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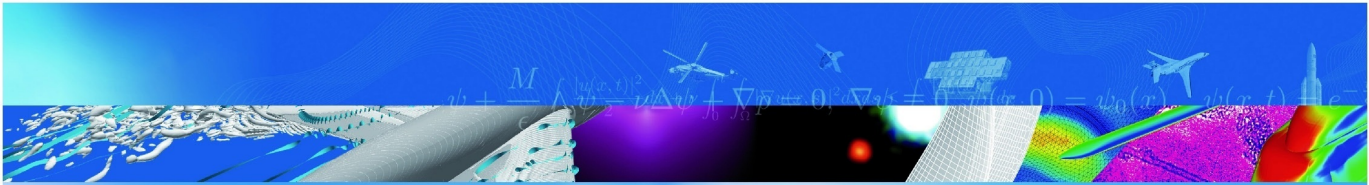
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COMMUNICATION A CONGRES

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# Plasma current collection of high voltage solar array: experimental results

Jean-Michel Siguier, Virginie Inguibert, Gaël Murat, S. Hess and Denis Payan

**Abstract**— Implementation of electrical propulsion on new generation satellites involves development of high voltage solar arrays which supposes to solve some technological problems. One of these problems is the interaction between the solar panel and the environment knowing that this environment is modified by the plasma created by electrical propulsion.

Concurrently to a numerical approach conducted with SPIS computations, presented in a dedicated presentation, we have carried out an experimental work in order to validate these simulation results.

Tests are performed in JONAS plasma facility on a semi-solar panel sizing  $4 \times 1 \text{m}^2$ .

The solar panel is polarized up to  $V_{\text{bus}} = 350 \text{V}$  to simulate the voltage generated by lightened solar cells. All the electrical setup and solar panel are kept electrically floating versus the chamber walls. Two electrical layouts of solar cell strings are studied with 3 plasma densities from  $10^{11}$  to  $10^{13} \text{m}^{-3}$ .

For each electrical layout, plasma density and  $V_{\text{bus}}$  value, we measure the floating potential of the solar panel and the collected plasma current by solar cells strings.

*Keywords*—ionospheric plasma; solar array; electrical propulsion

## I. INTRODUCTION

In a context where the all-electric platforms tend to grow, the issue of electric circuit taken by the electrons becomes essential. With electric propulsion, the orbital transfer times becomes longer. For LEO (low earth orbit) or GTO (geosynchronous transfer orbit), the solar generators (SG) of satellites are surrounded by primary and secondary plasmas relatively dense. Thus, the collected current (electrons) by GS interconnectors is likely to be high and then to disrupt the power circuit or change the electrostatic behavior of the satellite. This risk is even higher than the GS bus voltage is high as for direct-drive GS which are supposed to build voltages in the range of 350V on the interconnectors.

To estimate this risk, it is necessary to evaluate the current collected by the interconnectors of a standard GS and its influence on the satellite potential. The only possible approach for an in-flight satellite is the numerical simulation. So, the aim of this study is to give some data, extracted from a laboratory experiment carried out as close as possible to in-

flight conditions, in order to validate a numerical study conducted in parallel with SPIS (Spacecraft Plasma Interaction Software) [1].

Following works performed few years earlier [2] [3] [4] [5], we have performed a series of experiments on a half solar panel in the JONAS facility to estimate the interconnectors collected current and the floating potential achieved by the solar panel function of various parameters:

- Plasma density,
- Plasma ion energy,
- Voltages between the strings, up to  $V_{\text{bus}} = 350 \text{V}$ ,
- Voltage between the plasma and the panel structure ( $V_{\text{bias}}$ ).

One of the goals was highlighting the phenomenon of snapover (electrostatic funnel effect which appears from a certain voltage) drastically increasing the collection of particles.

## II. JONAS FACILITY

The tests are performed in JONAS facility located at DESP/ONERA-Toulouse. It is basically a  $9 \text{m}^3$  vacuum chamber extended with a 1.5m length cylinder which provides a total useful length of 4.5m with a 1.8m diameter. It is equipped with a plasma source, two 10keV electron guns and several electrostatic discharges (ESD) and plasma diagnostic devices such as transient current probes, surface potential probes, Langmuir probes, etc.

