FIRST RESULTS OF THE SILLAGE FLIGHT EXPERIMENT ABOARD SPOT-4

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Abstract

The French Earth-Observation spacecraft SPOT-4 was launched in 1998 in a low-altitude polar orbit. The orbit plane has a fixed direction with respect to the sun at the 10h30 local hour. SPOT 4 is "three-axes stabilized", which means that its orientation is fully controlled relative to three axes, with a side always in the wake.

Two voltage probes were aboard SPOT-4, one on the wake wall, the second one on the opposite face, on the ram side. Each sensor is an electrostatic voltmeter monitoring the positive or negative voltage of an insulated aluminum electrode with respect to the spacecraft main frame. The first objective of this experiment was appreciating the charging hazards on LEO orbits, especially when crossing the auroral zones.

Three kinds of profiles have been observed. At each output of eclipse, the ram probe becomes slightly positive as the result of a combination of the ion collection in the ram and photoemission charging when the sun illuminates the electrode. Some rare, short and low-differential-voltage charging events were observed while crossing auroral zones.

1. The SPOT-4 Spacecraft.

The satellite SPOT-4 was launched March 24, 1998 on a 98.7° inclination, quasi-polar orbit at 822 km altitude (at equator). SPOT is the French Earth-Observation program. A mission requirement is heliosynchronism. The descending node is at 10:30 am (sun local time) and the sun vector has a fixed angle on the orbital plane (figure 1).

The main payload of the spacecraft is a CCD push-broom camera, so SPOT-4 is three-axes stabilized, the velocity vector is fixed to spacecraft axes, one wall is permanently on the ram side, the opposite wall on the wake side (figure 2). The line of sight is the nadir direction. The design of the SILLAGE experiment ("sillage" is the French word for "wake") uses this specificity.

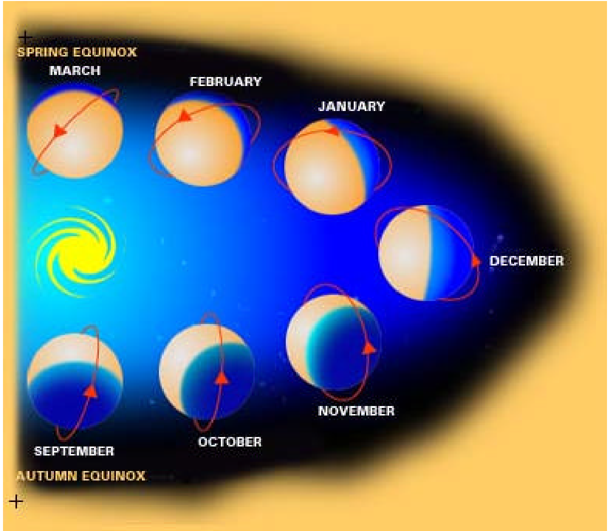

Figure 1 - Orbital plane of SPOT on six months

2. The SILLAGE payload

Charging events, experienced by several low-altitude polar orbit satellites, have been reported.

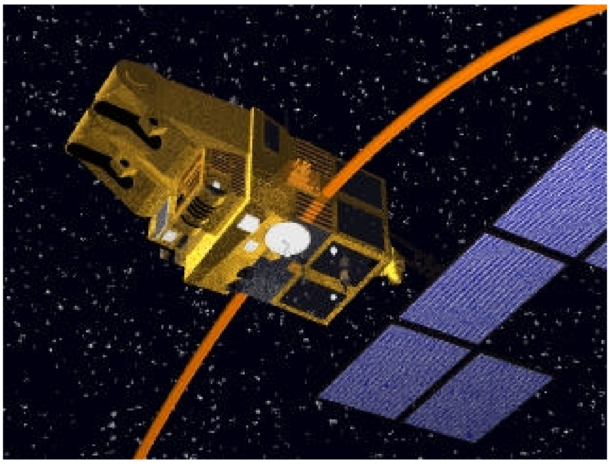

Figure 2 - Orbital configuration of SPOT-4
(the line represents the trajectory)

Some of them were instrumented with ion spectrometers: FREJA orbiting on the low-altitude interval 1000 to 1800 km or DMSP on the same orbit as SPOT.

