Active Charging Compensator based on the FEEP neutralizer:
Review of the instrument development activities at TAS-I

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Abstract: A new device for the mitigation and control of negative Spacecraft Charging phenomena has been developed at Thales Alenia Space Italia. The instrument is based on a very low weight and power consuming cathode, emitting electrons in a diode configuration. The emitting units can be moderately biased with respect to the Spacecraft ground in order to guarantee the net current exchange with the environmental plasma and assure the discharge of the Spacecraft (if negatively charged). The emitting unit was initially developed as neutraliser for FEEP thrusters; it already passed two flight qualification campaigns for the LISA Path Finder and the Microscope missions. A pre-qualification testing activity supported by ESA funds has been also recently performed on an Active Charging Compensator EM focused on the Spacecraft Charging Control Application.

Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>Active Charging Compensator; it includes the AESD-NU and AESD-PS Units</td>
</tr>
<tr>
<td>ACCS</td>
<td>Active Charging Compensator System</td>
</tr>
<tr>
<td>AESD</td>
<td>Active Electron Source Device</td>
</tr>
<tr>
<td>CCU</td>
<td>Control &amp; Conditioning Unit (referred to Caging Mechanism on Lisa PF)</td>
</tr>
<tr>
<td>CPO</td>
<td>Computational Particle Optics computational code</td>
</tr>
<tr>
<td>ECSS</td>
<td>European Cooperation for Space Standardization</td>
</tr>
<tr>
<td>EEE</td>
<td>Electric, Electronic, Electro-mechanical parts</td>
</tr>
<tr>
<td>E-GUN</td>
<td>Electron Gun</td>
</tr>
<tr>
<td>ESD</td>
<td>Electrostatic Discharge</td>
</tr>
<tr>
<td>FEEP</td>
<td>Field Emission Electric Propulsion (Technology for which the NU has been qualified)</td>
</tr>
<tr>
<td>GEO</td>
<td>Geosynchronous (Geostationary) Earth Orbit</td>
</tr>
<tr>
<td>HK</td>
<td>House Keeping (function implemented within the PSCU)</td>
</tr>
<tr>
<td>ITO</td>
<td>Indio Tin Oxide</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
</tr>
<tr>
<td>MPE</td>
<td>Microporopulsion electronics (referred to Micro propulsion on GAIA)</td>
</tr>
<tr>
<td>NU</td>
<td>Neutralizer Unit</td>
</tr>
<tr>
<td>PS</td>
<td>Power Supply (referred to the NU’s)</td>
</tr>
<tr>
<td>PSCU</td>
<td>Power Supply &amp; Control Unit (IF and command/control of both the ACC and the SPD)</td>
</tr>
</tbody>
</table>

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I. Introduction

The build-up of large electric potentials (up to the kV level) on a spacecraft relative to the ambient plasma has been experienced in many operational missions and is retained a serious concern from the spacecraft manufacturers and users community.

Environmental factors affecting the spacecraft charging are primarily the charged particle populations trapped by the Earth’s magnetic field. Many are the parameters affecting the spacecraft charging, some of them being below identified:

- Spacecraft Orbit
- Type of environmental particles (electrons, ions, protons, etc.)
- Particles Density, Flux and Energy
- Solar Activity level
- Geomagnetic substorm activity
- Auroral precipitation
- Sunlit/eclipse conditions
- Ram/Wave effects

With reference to the “surface” spacecraft charging, the build-up of electrostatic charge on exposed surfaces of spacecraft most likely takes place in the GEO and Polar LEO environments. Major responsible for this phenomenon are the low energy (< 100 keV) electron showers impinging on the satellite. Two types of spacecraft charging have been experienced:

- **Absolute Charging**: when the entire spacecraft potential relative to the ambient space plasma is changed uniformly (potential of the S/C truss or frame w.r.t. the local space plasma potential)
- **Differential Charging**: when different parts of the spacecraft are charged to different potentials relative to each other.

Differential charging is most likely the most dangerous: it could give rise to potential differences of the order of 10 kV between the sun-lit side and the shadow side of the spacecraft. The actual achieved level of spacecraft charging depends, in any case, on the net current balance between the charged particle flows from the space environment (that reach the satellite) and the charged particles that leave the satellite surfaces (e.g. secondary emission, photoelectric emission, active emission, etc.)