A cryogenic pump gives a working pressure less than  $10^{-7} \text{hPa}$ . The working pressure with plasma is about  $5 \times 10^{-6} \text{hPa}$ .

The plasma source is a Kauffman type, providing 10 to 30eV drifting  $\text{Ar}^+$  ions. The energy range corresponds to the orbital velocity (8km/s for 20V). This plasma is constituted of two ions populations: drifting ions and low energy ions (after interaction with neutrals). Rough characteristics are:  $N_i = 10^{11}$  to  $10^{13} \text{m}^{-3}$ ,  $T_e \approx 0.1 \text{eV}$  to  $0.2 \text{eV}$ . Argon is used as an inert gas, the most similar to oxygen (LEO plasma constituent).

Earth magnetic field is totally compensated by external coils within a volume of about  $2 \text{m}^3$  in the center of the chamber. The compensation decreases getting closer to the JONAS walls.

### III. SOLAR ARRAY SETUP

The solar array under test is from a  $2 \times 4 \text{m}^2$  panel built by Airbus DS-Ottobrunn, Germany. It is made with 52 strings of silicon cells and it was cut in two parts of  $1 \times 4 \text{m}^2$  in order to fit inside JONAS chamber (Fig. 1). This panel was also used for a flashover study in EMAGS3 campaign and well describe in [6].

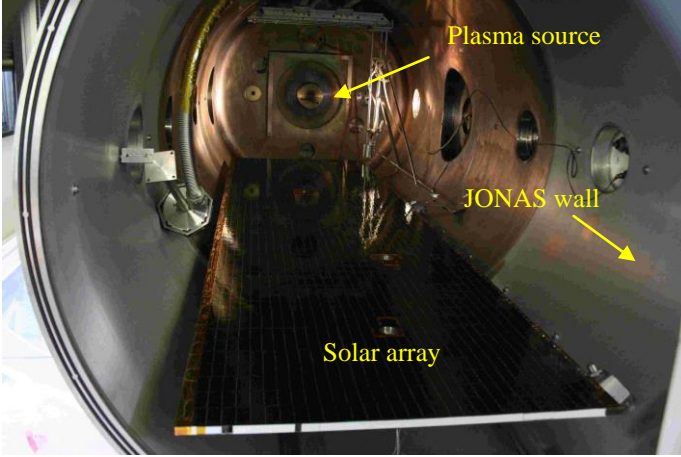


Fig. 1: semi-solar panel set inside JONAS chamber

The solar panel and all electrical connections are insulated from the ground so that it is floating in the ambient plasma.

Polarization of the solar cells, simulating the  $V_{bus}$  voltage of the panel under lightning, is applied only on the first 20 strings (number 33 to number 52) located close to the plasma source. Others strings are short-circuited, connected to the solar panel structure (honeycomb) and to the negative electrode of  $V_{bus}$ . In order to have a voltage distribution as close as possible as inflight conditions and low currents flowing across the cells, making possible the measurement of plasma collected currents,  $35 \text{k}\Omega$  resistors are set in series every 2 strings. This produces a current of about  $1 \text{mA}$  which lowers the photocurrent produced by the cells under plasma source neutralizer lightning (about  $5 \text{mA}$ ). These string currents are measured with ammeters battery powered.

Two voltage configurations, corresponding to two electrical layouts, are tested:

- The first layout (Fig. 2) provides the  $V_{bus}$  negative polarity on the last strings (#51 and #52) and the positive polarity on strings #41 and #42, then the negative polarity on string #33 and on all others strings including the panel structure.
- The second layout (Fig. 3) provides the  $V_{bus}$  positive polarity on the last strings (#51 and #52) and the negative on strings #41, #42 and on all others strings including the panel structure.

