LABORATORY GROUND SIMULATION OF GEO AND LEO ENVIRONMENT

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Abstract :

The geosynchronous electron environment is well known to induce surface as well as internal charging especially during magnetic active periods. In order to reproduce on ground, the charging phenomena observed in space, several experiments were developed at ONERA/DESP. These experiments deal with surface but also internal charging effects. The development of a good simulation facility has to be based on a reference spectrum. For this purpose, a "worst case" spectrum was produced based on the electron flux variability measured during more than one solar cycle by LANL geosynchronous spacecrafts.

1. Introduction

The geosynchronous electron environment is well known to induce surface as well as internal charging especially during magnetic active periods. Using more than one solar cycle measurements with LANL geosynchronous s/c the electron flux variability has been studied to define a worst case spectrum. Then to understand or prevent any s/c charging it is necessary to reproduce this harsh environment in laboratory. To do so several facilities have been developed at ONERA/DESP :

A dedicated facility "CEDRE" was constructed for the general purpose of electrostatic testing. It includes geosubstorm environment simulation and associated instrumentation for characterization of induced effects. Simulation of the electrons of the geo plasma is achieved by

In order to study surface and internal charging an electron source with a "space like" energy distribution in the range 10-400 keV was developed : "SIRENE" is dedicated to the study of voltage building on spacecraft dielectric materials and equipment samples for geostationary orbit, evaluation of materials properties and protections, characterization of discharges and measurement of natural and radiation induced conductivity of materials.

The facility which has been called "GEODUR" provides an extended energy range and realistic spectrum to simulate in the laboratory the worst case geosynchronous environments in terms of internal charging.

A satellite in geostationary orbit equipped with plasma thrusters has not only to be qualified for natural environment but also thruster induced artificial environment. For this purpose and to study interaction between in-flight equipment and ionospheric plasma in case of LEO orbits, a large chamber JONAS was developed. The chamber can support either a ionospheric plasma source or a Stationary Plasma Thruster SPT-50. Surface charging electrons (5-40 keV) and compensation of earth magnetic field are also available.

2. Worst case spectrum definition

Continuous electron measurements at geosynchronous orbit are now available since year 1976 at Los Alamos National Laboratory (LANL). The energy range extends from 30 keV to 2 MeV on spacecraft with CPA detector on board (launch before 1987) and from 50 keV to 1.5 MeV on spacecraft with SOPA detector on board (launch after 1989) with a time resolution of 10 seconds [http://leadbelly.lanl.gov/lanl_ep_data/]. Based on this data set we investigate on determining a worst electron spectrum that can impact a spacecraft during a geomagnetic storm and induce spacecraft charging.

First, all the data coming from different spacecraft have been cross-calibrated owing to overlaps in time from one satellite to the other whereas absolute values are deduced using CRRES MEA measurements [Vampola et al., 1992] during a conjunction between CRRES and LANL 1984-129 on September 3, 1990.

Then scanning all measurements year by year we have looked at the flux variability as a function of the solar cycle. The maximum flux values for 30, 250 and 1000 keV electron recorded over each year is reported in Figure 1. It is found that hard spectrum are more likely encountered during the declining phase of the solar cycle. This is consistent with the occurrence of high speed solar wind stream events due to coronal holes. It is now well known that such events are very effective to produce high electron flux levels in the MeV range [Baker, 1986; Reeves, 1998] for time as long as two weeks.

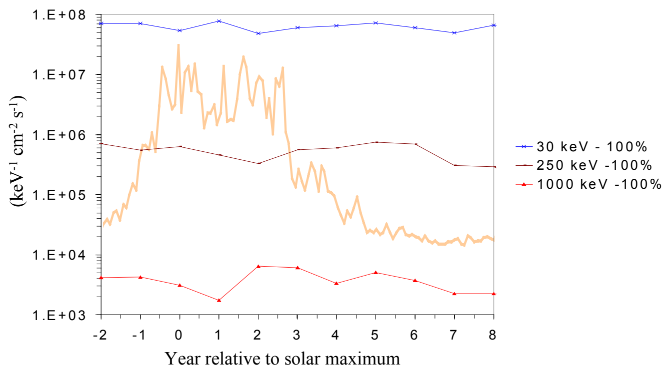

figure 1 : Instantaneous maximum flux over each year as a function of solar cycle for 30, 250 and 1000 keV electrons.

From this result we deduce a worst case that can be encountered by a satellite at geosynchronous orbit. The highest and lowest flux levels for most energies over one solar cycle are respectively found 5 and 7 years after solar maximum (Figure 2). A factor on the order of 3 is seen between year 5 and 7 in the maximum flux values. This new worst case model (year 5) is compared with three other spectrum, denoted as Scatha 22 September 1982 [Reagan, 1983], Kp >5 [ESA contract] and NASA suggested worst case [NASA HDBK, 1999]. Scatha 22 September spectrum was only available for surface charging which can explain the large differences at high energies. But the other models are all close to ours, especially at high energies, the differences being due to calibration procedure. Superposed on these curves are plotted the intensities we can reproduce on ground simulation to study spacecraft charging effects.