Events always occur on the night side, when crossing the thin aurora zone where plasma density is deeply decreased during a particle precipitation. Moreover in a few cases, a discharge from an estimated 3 kV-differential voltage triggered resets an on-board computer of the DMSP satellites [1].

Figure 3 - Voltage probe on the wake side

Designed with mitigation techniques of geosynchronous satellites, added to the fact there is no internal charging at low altitudes, none of the four SPOT satellites experienced electrostatic discharges. To share between the roles played by technology and environment in this success, it was decided to implement surface voltage monitors on SPOT-4. As the worst case of differential charging was expected in the wake, a voltage probe was implemented on the backside wall (figure 3). For reference, an identical probe was set on the front side in the ram. This experiment is not science, only the measurement of the voltage build-up on a floating aluminum piece set on the external spacecraft surface. It is reduced at the minimum, there is no companion payload monitoring the environmental parameters, plasma density and flux. The voltage is measured in permanence and transmitted when crossing over a predefined threshold or on ground command.

3. Description of hardware

The probe was designed by SNECMA (formerly SEP, Société Européenne de Propulsion) under a contract of the European Space Agency [2]. It is a miniature voltage probe initially designed for measuring the surface voltage to ground of a solar cell. It vas modified for fixing on a wall, integrating a preamplifier (figure 4).

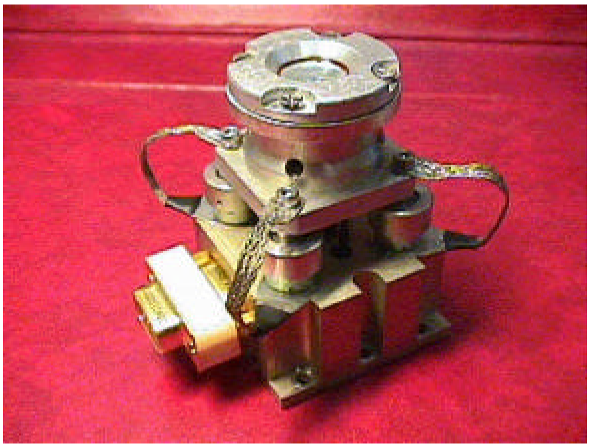

Figure 4 - Photograph of the voltage probe including the preamplifier, the 9-pins Sub-D connector gives the scale

The command and measuring electronic boards were designed at CNES. The principle of the probe is a variable capacitance. An aluminum electrode collects impinging charges from the environment. An underlying vibrating electrode is connected at the input of the preamplifier (figure 5). This electrode presents a variable capacitance with respect to the collector and to the ground. From the variable replacement current, a sine voltage, proportional to the static voltage of the collector, is present at the input of the preamplifier.

An electromagnet is generating the oscillation of the intermediate electrode (figure 6). The frequency was chosen at 517 Hz not to interfere with the main payload of the SPOT spacecraft, the CCD camera requiring high stability. Moreover, dampers isolate the probe mechanically from the spacecraft frame. The voltage range has been adjusted in the interval -4 to 4 kV with a sensitivity of 2 V, automatic polarity detection and range switching.

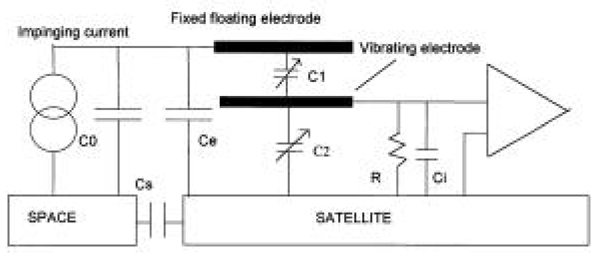

Figure 5 - Electrical scheme

There is one measurement per second for each probe. Due to the limited amount of on-board mass memory, a window of about 10 minutes has been allocated to this experiment every day. However for not missing a charging event, the voltage measurement is acquired an stored in permanence in a loop memory. When a measure is above a predefined value, storage is frozen 9 minutes later and transmitted to the spacecraft telemetry subsytem. This feature gives one-minute pretriggering capability and visibility to the actual beginning of the event. By reducing the time resolution and requesting more resources, data of a whole orbit was also available.