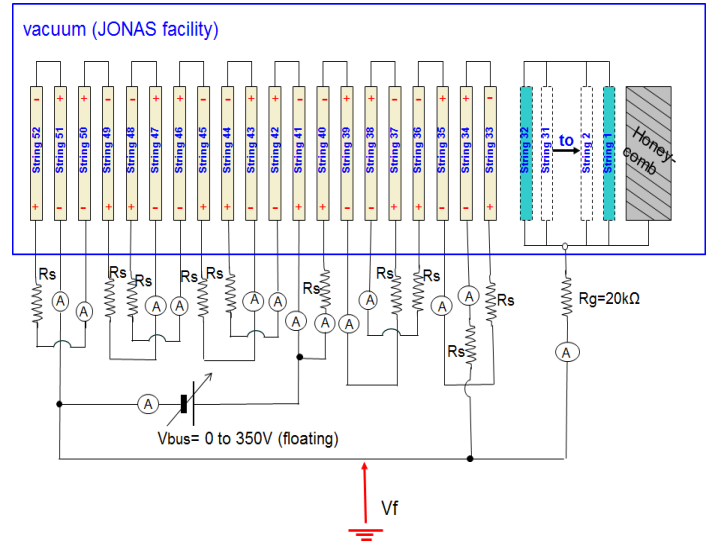


Fig. 2 : setup 1 with floating panel

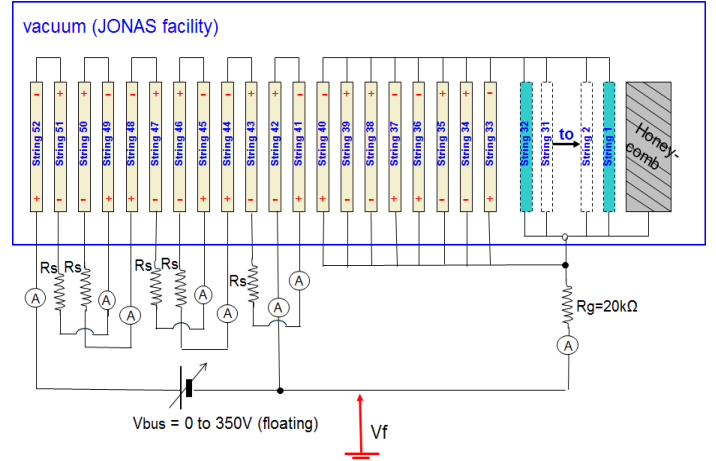


Fig. 3: setup 2 with floating panel

### IV. RESULTS WITH SETUP 1

Once  $V_{bus}$  voltage is set and plasma source is on, string currents are measured after a stabilization times varying with  $V_{bus}$  values and plasma source settings. Most often it is in the range of 10s but it can take more than 1 minute as observed by [5] who attributed it to a change of secondary emission yield of the solar panel surfaces and interconnectors impacted by energetic electrons (up to  $200 \text{eV}$ ).

According to [4] results, primary arcs are also detected when  $V_{bus}$  voltage and plasma are operating but they are mainly located on the edges of the panel and correspond to the blow-off discharge of the panel capacitance versus ground (few tenth of nF). As they are transient currents with a period of 1 to 10s, string currents are measured between two discharges when they are stabilized.

Fig. 4 shows, for  $V_{bus}=350 \text{V}$ , the floating potential of each string for 2 plasma densities.

Fig. 5 to Fig. 8 give the string currents, function of  $V_{bus}$ , for different plasma source settings (ion energy and density).

Fig. 9 curves are the collected plasma current of strings 42 and 41 function of  $V_{bus}$  for different plasma densities (from Fig. 7 and Fig. 8)

Fig. 10 shows the floating potential of the panel structure function of  $V_{bus}$  for different plasma settings

Fig. 11 represents the setup, derived from Fig. 2 setup, of the panel not floating but biased at a definite voltage.

Fig. 12 shows the total collected panel current function of biased voltage, that is a kind of I(V) Langmuir probe characteristic.

Fig. 13 shows the string current values for different biasing, from -200V to +200V, with a fixed  $V_{bus}$  value (+100V) and a fixed plasma setting.

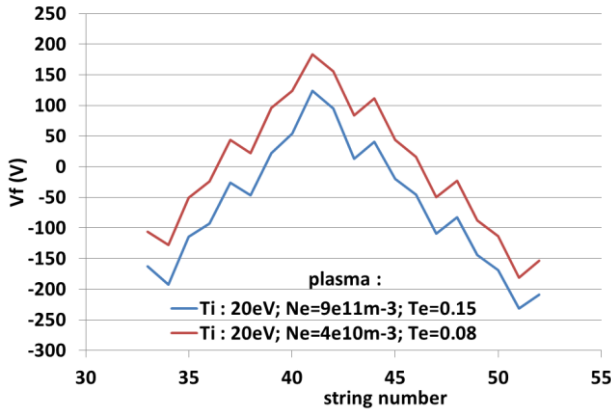


Fig. 4: floating potential of the strings for  $V_{bus}=350V$  (setup1)