The hallmark of the spacecraft charging (absolute and differential) phenomena are the presence of anomalies in the S/C expected performances. These anomalies are most likely associated to transients caused by the arising of uncontrollable “Electrostatic Discharges”, due to the exceeding of materials breakdown voltages. Such events can couple into the spacecraft electronics and cause upsets ranging from logic switching up to permanent degradation/failure of on board apparatus.

![Figure 1. Spacecraft Charging anomalous events on Atlantic Bird satellite during year 2000](image-url)
Spacecraft Charging literature and reporting highlights that 100-200 annoying to serious and 10 critical operational anomalies due to electrostatic discharges caused by S/C surface discharge are expected over the lifetime of a S/C in GEO. In April 2010 Galaxy 15 experienced a loss of connectivity to Earth that caused an orbit drift. LEO DMSP F16, F17, F18 satellites exhibited up to 22 anomalies per months in the course of year 2010.

The prevention/alleviation of the S/C surface charging is an effective approach to drastically reduce risky situations impacting the S/C health. The charging status of a S/C can be influenced basically with two approaches:

- Passive techniques: By proper and careful selection of surface materials and geometries and by implementing suitable grounding philosophies
- Active techniques: By providing a suitable controlled current source that can compensate for the environmental charged particles (namely electrons) and thus keep the S/C potential close to zero.

The Active Charging Compensator System (ACCS) is an instrument, proposed and developed by TAS-I, dedicated to the Active Control of the S/C Charging level (preventing/alleviating the build-up of a surface charging retained dangerous for the S/C safe operation), by a controlled emission of electrons generated and accelerated through a suitable electron generation device. The ACCS can be considered an actively conditioned device, but its operation, once the cathode has been activated and the device switched on, acts in a passive way (as the electrons emission can be considered also self-controlled).

The ACCS is suitable for reducing or preventing negative absolute charging of the overall S/C main structure (absolute charging prevention). Furthermore, a S/C part – charged with respect to another S/C part - can be protected as well (differential charging prevention), provided that the eventual potential build-up around the S/C does not trap the emitted electrons.

II. ACCS Description

The general architecture of the proposed ACCS instrument includes:

- The AESD NU box that hosts the electron Emitter Units and that is directly interfaced with the AESD-PS;
- The AESD-PS box that hosts the Power Supply board front end, used to provide power conditioning to the Emitter Units;
- The SPD, which is the Sensor in charge of detecting and measuring the level of the S/C Charging (through the measurement of the local electric potential)
- The PSCU Unit whose function is to implement:
  - Data and Power I/F with the S/C
  - I/F with peripheral boxes such as SPD and AESD-PS
  - Data conversion and logic Control.

The “basic” ACCS configuration (see Fig. 2a), or ACC, includes the Active Electron Source/generator (AESD-NU) and its relevant power supply electronics (AESD-PS). The ACC has been developed and successfully submitted to the performance and pre-qualification tests in the frame of an ARTES 5 technology contract with ESA (funded by ASI).
A. AESD-NU

The key ACC element is the electron generation unit (AESD or Active Electron Source Device) that is based on the Neutralizer Unit (NU), shown in Fig. 3a and 3b, developed and successfully qualified by TAS-I for the FEEP Electric Propulsion on ESA missions Lisa Path Finder (PF) and Microscope.

The NU main elements/parts are:
- Electron emitter (cathode subassembly or emitter) and its heating provision
- Thermal Screen
- Extraction Anode through which the accelerated electron beam is extracted and focused
- Electrode Insulation Structure
- Gun shell or Mechanical/supporting Structure.

The NU is basically a moderately high perveance miniaturized Electron Gun (E-GUN) which works in a “diode” configuration. The E-GUN is realized by integrating the thermionic cathode and the beam conditioning electrode structure into a suitable mechanical support that will also be in charge of handling thermal issues. The electron gun is configured with an axial-symmetric cylindrical structure. The accelerating electrode configuration is simply planar while the cathode (emitter) is shaped as a spherical segment.