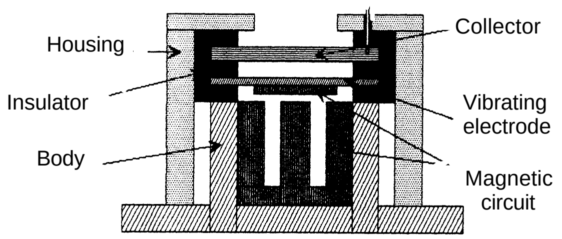

Figure 6 - Mechanical drawing

4. Flight data

In April 2001, more than three years of data have been accumulated showing three typical signatures.

4.1 Signature of quiet environment

Most of the time, there is a null collector voltage with respect to the frame reference. However, without any exception, at each revolution, the ram-probe exhibits a positive voltage roughly twenty minutes, the wake probe is remaining uncharged the whole orbit. On figure 7, four measurement sequences of the same revolution have been gathered with respect to the orbital angle from the ascending node.

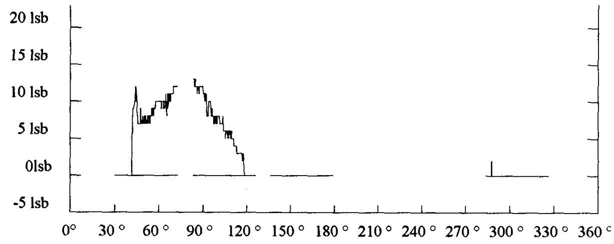

Figure 7 - Ram probe response

The collector voltage becomes positive with a fast rise time, there is a maximum by the north pole, a slow decrease to zero. The y-axis is graduated in "lsb", least significant digit of telemetry. Roughly, 1 lsb represents 1 volt. The voltage is measured with respect to the satellite ground, not to the plasma potential. As the solar array is positive (28 to 34 V, depending on the battery voltage), the voltage frame with respect to plasma potential is a few volts negative.

As it can be seen on figure 1, the ascending node is always in the night side (at local time 10:30pm). On the figure 8, the sunlight flux is drawn with respect to time, taking into account the earth shadow and the angle cosine between the sun direction and the collector surface. The x-axis is time, with the ascending node at about 5000 s.

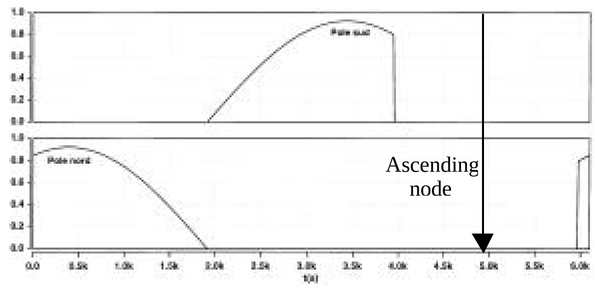

Figure 8 - Sun illumination of probes (wake probe, top view and ram probe, bottom view).

The ram probe voltage is in relation with the photoemission by the UV sunlight (mainly the Lyman alpha line at 10.2 eV) which makes the floating collector positive. There is no symmetry between both probes, the wake probe voltage stays to zero, even lightened. As the satellite velocity is larger than the thermal velocity of ions, positive hydrogen and oxygen ions are collected by sweeping, also participating to make the collector positive. This is not the case in the wake for there is a depletion of ion [3].

4.2 Signature of charging events

In some rare cases, we have observed other signatures, characterized by a positive or negative deviation from zero of the wake probe voltage, with a simultaneous positive increase of the ram probe voltage.