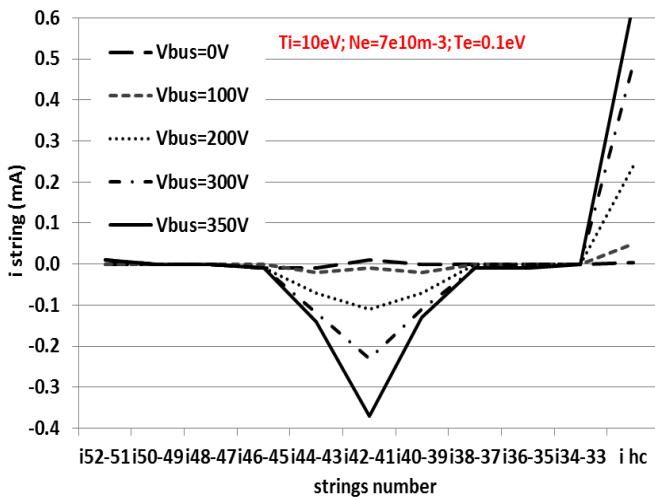


Fig. 5 plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 1

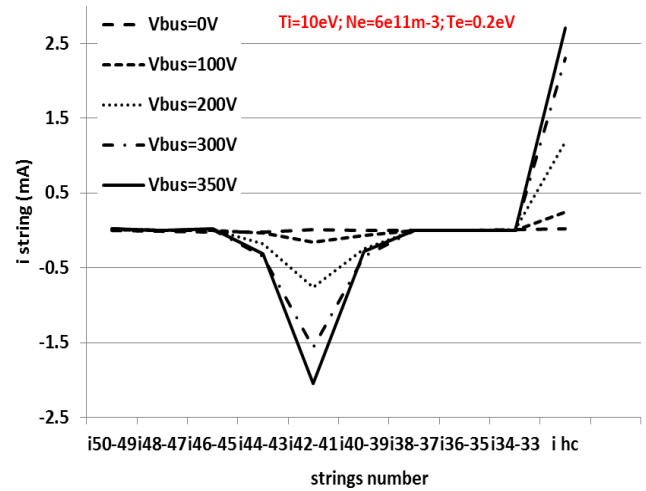


Fig. 6: plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 1

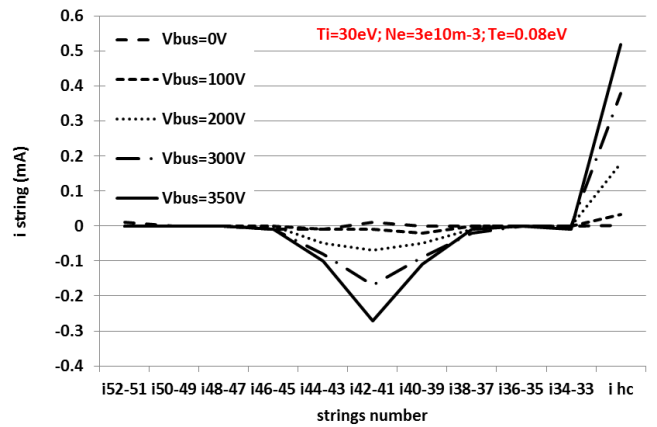


Fig. 7: plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 1

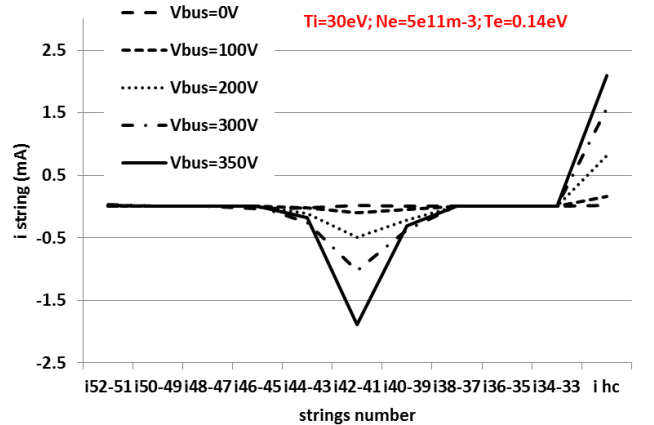


Fig. 8: plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 1

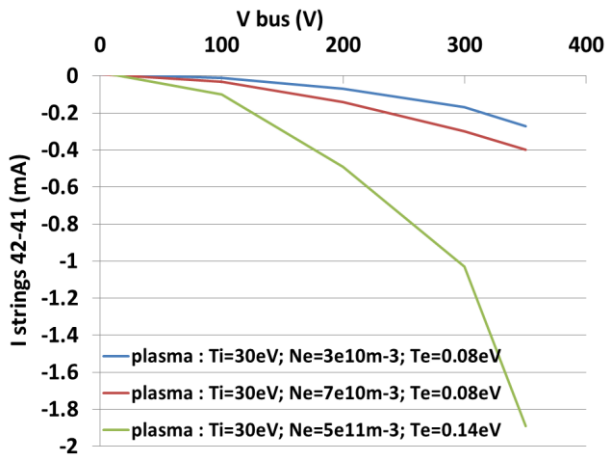