The NU electron emitter (cathode) is based on an “impregnated” porous Tungsten (W) matrix. The selected impregnation is the 6:1:2 mixture (BaO – CaO – Al₂O₃) with added chemicals; it may exhibit an improved work function (about 1.9÷2.0 eV). The W matrix impregnation has been chosen to allow the best possible trade-off between emitted thermionic current and electrical power necessary to heat up the cathode at the thermionic emission temperature.

The parameters that affect the electron emission process and their impact on the NU dimensioning have been analyzed through the use of an electron optic numerical code (named CPO© : see figure 5 for a simulation example). These parameters (see also Fig. 4) are:
- the distance between the cathode and the accelerating electrode;
- the cathode radius of curvature;
- the shape of the accelerating electrode;
- the accelerating potential (\(V_a\));
- the perveance (product \(I_e \times V_a^{-3/2}\)).

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The NU main features, all measured and confirmed in the FEEP program are presented in Table 1 here below.

<table>
<thead>
<tr>
<th>NU parameter</th>
<th>Value or required performance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extracted electron current into the FEEP beam</td>
<td>6 mA, Extraction of up to 30 mA in principle possible</td>
<td>Vacuum level shall be better than 1 x 10⁻⁸ mbar</td>
</tr>
<tr>
<td>Operating modes</td>
<td>• Activation/regeneration • Stand-by (heater on, anode off) • Operation (heater on, anode on)</td>
<td></td>
</tr>
<tr>
<td>Operation regimes</td>
<td>• Continuous • On/off Throughout the whole mission</td>
<td></td>
</tr>
<tr>
<td>Anode (Accelerating) Voltage</td>
<td>&lt; 200 V&lt;sub&gt;DC&lt;/sub&gt;, for achieving the required emission current</td>
<td>Emission of 6 mA has been verified at a voltage lower than 100 V&lt;sub&gt;DC&lt;/sub&gt;</td>
</tr>
<tr>
<td>Heating up power (transient)</td>
<td>5.0 max W (during activation)</td>
<td></td>
</tr>
<tr>
<td>Steady state operating power</td>
<td>&lt; 5 W</td>
<td></td>
</tr>
<tr>
<td>Cathode Bias Voltage</td>
<td>0V,30V,100 V selectable by TLC</td>
<td>A net acceleration can be provided to the cathode emitted electrons after their extraction from the cathode by applying a negative voltage to the cathode surface with respect to the S/C gnd.</td>
</tr>
<tr>
<td>Heating up time for achieving nom. emission temperature</td>
<td>≤ 4 min (if “activation” has been previously completely achieved)</td>
<td>Activation process requires a total time of about 48 hours. To be performed once at the beginning of the emission as during S/C orbit rising phase (for example)</td>
</tr>
<tr>
<td>Operating temperature Range</td>
<td>-30 °C to + 100° C (for Lisa PF application)</td>
<td>Required current emission verified with mounting I/F at -30°C</td>
</tr>
<tr>
<td>Operational Lifetime</td>
<td>12000 h for LPF application</td>
<td>Demonstrated within the NA Lisa PF program : expected more than 50000h</td>
</tr>
<tr>
<td>NU Mass</td>
<td>&lt; 100 g Without cable and connector</td>
<td></td>
</tr>
<tr>
<td>NU Envelope</td>
<td>φ 23 x 31 mm</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1. Neutralizer Unit main features/characteristics**

Fig. 6 and 7 below show respectively the NU electrical configuration and a simulation of the NU electron extraction process with defined boundary conditions.
The AESD-NU box design is based on the heritage coming from the Lisa PF program for what concern general features, Electron Emitter allocation and functionalities.

However some modification have been implemented, such as the connector allocation that is for the AESD-NU, located on a lateral panel of the box. (in the Lisa PF design it was allocated in the box bottom). The connector type is the one already qualified within Lisa PF mission, i.e. the Positronic, model 1483C (9 pin std submin., non magnetic sealed, small/light and with a very low out-gassing figure).