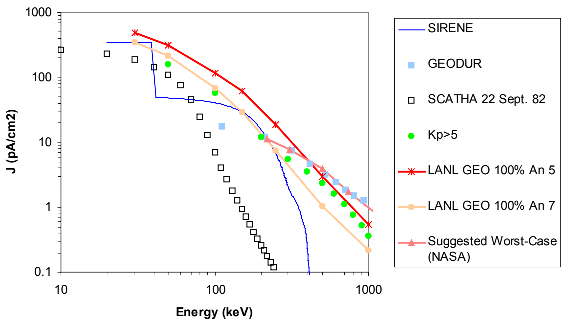

figure 2 : Comparison of the spectrum defined with our method and 3 other models – superposition with experimental SIRENE and GEODUR spectra

3. High energy experiments relevance

The purpose of this paragraph is to demonstrate the pertinence of experiments with extended sources. For this purpose, we present two experiments performed at ONERA/DESP :

First example concerns the comparison of two experiments performed on the same sample of kapton 25µm irradiated either with a monoenergetic source of 30 keV electrons or with a polyenergetic source 30-220 keV (old experiment SIRENE).

A schematic view given the principle of this experiment is presented on figure 3.

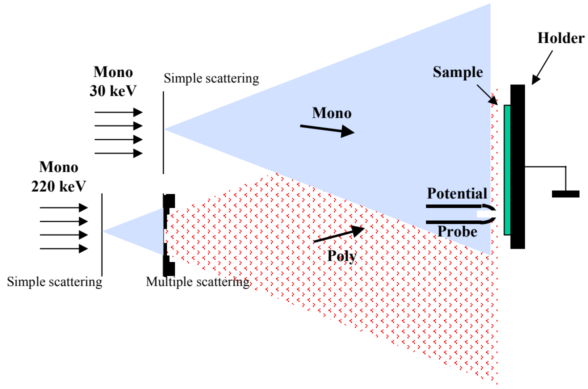

figure 3 : Principle of old-SIRENE experiment

Let's compare the results obtained on this sample with both irradiation types (see figure 4).

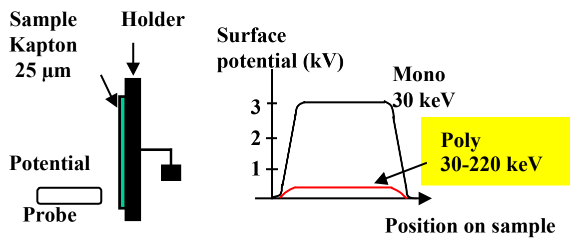

figure 4 : Irradiation of a kapton sample with 300 keV electrons or an extended source 30-220 keV

The result shows that a kapton sample (25µm) submitted to a monoenergetic beam of 30 keV electrons can reach a surface potential of 3 keV.

The same sample under the polyenergetic beam 30-220 keV never attains this level of charge. This can be explain by the phenomenon of conductivity induced by radiation (R.I.C.) since the monoenergetic beam induces only surface charging and the polyenergetic beam is responsible to a R.I.C. all through the sample.

The second example concerns an experiment performed on 2 Teflon samples. These samples were supposed to have the same thickness (125 µm) . Nevertheless, their behaviors under polyenergetic electron beam radiation were totally different as it can be seen on figure 5.

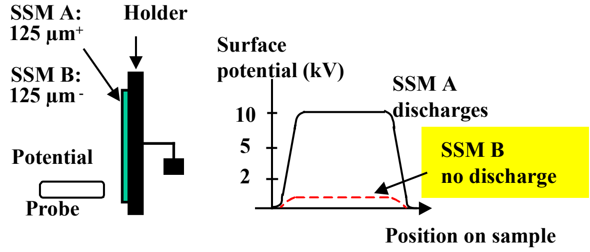

figure 5 : Irradiation of two Teflon samples with an extended source 30-220 keV.

Since, one sample (A) saturated at a potential of 4 keV and did not develop any discharge, the second one (B) reached 10 keV of surface potential with occurrences of discharges on the surface. A more precise measurement of the samples thickness showed that sample A was slightly thicker that sample B. Again, Radiation Induced Conductivity explain these different behaviors : Since, the penetration depth of these electrons was very close to their thickness, one (sample B) had R.I.C. all trough it and the other one (A), presented a R.I.C. on a part only of it thickness.