Fig. 9: collected plasma current of strings 42 and 41 function of  $V_{bus}$  for different plasma densities (from Fig. 7 and Fig. 8)

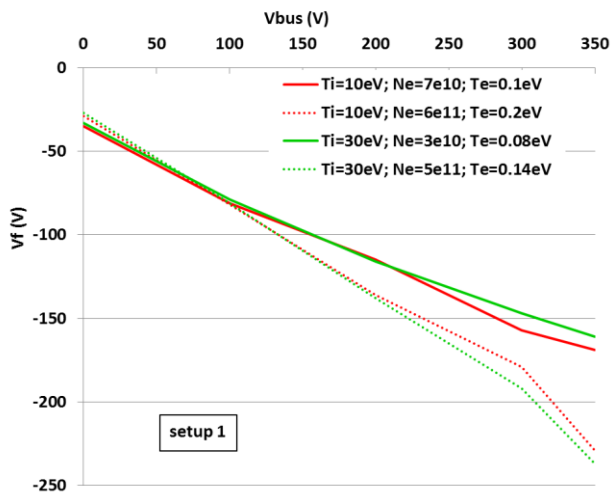


Fig. 10: floating potential of the panel structure function of  $V_{bus}$  for different plasma settings

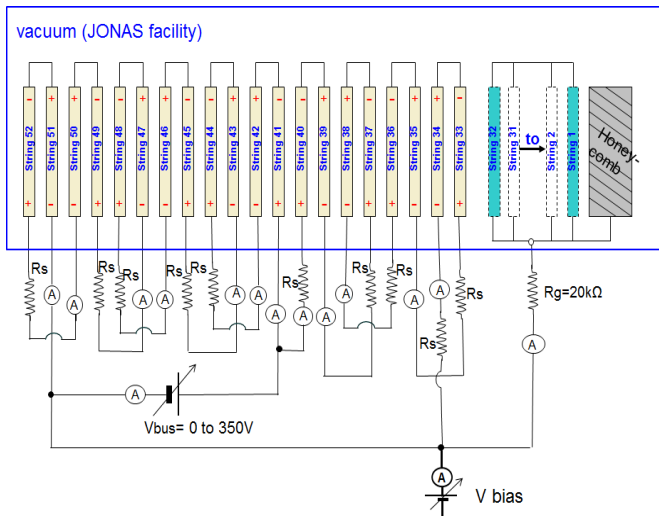


Fig. 11: setup 1 with biased panel

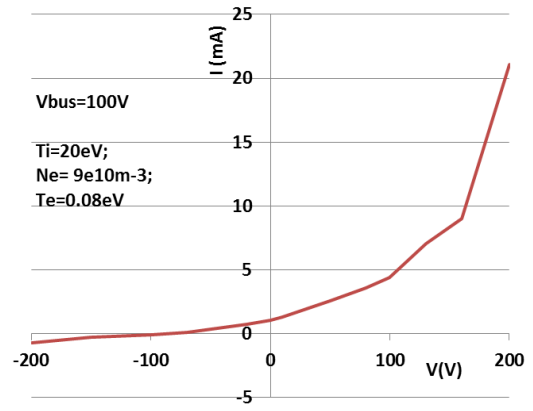


Fig. 12: I(V) characteristic of the biased panel (setup 1)