The box (overall dimension 133 mm length x 92 mm width x 50 mm height; mass about 500 g, when 2 NU’s are mounted ) is realised in one piece of aluminium (see Fig. 9 and 10) to maintain sealing capability through a protection cover equipped by provision for gas inlet and air exhaust. Venting during the launch phase is assured by holes on the top-plate where the NU’s are also fixed. When the 2 NU’s are integrated, the total height of the AESD-NU reaches about 80 mm.
B. AESD-PS

The AESD-PS box has been designed taking into account the two possible mounting configurations i.e: AESD-PS as a separate box or the AESD-NU mounted on top of the AESD-PS cover plate (see respectively Fig. 10a and 10b).

In view of implementing the first mounting configuration, the design of this box has been performed looking at a high degree of mechanical stiffness and wall thickness adequate for the EEE parts to withstand the typical radiation environment (total dose figure) of a GEO environment.

The AESD-PS (dimensions: 224 x193x 64 mm; mass about 2 kg) hosts an electric board (see Fig. 11a and 11b) which implements the following functions:

- **Anode Power Supply**: a FLAYBACK constant power generator at 1.6W clamped at 220V, with an input current limiter.
- **Bias Power Supply**: a STEP-UP programmable voltage source at 0, 30 and 100V, with an input current limiter.
- **Heater Power Supply**: it is a PUSH-PULL programmable voltage source in the range 0 to 8V able to provide up to 5W, with a input latching current limiter.
- **Aux Power Supply**: an isolated 12V generator, devoted to power the internal circuit, with an input current limiter.
- **Command and Decoder Section**: devoted to receive the command signal from the PSCU.
- **Monitoring Section**: six isolated analogue monitors proportional to the voltage and current generated by Anode, Bias and Heater Power Supplies respectively.
- **Relay Section**: that connect the Anode, Bias and Heater Power Supplies to the nominal or redundant NU. The commutation between nominal and redundant ESU will be performed with all Power Supplies in OFF condition.
III. ACCS extended configuration

The ACCS extended configuration includes, in addition to the ACC (composed by the AESD-NU and AESD-PS) two further units: The PSCU and the SPD.

In the extended configuration the ACCS can be operated by implementing a closed loop S/C charging control where the ACC is the actuator of the control (generated neutralization electron current) and the SPD is the charge/potential sensing element which “drives” the switch ON (and OFF) of the device allowing the emission process to take place in a self controlled way during the active phase.

The emission of the electron current can be commanded by a direct switch-on command from the instrument PSCU (or S/C OBDH) or can be driven by the signal provided by a Surface Potential Detector (SPD) Unit upon a decision making process managed internally by the PSCU on the basis of an established control algorithm.

In the case where the electron current emission is commanded (in closed loop control) on the basis of the surface charging level measured by the SPD, the PSCU makes the decision when and how (and eventually in which electrical configuration, i.e. heating power and bias voltage) command the electron emission process to avoid “risky” situation in the satellite operation due to the surface charge build up.

While the ACC has been designed and developed at EM level the PSCU and the SPD have been so far addressed at preliminary design level. Fig. 12 presents the detailed Electrical Sketch of the extended ACCS instrument.
C. Power Supply & Control Unit (PSCU)

The architecture of the PSCU unit is based on the sharing of the functions between Power Supply, Control and Interface. The PSCU main functions are:

- to retrieve power from the main S/C power Bus and to feed secondary power to both AESD and SPD units;
- to collect/feed signals from both ACC (AESD) and SPD and to provide relevant TLM data to the S/C bus.
- to accept TLC and to perform the relevant logic, mode operation and mode transitions and the relevant controlling sequences for both the ACC and SPD as required by the exchanged TLC or internal initialisation routines.

The ACCS PCU box includes 3 boards (3 extended single euro-card boards connected through a small motherboard):

- Power Board: in charge of receiving the Primary power from the S/C (e.g. 50V or 100 V) and of providing the relevant secondary power to all the ACCS parts.
- Control Board: it is similar to ones used in LISA CCU and GAIA MPE and is in charge to receive the telecommands from the S/C and to provide the relevant telemetry through its 1553 Bus interface. The Control Board, hosting the µController and dedicated SW, is also in charge to manage the cathode(s) activation and heating profile, to activate the anode and the Bias Power Supplies and to switch the power Supplies feed lines between the two neutraliser units, according to the Operational Modes and the received telecommands. In addition, the Control board is also in charge of collecting the HK signals of the ACCS for their digitalization, formatting and transmission to the S/C.
- SPD Interface Board: it is designed on purpose, according to the specific requirements of the SPD to be interfaced. The chosen SPD (see paragraph III B below) requires a simple circuitry, composed essentially by a current amplifier that provides an output proportional to the potential actually read.

