CHARGING OF COAXIAL LINES WITH FLOATING CORE AT GEOSYNCHRONOUS ALTITUDES

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ABSTRACT : For telecommunication satellites, RF equipment switching can lead to coaxial cables electrically floating. In a geostationary orbit, space environment can charge floating cables to potentials as high as some tens of volts. With switches, the charge stored on the core flow out and the generated current can trigger interference or damages on MOS transistors.

This paper deals with experimental results at electrostatic behaviour level for such cables under electron irradiation. Two coaxial cables used in satellites (an overshield brand of 7 coaxial cables and a cable connected to a switch) are irradiated by an electron beam source simulating geostationary orbit equivalent energy range and flux intensity. During these experiments, we monitored the current collection and the voltage gained on core and/or cables shielding after their irradiation in order to evaluate the probable occurrence of an electrostatic discharge.

1 - INTRODUCTION.

This chapter is aimed at presenting experimental results for the electrostatic behaviour of coaxial lines. Several cables samples, usually used onboard geostationary spacecraft, were submitted to high energetic geostationary representative flux levels. Floating core and/or floating shield voltage, current collected on core and shield and ESD transients were measured to evaluate risky events on electronics.

All the tests hereafter presented were performed in GEODUR vacuum chamber implemented at ONERA DESP (space environment department) in Toulouse, France.

This test facility is capable to reproduce the penetrating electrons of the charging space environment thanks to a high energetic electron gun. Measurements of typical features as voltages on surface and transient currents are possible.

2 - ESD TEST SET-UP ON COAXIAL LINES WITH FLOATING CORE

2.1 - DESCRIPTION OF THE GEODUR FACILITY

The vacuum chamber is cylindrical and connected to a 2.7 MeV Van de Graaff accelerator used as an electron source. The delivered beam has an energy range distributed between 0,2 and 1MeV behind an aluminium diffusion foil. The maximum flux is around 50µA.

The functioning threshold pressure is about 10^{-6} hPa.

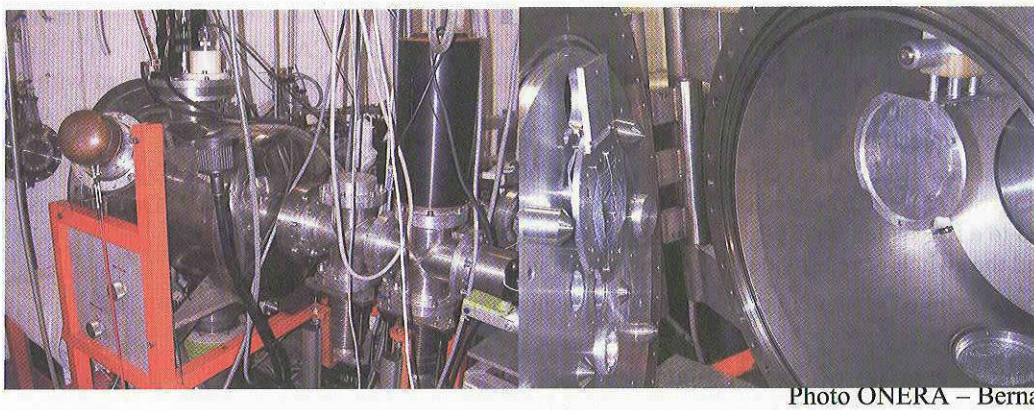

Photo ONERA – Bernard Dirassen

Figure 1 View of the GEODUR facility.

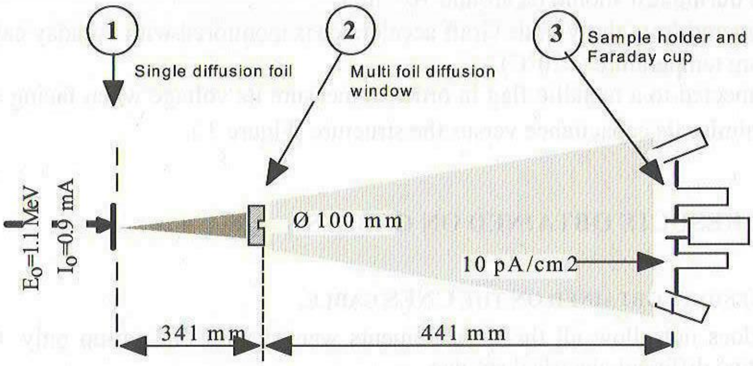

Figure 2 GEODUR Schematic set-up

2.2 - Description of the studied câbles samples

Inside the chamber, a voltage probe allows to measure voltages profiles on a vertical axis, in the range ±20 kV. Current probes are implemented in order to measure discharge transient current. The irradiation current is monitored around the samples-holder thanks to five Faraday cages.

Instrumentation implementation is showed on Figure 3.