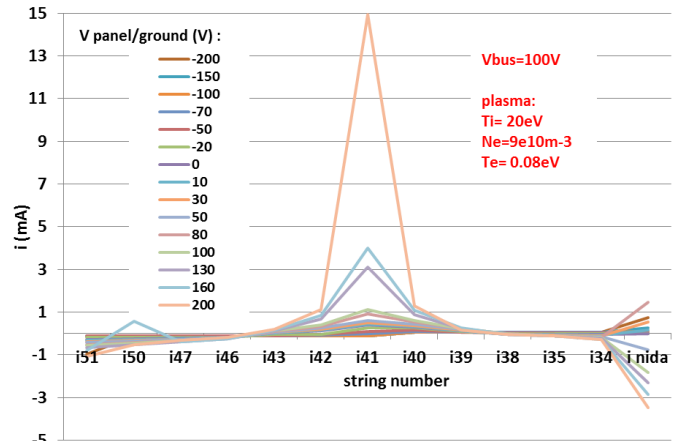


Fig. 13: collected current for each string function of  $V_{bias}$  (Setup 1)

## V. RESULTS WITH SETUP 2

Setup 2 results are similar to setup 1 results according to the electrical layout fixing the maximum positive value of  $V_{bus}$  to the edge strings (#51 and #52) instead of strings #41 and #42.