As the ACCS is not a “critical” payload or element of the S/C the baselined PSCU configuration is “non redounded”.

The redundancy of its functions (if specifically required for a S/C mission) can be easily achieved either by doubling the box footprint or by simply doubling the boxes.

The PSCU operational modes are presented in the following table:

<table>
<thead>
<tr>
<th>Modes</th>
<th>Implemented task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off</td>
<td>The ACCS is Off and no Power is applied to the PCU</td>
</tr>
<tr>
<td>Boot</td>
<td>Power is given to the ACCS; the necessary initialisation routines apply to put the PCU in condition to perform a mode transition to STANDBY or to a RELOAD mode</td>
</tr>
<tr>
<td>Stand-by</td>
<td>PSCU is On and is able to exchange TLC/TLM with the main bus but no secondary power (PS) is fed to the AESD.</td>
</tr>
<tr>
<td>Pre Operating</td>
<td>PSCU is ON and the AESD is partially powered to hold the cathode at a temperature ready to start to emission in a very short time. Bias is at zero potential and Anode are not powered. SPD can be activated optionally</td>
</tr>
<tr>
<td>Activation</td>
<td>A heater power ramp sequence is initiated to activate the NU cathodes. The anode and bias are not powered.</td>
</tr>
<tr>
<td>Emission 1</td>
<td>A time ramp is fed to one of the NU in order to heat up the selected NU and to provide anode and bias power. The SPD can be operated optionally (it should be typically ON).</td>
</tr>
<tr>
<td>Emission 2</td>
<td>A shorter time ramp is fed to make the selected NU ready to operate starting from the Pre</td>
</tr>
</tbody>
</table>
### Table 2. Summary of ACCS PSCU Operational Modes

<table>
<thead>
<tr>
<th>Modes</th>
<th>Implemented task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Mode</td>
<td>The SPD can be operated optionally (it should be typically ON for this mode). The mode transition can be semi automatic and selected by the Control logic through data from the SPD (if it is ON) or performed through a dedicated TLC.</td>
</tr>
<tr>
<td>SPD Monitor</td>
<td>The SPD can be commanded and operated with the AESD OFF in order to provide TLM to ground (see Dump mode)</td>
</tr>
<tr>
<td>Reload</td>
<td>Reload of the SW code can be performed to upgrade the basic SW routines in the EEPROM.</td>
</tr>
<tr>
<td>Patch</td>
<td>Patch mode is entered through a dedicated TLC and would allow a direct modification of data into the RAM memory</td>
</tr>
<tr>
<td>Dump</td>
<td>In this mode download of science data packets can be activated as per SPD self standing operation (SPD monitor).</td>
</tr>
</tbody>
</table>

### D. Surface Potential Detector (SPD)

The SPD instrument operates by sensing the potential acquired by a plate covered with specific material (deposited on top of the supporting plate in the form/shape of a thin layer) that can be customised depending on the S/C material to be monitored. The coating can be paint, kapton, ITO, Cover glass, antenna patch, etc. or any material that is representative of a material typically present on the S/C, exposed to the open space, and potentially subjected to the surface charging process. It could be convenient to use a sample of a S/C material retained the most “critical” (for charging aspects): this assessment can be done with the support of modelization/simulation tools on the basis of the specific S/C design.

The electrons impinging the surface of the SPD charge up the capacitance formed by the metal cover, the dielectric layer and the space plasma environment.

The SPD instrument can be configured to detect:
- the potential of a sample of the S/C surface (approximately) floating with respect to the S/C truss ground
- the potential of a sample of the S/C surface connected to the S/C truss ground through a dedicated suitable resistor representative of the actual resistive path of the S/C surface material vs. the S/C truss ground.

These two configuration have their own advantages on depending the application. In the specific application of S/C potential monitoring the second option is more representative as giving a value of the potential more correlative to S/C surfaces potential.