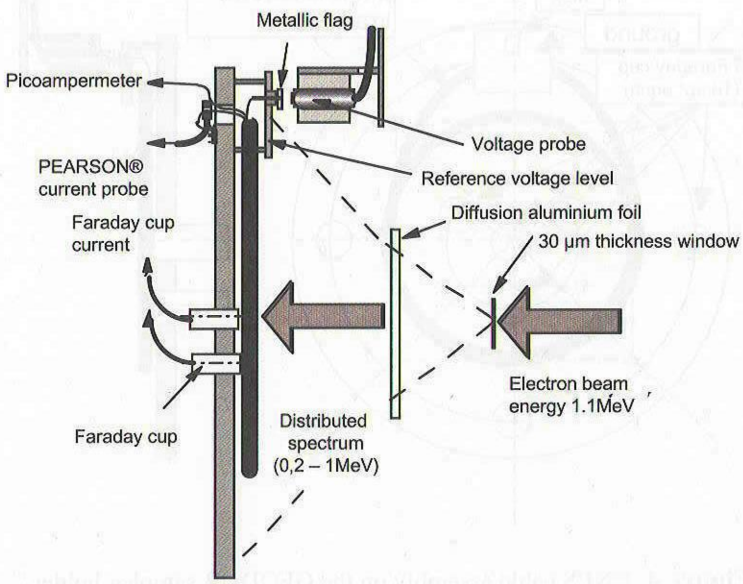

Figure 3 : Schematic view of the instrumentation around the GEODUR sample holder.

Two kind of coaxial lines were tested.

⇒ A cable strand referenced P/N 167.2896 HIGH VOLTAGE COAXIAL CABLE TYPE "L" of 1.5 m length. It is made of 6 coaxial cables distributed around a seventh middle one. This strand is overshielded with an aluminium foil. Each coaxial has is own metallic shield. This strand was developed at CNES in the frame of SPI (Integral Spectrometer) project. In this paper this strand will be refered as "CNES cable".

⇒ A high reliability RADIALL cable referenced R286.000.600, LOT/N°SERIE 9618 RAD 001 of 1 m length, with two ending SMA (RIM) connectors. This cable will be called "RADIALL® cable". During tests, the cable is connected to a RF-switch type T.

The cable and the switch were provided by Alcatel space in Toulouse.

Each sample was studied separately in the GEODUR vacuum chamber.

2.3 - General experimental Procedure.

Common experimental procedures for the tests are the following:

- a minimum of 3 days in vacuum is necessary before each experiments to let materials outgassing
- The residual pressure during test should be around 10^{-6} hPa,
- The electron flux delivered from the Van de Graff accelerator is monitored with Faraday cage,
- Tests are made at room temperature (≈20°C).

Each cable core was connected to a metallic flag in order to measure its voltage when facing a voltage probe. The flag has been designed to minimise its capacitance versus the structure (Figure 3).

3 - EXPERIMENTAL RESULTS OBTAINED ON CABLES

3.1 - Experimental results obtained on the CNES cable.

The strand complexity does not allow all the measurements wanted with one set-up only. Consequently, tests were made in two steps, with two different electrical set-ups.

3.1.1 - *Cable mechanical assembly in the vacuum chamber.*

The CNES cable assembly on the samples-holder is showed on Figure 4 . This cable is fixed on the support in two flat loops and electrically isolated from it. The irradiated length is about 1.30m and the two endings are protected from the irradiation beam.

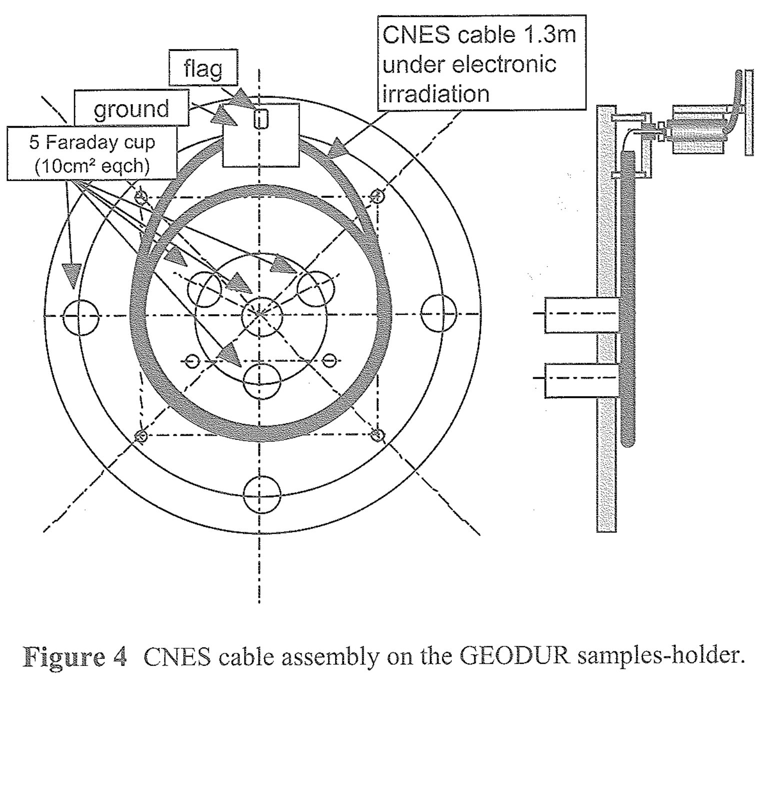

Figure 4 CNES cable assembly on the GEODUR samples-holder.