These two examples show the relevance of the development of large energy range experimental means able to perform deep internal charging. They are at the origin of development of a new experiment called SIRENE (new version). This experiment will be presented in the following with other set-up developed at ONERA/DESP. These set-up allow to cover a large range of charging effects from surface to internal charging.

4. SIRENE

As it was shown before, there is a large interest in developing experiments on a large range of energy.
The objective of the new experiment called “SIRENE” is to cover an energy range of few keV to 400 keV.
This is done with two radiation sources : a low energy (E≤35 keV) electron gun and an accelerator Van de Graaff producing electrons of 400 eV. The monoenergetic beam given by this accelerator is scattered by a complex diffusion foil. This complex diffusion foil was defined knowing the fluxes transmitted by simple foils of different thickness. The analysis of transmitted fluxes was performed with a specific detector ERMD (EPIC radiation Monitor Detector) given by the CESR (Centre d’Etude Spatiale des Rayonnements).
The figure 6 shows a photograph of this set-up.

figure 6 : photograph of “SIRENE” experiment.

Concerning the sample holder, its capacity is 25 x 25 cm² with a temperature range of -100°C/+100°C. The characterisation of experiments is given by photography, current probes and voltage probes.

A good complement of this experiment is GEODUR set-up whose energy range is 200 keV- 1MeV. Both spectra of SIRENE and GEODUR are given on figure 2 and compared with different models.

5. GEODUR

The experimental facility GEODUR presents the following characteristics :
- Sample holder large enough to accommodate several samples simultaneously.
- Reference environment : this is either a "space like" electron source (selected as being known to have produced internal charging/discharging problems in space) in the energy range from 200 to 1000 keV, or a classical monoenergic beam (few tens of keV).
- Surface potential and current measurement, discharge detection capability.

The extended energy range is obtained with a Van de Graaff 2.7 MeV electron accelerator followed by a double scattering system.
The figure 7 shows a photograph of the experiment.

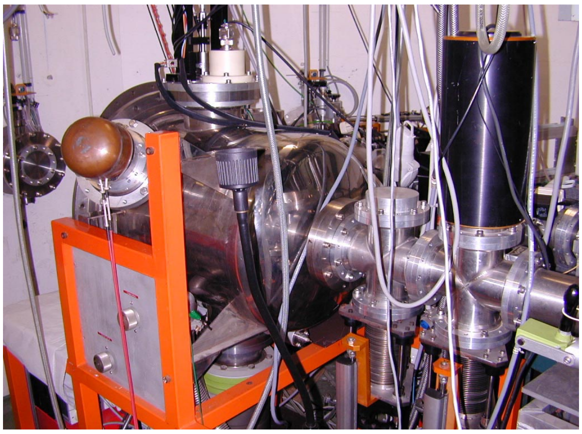

figure 7 : View of GEODUR experiment

Two examples of experiments have been selected to illustrate again the phenomenon of Radiation Induced Conductivity (R.I.C.). They deal with charging of Teflon and Epoxy precharged with a monoenergic electron beam of 20 keV and irradiated with the extended source of GEODUR. Concerning the Teflon, two kinds of samples were tested (190 and 350 µm). As it is seen on figure 8, the phenomenon of induced conductivity is very important since the resistivity is reduced by radiation with 3 orders of magnitude.

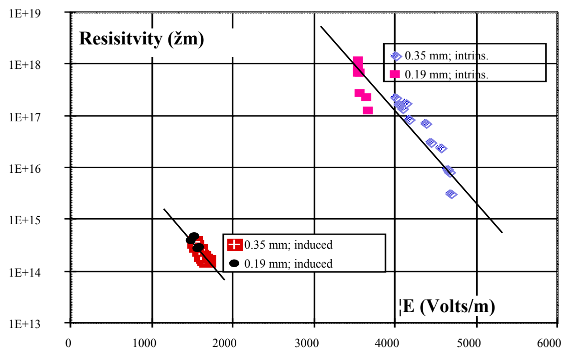

figure 8 : Intrinsic & R.I.C. on Teflon precharged with 20 keV (intrinsic) and 10^{12} é/cm^2 GEODUR (rad; ind.)

The sample of Epoxy tested (325 µm) in the same configuration (see figure 9) does not behave the same way and the induced conductivity is not as spectacular as for the Teflon samples.

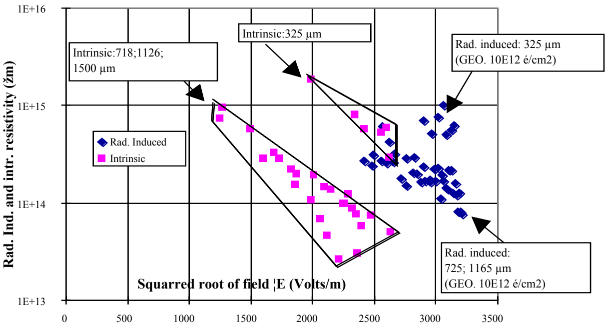

figure 9 : Intrinsic & R.I.C. on Epoxy precharged with 20 keV (intrinsic) and 10^{12} é/cm^2 GEODUR (rad; ind.)