Practically what the instrument measures/detects is the current that manifests as a consequence of the sample charging. This current (in general very low) is fed to a front end electronics, based on an instrumentation amplifier, through a suitable partition network. The measure performed is based on the “electrometer” concept.
IV. ACC Laboratory Tests

E. ACCS Laboratory Test Set-up and EGSE

For the ACCS Test in Laboratory a dedicated EGSE (Electrical Ground Support Equipment) has been designed and developed. The EGSE has to provide the necessary I/F to operate the ACC (AEDS-NU + AESD-PS) without the PSCU. The EGSE includes two separate electrical I/F for the experiment, one for supplying the AESD-PS unit lines with the necessary power lines, analog and Bilevel lines. The other to I/F the Test Equipment.

During the tests the EGSE is operated to:
a) control the Power Supply Unit board inside the AESD-PS box (in air) that commands the Neutraliser Units inside the AESD-NU box (placed in the ultra high vacuum chamber)
b) control the Test Equipment for plasma simulation/charging simulation.

The Main Set-up (see also Fig. 16a and 16b) is composed of:

- Vacuum Chamber in which the AESD-NU will be installed;
- Main metallic structure simulating the S/C external Panel, insulated vs. the mechanical structure;
- Target that can be optionally used as alternative to the floating S/C metallic panel simulator. The target or the S/C panel simulator can be biased through a dedicated PS (HV PS);
- Plasma simulator box including a network of resistances and diode connected to the Target roughly approximating the sheath impedance of the S/C for a reference plasma environment related to GEO.
- Cable coming from the AESD-NU to the AESD –PS box (Hns3) and a cable Hns1 from the EGSE rack to the AESD-PS is also realised to feed the necessary signals and power supply voltage from the AESD-PS to EGSE RACK.

- EGSE rack including:
  - Low voltage PS (+28V) for powering the AESD-PS board
  - High Voltage PS (200V) to drive the S/C Panel Simulator or Target
  - PC with Windows, Labview and National Instrument board(s) to drive the TE HV PS and the AESD-PS board Labview SW is used to implement the Experiment Logic and drive/acquire the correct signals from the AESD-PS board.

F. Overview of ACCS Test Activity

In the frame of the ARTES 5 contract with ESA the developed ACC (AESD-NU + AESD-PS) has been successfully submitted to a sequence of test as summarized in the following test matrix:

<table>
<thead>
<tr>
<th>TEST ID.</th>
<th>TEST DESCRIPTION.</th>
<th>PHYSICAL PROPERTIES</th>
<th>FACILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP – NA – 01</td>
<td>Visual Inspection respect to applicable ICD</td>
<td>TAS-I Clean Room</td>
<td></td>
</tr>
<tr>
<td>PP – NA – 02</td>
<td>Dimension verification</td>
<td>TAS-I Clean Room</td>
<td></td>
</tr>
<tr>
<td>PP – NA - 03</td>
<td>Weight verification</td>
<td>TAS-I Clean Room</td>
<td></td>
</tr>
<tr>
<td>PP – NA - 04</td>
<td>Cathode Surface optical inspection</td>
<td>TAS-I Clean Room</td>
<td></td>
</tr>
<tr>
<td>EC – NA – 01</td>
<td>Continuity verification</td>
<td>TAS-I Clean Room</td>
<td></td>
</tr>
<tr>
<td>EC – NA – 02</td>
<td>Insulation verification</td>
<td>TAS-I Clean Room</td>
<td></td>
</tr>
<tr>
<td>EC – NA – 03</td>
<td>COLD resistance verification</td>
<td>TAS-I Clean Room</td>
<td></td>
</tr>
<tr>
<td>FT- NA -01</td>
<td>Activation</td>
<td>TAS-I Ultra vacuum Chamber</td>
<td></td>
</tr>
<tr>
<td>FT- NA -02 A,B,C</td>
<td>Functional charact</td>
<td>TAS-I Ultra vacuum Chamber</td>
<td></td>
</tr>
<tr>
<td>ML- NA -01</td>
<td>Sine load</td>
<td>Selex-Galileo Vibration Facility</td>
<td></td>
</tr>
<tr>
<td>ML- NA -03</td>
<td>Random vibrations</td>
<td>Selex-Galileo Vibration Facility</td>
<td></td>
</tr>
<tr>
<td>ML- NA -04</td>
<td>Shock loads</td>
<td>Selex-Galileo Vibration Facility</td>
<td></td>
</tr>
<tr>
<td>TV – NA - 01</td>
<td>Thermal Vacuum Test</td>
<td>TAS-I Thermal Vacuum Chamber</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Outlook on of ACC Test sequence

