE

1 **Slave Plasma Diagnostic Assembly (s-PDA)** unit equipped with:

- 1 RPA suitable to characterize both secondary and primary ions (**up to 1 kV**)
- 1 RPA (1 kV) FEE

1 **BSE board,** to interface the Master and Slave PDA and the QCMs,

MM-PDP spin-off for Plasma Environmental Monitoring

By rescaling probes dimension and FEE current amplification, a spin off of the MM-PDP instrument using a configuration already identified for the low current ranges for LISA PF instrument can be defined. This will be suitable for environment plasma monitoring on low-medium orbits.

Parameter	**SMART 1**	**LISA PF**	**MM-PDP**
LP Current Monitor	7mA÷60nA	1.5mA÷~200pA (eff.)	3.0mA÷~600pA (eff.)
RPA Current Monitor	5uA÷3nA	1uA÷~50pA (eff.)	2uA÷~100pA (eff.)
LP Voltage	-150÷120V	-200÷200V	-200÷200V
RPA Voltage	0÷450V	0÷450V	0÷450V
RPA HV Voltage	N/A	N/A	0÷1000V
TLM ramp capability	255 points	512 points	512 points

Changes on performances between various EPDP instruments

Simulation needs

ACCS:

- validation of the effectiveness of its use under different environment condition
- Definition of optimised operational timelines depending orbit condition (eclipse , eclipse exiting/entering)
- Optimisation of Bias accelerating parameter

EPDP

- Correlation of measured plasma measurements with far-way plasma parameters (sheath effect) and on S/C potential distribution
- More precise dimensioning of needed operating range and performance prediction on depending mission requirements.

PC

Possible interest for SPIS code validation on ISS/PlegPay experiment data ?