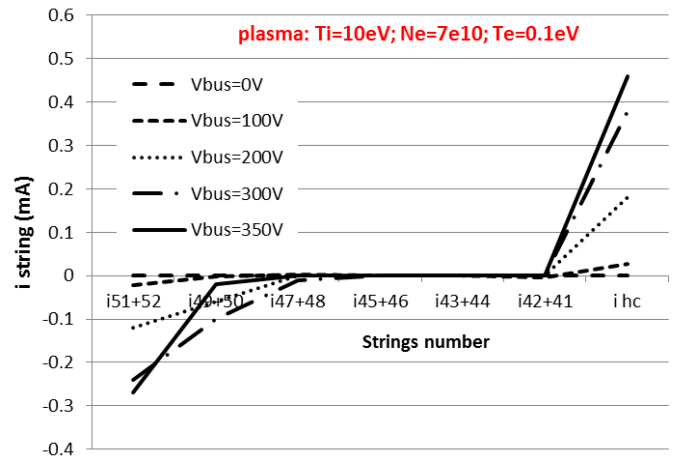


Fig. 14: plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 2



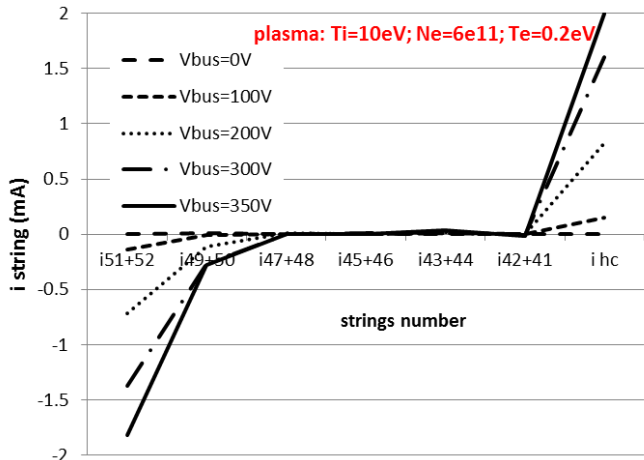


Fig. 15: plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 2

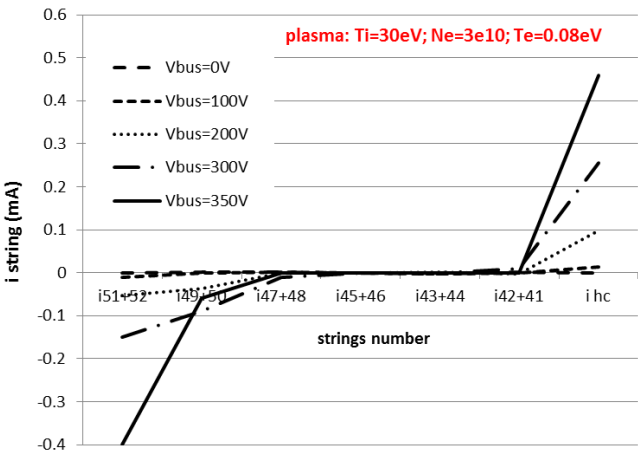


Fig. 16: plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 2

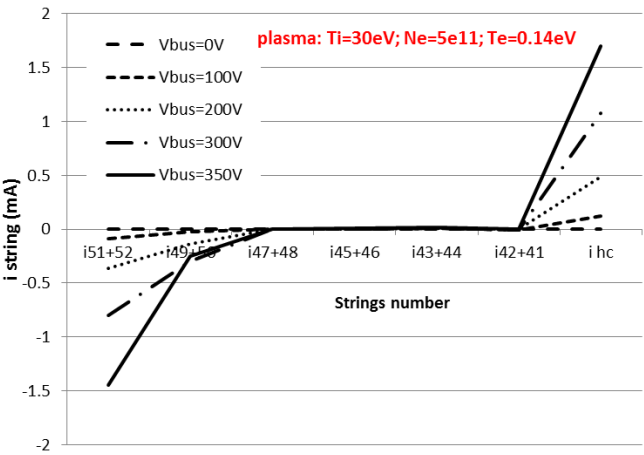


Fig. 17: plasma current collected by the strings for different  $V_{bus}$  values and plasma source set as specified (in red). Setup 2

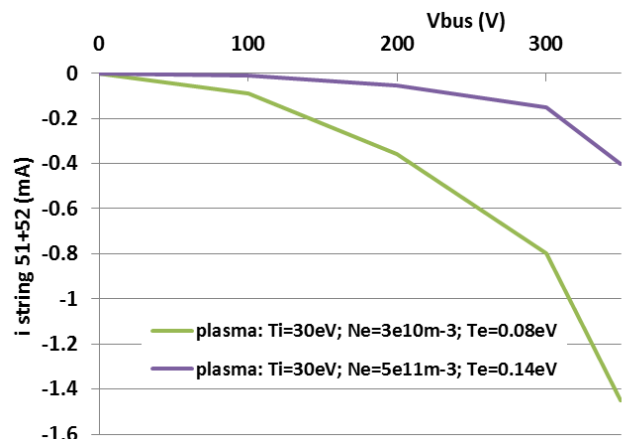


Fig. 18 collected plasma current of strings 51+52 function of  $V_{bus}$  for different plasma densities (from Fig. 16 and Fig. 17)

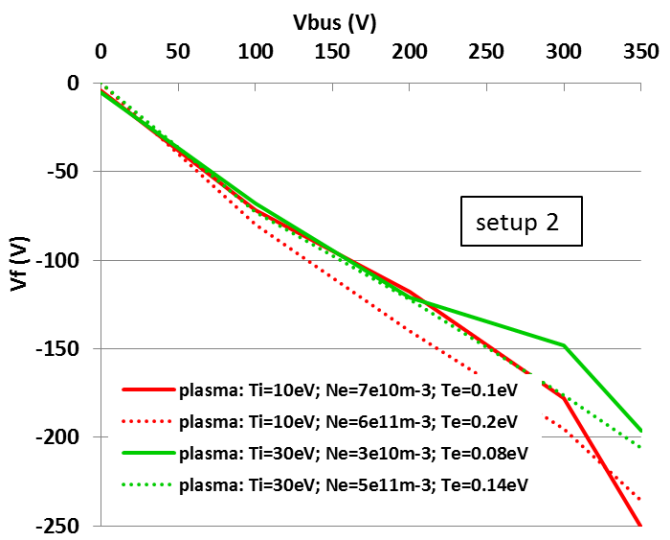


Fig. 19: floating potential of the panel structure function of  $V_{bus}$  for different plasma settings