These events have always been very short, less than one minute and occurring in the auroral zones (figure 9).

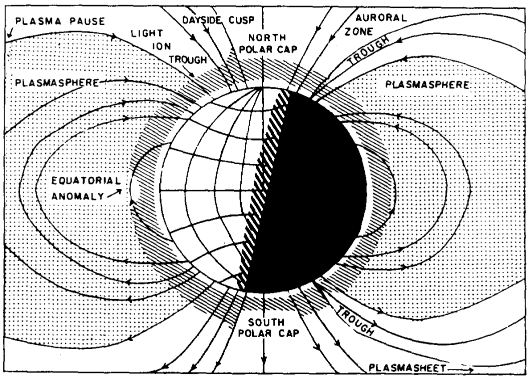

Figure 9 - Low-altitude magnetic and plasma earth environment.

On April 25, 1998, at 14:08 UT, an event occurred when the satellite was crossing the South auroral zone. Initially at a null voltage, both probes became positive (figure 10). This happened seven minutes after the maximum South latitude, at 14:01 UT. The calculated latitude is 65°S at the time of the event.

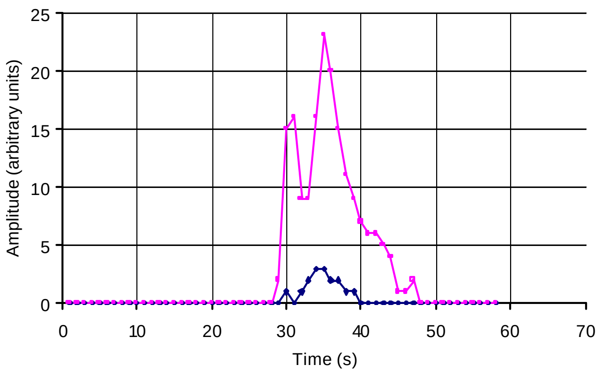

Figure 10 - April 25, 1998 event, South auroral zone.

We infer from both positive measurements that inside the auroral precipitation of electrons, the satellite frame builds up an absolute negative voltage. The wake probe collector can carry a positive charge due secondary electron emission and photoemission (near the South pole, the wake side is illuminated). Inside the precipitation, the secondary electron emission yield becomes more effective with increased energy of impinging electrons.

On May 2, 1998, at 09:08 UT, an event occurred when the satellite was flying through the North auroral zone, four minutes before the instant of maximum latitude. The event latitude is 76°N. As usual, in this zone, the ram probe voltage was positive around 10 volts while the wake probe voltage was zero. During 30 s, the ram collector voltage has become more positive and the wake side negative (figure 11). We infer that during the event, the absolute satellite frame voltage was more negative. The ram probe remained clamped on the plasma voltage while the wake probe collector was negatively charged by the impinging electron flux.

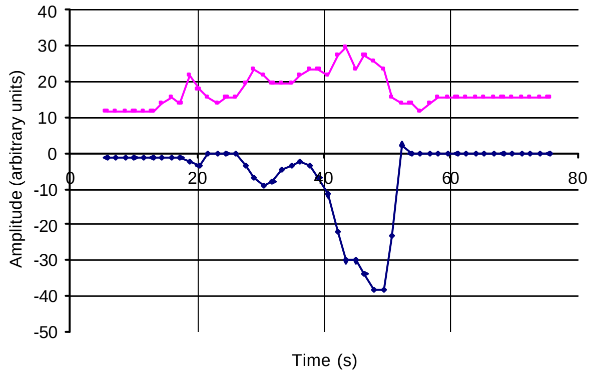

Figure 11 - May 2, 1998 event, North auroral zone.

5. Summary and conclusions

As expected, all charging events have occurred in auroral zones on the night side. The duration of events was always less than one minute. Any hazardous voltage has never been recorded in three years. These results confirm the fact that electrostatic discharges in LEO are exceptionally reported

References

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