G. ACCS Performance Test

The main aim of the performance test has been the characterization of the ACC with an effort to reproduce in laboratory the conditions in which the device would operate on a S/C. The exchange of current between the environment and the S/C, depending on the potential difference between the S/C (GND) and the plasma (Target), has been roughly simulated using a dedicated circuit.

A worst case (for current emission requirement) GEO high density plasma environment has been assumed to design the plasma impedance simulator.
The NU has been put in emission varying operational parameters in order to characterise its functionality and its ability to exchange current with the target and lower the potential difference between the target (plasma) and the S/C (GND).

The most significant test accomplished to investigate the performances of the ACCS is the one where the target voltage has been varied vs. the reference GND, at different accelerating bias voltage in a temporal sequence.

In the test set-up used, the effective equilibrium target potential vs. the reference GND gives an estimate of the S/C potential vs. the undisturbed plasma, with the assumed S/C geometry and GEO plasma parameters. Even though it is a laboratory rough schematisation (which strongly depends on the plasma simulator circuit design in terms of absolute values) of more complex phenomena taking place in space, the trend of the target potential, varying the NU emission parameters, are considered of interest to validate the concept.

The obtained information from the test showed (see fig. 17a and 17b) that, at a bias voltage equal to zero, the charging potential was substantially reduced by a factor of about 2 for the used impedance, whereas, once the bias is changed from 0V to -30V and/or -100V, the NU has been able to perform a complete neutralisation by reducing the simulated charging potential (-V_{\text{target}}) down to near 0 Volts (i.e the simulated reference S/C potential). The latter results can be considered a key experimental result to validate the ACCS concept and present design.

V. ACCS at S/C level: accommodation and performance simulation aspects

The ITALBUS GEO platform developed by TAS-I, and used in several programs (see tab.4) was used as a reference case for the ACCS program. The possible allocations of the ACCS boxes on the platform, compatible with the general specifications, were identified implementing a collaboration with TAS-I Rome.

![Figure 17a. Heater Voltage, HV-PS, anode, target and bias:](image1)

![Figure 17b. Heater current, HV-PS, anode, target and bias](image2)

Figure 17a. Heater Voltage, HV-PS, anode, target and bias:
1) No NU emission: V_{\text{target}}=V_{\text{HVPS}}
2) NU in emission with V_{bias}=0 V; V_{target}~ 0.5 V HVPS
3) NU in emission with V_{bias}=-30 & -100 V; V_{target}~ 0 V

Figure 17b. Heater current, HV-PS, anode, target and bias

<table>
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<tr>
<th>ITALSAT</th>
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</table>

Table 4. ITALBUS Platform application missions
ITALBUS main characteristics are:
- Wet mass: ~ 3 tons
- Power available for payload: ~ 3000 W
- Payload embark capability: up to 24 active transponders
- Lifetime: up to 15 years.

According to allocation strategy of payloads for the ITALBUS platform, the most suited panel for the AESD and the PCU boxes allocation has resulted to be the North lower panel (see Fig. 18).

![Figure 18a. ITALBUS Platform CAD Drawing](image)

![Figure 18b. North Lower panel exterior view showing the position for the AESD box](image)

![Figure 18c. North Lower panel interior view showing the position for the PSCU box](image)

A preliminary simplified simulation has been performed to assess potential benefits achievable by operating the ACCS on board ITALBUS platform. The Double Maxwellian plasma model has been assumed.