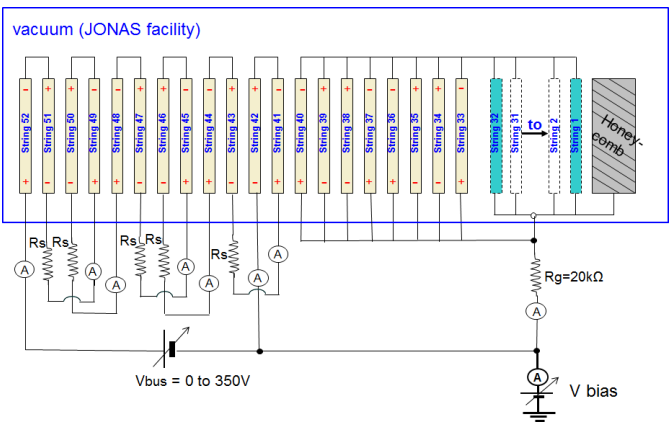


Fig. 20: setup 2 with biased panel



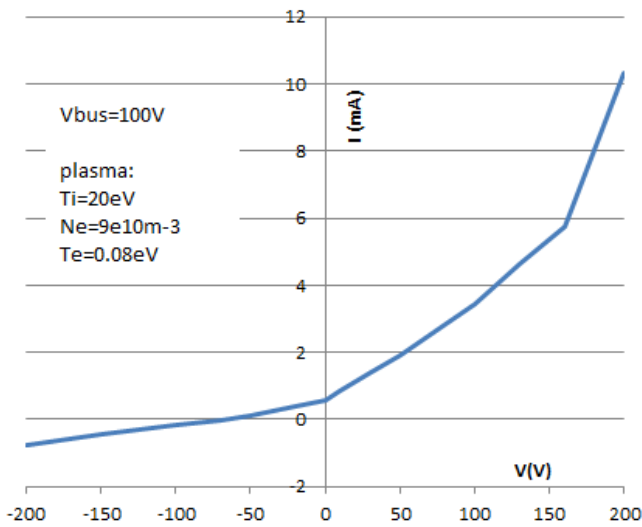


Fig. 21: I(V) characteristic of the biased panel (setup 2)

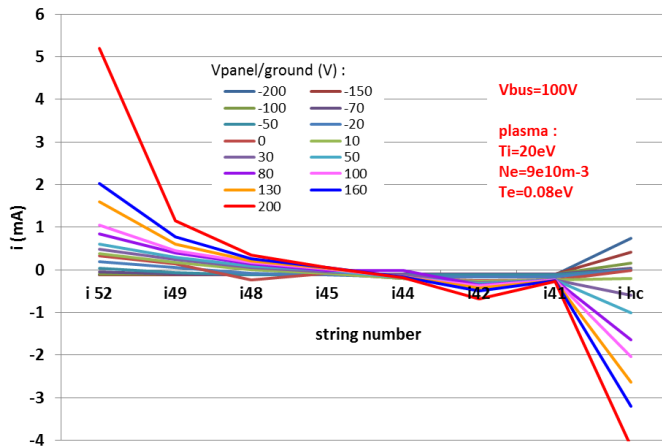


Fig. 22: collected current for each string function of  $V_{bias}$  (Setup 2)

## VI. DISCUSSION

These results are to be kept in their context that is with experimental conditions which are not exactly in-flight conditions, because the plasma source has a limited current capacity, because the wall chamber are closed to the solar panel, because we do not simulate the photoemission effect and, consequently of all these reasons, the actual surrounding electric field.

Nevertheless, once experimental conditions are taken into account, the results are showing realistic trends with a similar behavior of setups 1 and 2. Of course these results are depending on the technology (shape, materials,...) as measured by [2].

On Fig. 4, the floating voltage of the solar panel is shifted towards negative values, also noticed by [7], and the denser is the plasma, the more negative is the panel, as seen on Fig. 10 and Fig. 19.

On Fig. 5 to Fig. 8 for setup 1 and on Fig. 14 to Fig. 17 for setup 2, the snapover effect is observed as only few strings, surrounding the more negative strings, are participating to the plasma current collection.

The higher is  $V_{bus}$ , or the plasma density, the higher is the collected current as seen on Fig. 9 and Fig. 18.

When the panel is no more floating but biased at different values, Fig. 12 and Fig. 21 show that I(V) curves look like a Langmuir probe characteristic and the snapover appears clearly when  $V_{bias}$  is getting close to 200V (Fig. 13 and Fig. 22).

## VII. SUMMARY

In the frame of direct drive satellites development, we have studied the behavior of a high-voltage solar panel immersed in ionospheric and densified plasmas. The floating potential and the string collected currents of the solar panel are measured for different solar panel voltages and different plasma densities.

Two electrical layouts have been simulated, showing both a snapover effect, that is an increase of the plasma current collection by the most polarized strings.

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