The previous experiments dealt mainly with internal charging and Radiation Induced conductivity. We wanted to complete this paper with other aspects of charging problems. To answer to the problems of surface charging, an experiment called CEDRE was developed. It will be presented in the next part followed by the chamber JONAS devoted to ionospheric plasma simulation but also to the study of interactions between the plasma thruster plume and s/c equipment.

6. CEDRE

The CEDRE simulation facility was specially designed for carrying out ESD studies. The charge state configurations simulated were representative of those found in space and the instrumentation is particularly well-suited to measuring the charge potential profiles induced by the irradiation and to detecting the discharge transients.

The leading characteristics of this facility are as follows:

- the residual pressure in the chamber during the experiments is of the order of 10^{-6} hPa,
- the electron beam reproduced is quasi monoenergetic, the energy can be varied between 5 and 40 keV and the flow between 0.05 and 10 nA/cm²,
- it is also possible to obtain electron irradiation with an Sr90 radioactive source,
- the rotating cubic specimen holder can receive specimens with maximum dimensions of the order of 20x20 cm² on three of its faces, one of which is heat-regulated between -180 and +120°C,
- the discharge transient signals are detected by a current probe with a pass-band of 300 MHz, the signal is recorded by a digital oscilloscope at a sampling frequency of 1 GHz,
- specimen geometry permitting, the profiles of the surface potential induced by the irradiation can be defined by means of a probe shifting a few mm from the surfaces being explored within a range comprised between ± 20 kV,
- the probe's movement range in front of the heat-regulated face is of the order of 12 cm.

The following measurement means are provided :

- surface potentials or surface potential profiles
- discharge current transients,
- location of discharges (by photographs and video camera)
- light spectrometry (to identify vaporized species)

A photograph of the experiment is shown on figure 10.

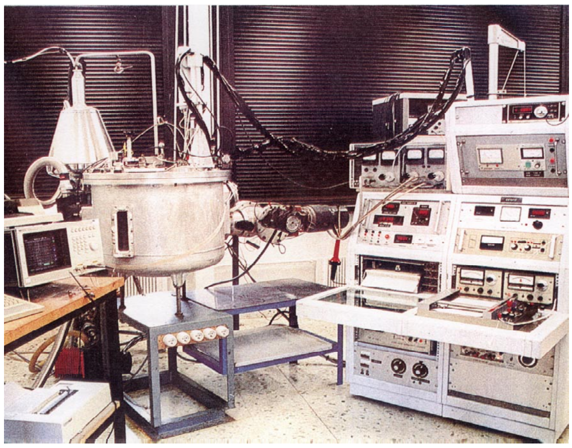

figure 10 : CEDRE experiment.

No example of experimental results are given in this part and the reader is invited to refer to two other papers presented during this conference [Levy, 2001] and [Amorim, 2001]. On these papers, the tackled subject is secondary arcs on solar arrays which is one of the main activity developed recently with CEDRE.

7. JONAS

The last experimental mean presented here is called JONAS. This vacuum chamber is quite large with a length of 3 m and a diameter of 1.85 m (see figure 11). It is built with a non-magnetic stainless steel envelope. A set of several Helmoltz coils is used to compensate the terrestrial magnetic field (with a working volume of 1,5 m3) or to add a known magnetic field in a given direction.

A cryogenic pumping system allows the internal pressure to reach 2 10^{-8} hPa after 15 hours. With the SPT-50 plasma, the pressure is around 4 10-5 hPa. In the configuration of thruster plasma experiments (with internal chamber protections and with SPT-50), the residual pressure is from 1 to 5.10^{-7} hPa.

The chamber is equipped with a plasma thruster SPT-50 built by MAI (Moscow Aviation Institute) Laboratory. In order to limit erosion and contamination problems of the chamber JONAS usually used for ionospheric plasma simulation, internal walls are protected by aluminum foils giving a "second skin" to the chamber.

figure 11 : JONAS experiment.

8. Conclusions

The ONERA/DESP has developed a complete set of activities around space charging. In one hand, the method to define a "worst-case" spectrum has been developed and shown here. In an other hand, the experiments reproducing "space-like" spectra were presented. This complete method enhance several points :

- The interest of define as precisely as possible worst case spectrum which can be used as a reference in the development of on-ground experiments.
- The relevance of extended sources experiments in order to reproduce in-flight surface and internal charging phenomena.
- The pertinence of these experiments in the enhancement of phenomena such as radiation induced conductivity.

References :

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