![Figure 19. Simulation of ITALBUS charging with S/C partially in sun light: GEO environment according to the ECSS standard. Red bar w/o ACCS and Blu Bar with ACCS activated for electron emission](image)

In addition to the study activities performed for ITALBUS, a preliminary analysis has also been performed by TAS-F Cannes to assess theoretically the effects of using an electron emitter during the operation of a GEO satellite. The aims of this preliminary investigation was to highlight possible benefits expected with the use of the ACCS instrument for significantly alleviating the phenomenon of charge build-up on the exposed surfaces of typical GEO satellites.
The analysis has been performed through the SPARCS code. The main goal of the performed theoretical investigation has been to verify capability of ACCS to avoid primary arc on solar array and perform a trade off with other “passive” solutions (germanium antenna or ITO coating on sun side of solar array).

The S/C charging simulation has been performed by comparing the charge distribution on the satellites surface with and without the use of the ACCS instrument. The reference spacecraft used for the simulation was the Galaxy 17 (based on platform SB 3000 B3), in GEO orbit. Both Absolute and differential charging have been addressed.

Results of differential voltage distribution in eclipse for a reference case compared with the same case (on the right) where the ACCS has been assumed active substantially lowering the absolute gnd. voltage to plasma down to –200V. Also the differential voltage looks well mitigated.

The conclusions drawn from the performed preliminary analyses, also against other mitigating actions such as the use of coatings, presented hereafter are quite promising:

a) Out of eclipse:
   Concerning inverse gradient (solar array problematic):
   • ITO and ACCS fit requirement ($\Phi_{\text{diff}}$ max < 200 V);
   Concerning normal gradient (coating and cold surface problematic):
   • ACCS allow lower differential potential on dielectric surfaces;
   Concerning $\Phi_{\text{Abs}}$:
   • ACCS and ITO induce near zero absolute potential;

b) During eclipse (and potential gap during out of eclipse transient)
   • ACCS is the only solution which allow low absolute (and differential) potential mitigation.

c) Level of current required for observing computed results are largely reachable by ACCS
   • Require ~ 1.3 $\mu$A for a $\Phi_{\text{diff}}$ max less than 200V
   • ACCS is qualified for a few mA (LISA PF program)
   • Require “only” a contact with S/C structure
   • Less risk if failure (vs. ITO coating solution)
VI. Conclusions

In the perspective of using a controlled electron emission generated by an active device hosted on board for alleviating the electrostatic charge build up on GEO and Polar LEO satellite an ACCS instrument has been defined, and evaluated by analysis. In a second step the Key unit of the identified ACCS instrument i.e. the AESD-NU and AESD-PS units have been developed, designed in detail, manufactured at EM level and tested.

The key element of the AESD-NU is the Neutralizer (electron generator) qualified and manufactured at FM level for the Lisa PF Mission.

Results of tests performed on the AESD-NU coupled to the AESD-PS (with a dedicated EGSE) are considered quite satisfactory both in term of environmental testing but especially in term of functional and performance testing according to results presented showing as the absolute negative charging of a S/C in GEO (but for the level of current used during test even in LEO) may be effectively controlled through the use of a low electron accelerating e-gun and power emitting cathode.

Integration of the basic ACC instrument with an additional sensor, the SPD, dedicated to the measurement of spacecraft potential has been taken into account and the preliminary design of the SPD probe has been identified. The operation of the AESD in closed loop control with the SPD would give to the system the max. degree of flexibility and versatility. In this perspective the preliminary design of a dedicated PSCU interfaced to both the AESD and SPD has been performed.

The problem of differential surface charging and how the operation of ACCS may solve such issue, has been approached through preliminary analyses and simulations. Results indicated that benefits are expected in terms of lowering differential charging as, in general, lowering absolute charging would imply also lowering differential charging at steady state and for the surface material and S/C equivalent resistive network considered.

A general philosophy for the operation of the ACCS instrument has been also identified.

In general a proper timing approach shall be identified to avoid charging/discharging transients between S/C parts; the preferred operational guidelines are summarised here below:

- Switch-on the AESD-NU before adverse charging condition would take place if these can be a priori known as eclipse (switch-on before entering and switch-off after exiting the eclipse condition)
- Switch-on the AESD NU when a charging event is started to be detected (this would imply the presence on board of a SPD unit)

A flight mission for the validation/confirmations of the ACCS concept design and operation would be the next preferred step approach. In this optics a dedicated ACSS in flight experiment has been proposed to ESA in the framework of the In Orbit validation Program.

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- G. Daprati (TAS-I Roma) for charging simulation at Italbus level

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