3.1.2 - *Cable electrical assembly on the sample-holder.*

The electrical set-up and associated measurements probes (current and voltage) are showed Figure 5 .

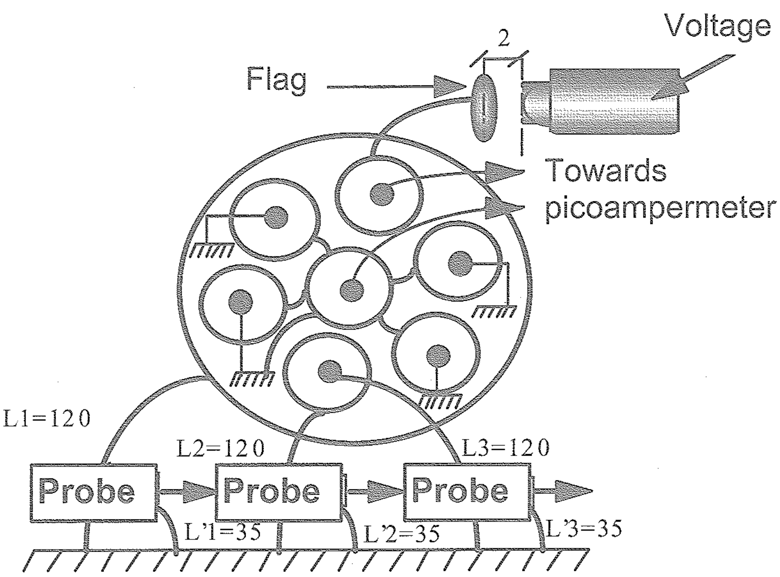

Figure 5 CNES cable and its associated measurements set-up.

Electrical connections for this set-up are the following:

- Core of the axial coaxial is connected to a pico-amperometer (n°2), its braid is connected to the ground.
- The core of one of the external (peripheral) coaxial cable is connected to a pico-amperometer (n°1), its braid is connected to a flag facing a voltage probe.
- The core of another external coaxial cable and its braid are connected to the structure through two Pearson® probes.
- Cores and shields of all others external coaxial lines are connected to the structure.
- The aluminium rubber wrapping and shielding all the lines is connected to the structure through a third Pearson ® probe.
- Wire lengths are in mm on figure Figure 5 .

3.1.3 - *Experimental results*

3.1.3.1 - Current measured on the different core during irradiation.

Measured current flux on peripheral and axis lines versus different irradiation (from 10 to 60pA/cm$^{2)}$ are reported in table above, (Figure 6)

Irradiation flux on CNES cable in pA/cm^2				
Distributed electrons spectrum from 0,2 to 1MeV	10	20	40	60
Courant measured on core of the peripheral coaxial line (in pA : pico-amperometer n°1)				
Floating braid facing a voltage probe	43 pA	85 pA	160 pA	220 pA
Current maesured on core of the central coaxial line (en pA, pico amperometer n°2)				
Grounded braid	1 pA	3 pA	4,8 pA	6 pA

Figure 6 Measured current flux on core of peripheral and axis lines versus electron irradiation.

3.1.3.2 - Voltage measured on external coaxial braid.

Figure 7 & Figure 8 show registered potential variations on the braid of an external coaxial line versus irradiation fluxes. Voltages under irradiation flux (10 and 20 pA/cm2) are registered after 3 hours, 3 days or 5 days of outgassing in vacuum (Figure 8).

These cycles indicate that;

- After 3 free outgassing hours, the voltage seems to be stabilised at -100 volts, under a 10pA/cm² irradiation flux.
- After 3 free outgassing days, the voltage reaches -1100 volts, under a 10pA/cm² irradiation flux and does not seem to be steady. Voltage relaxation versus time when irradiation is stopped shows a decrease from -1100 volts to -500V in 180 min.
- After 5 outgassing days, voltage reaches -1300 volts in 60 min, under a 20pA/cm² irradiation flux. Electrostatic discharges are observed when the voltage crosses -1450 volts.
- After the first Electrostatic discharge, when irradiation in the same conditions, -2000 volts are reached in 120 minutes. During relaxation, voltage decreases of 600 volts in 120 minutes.

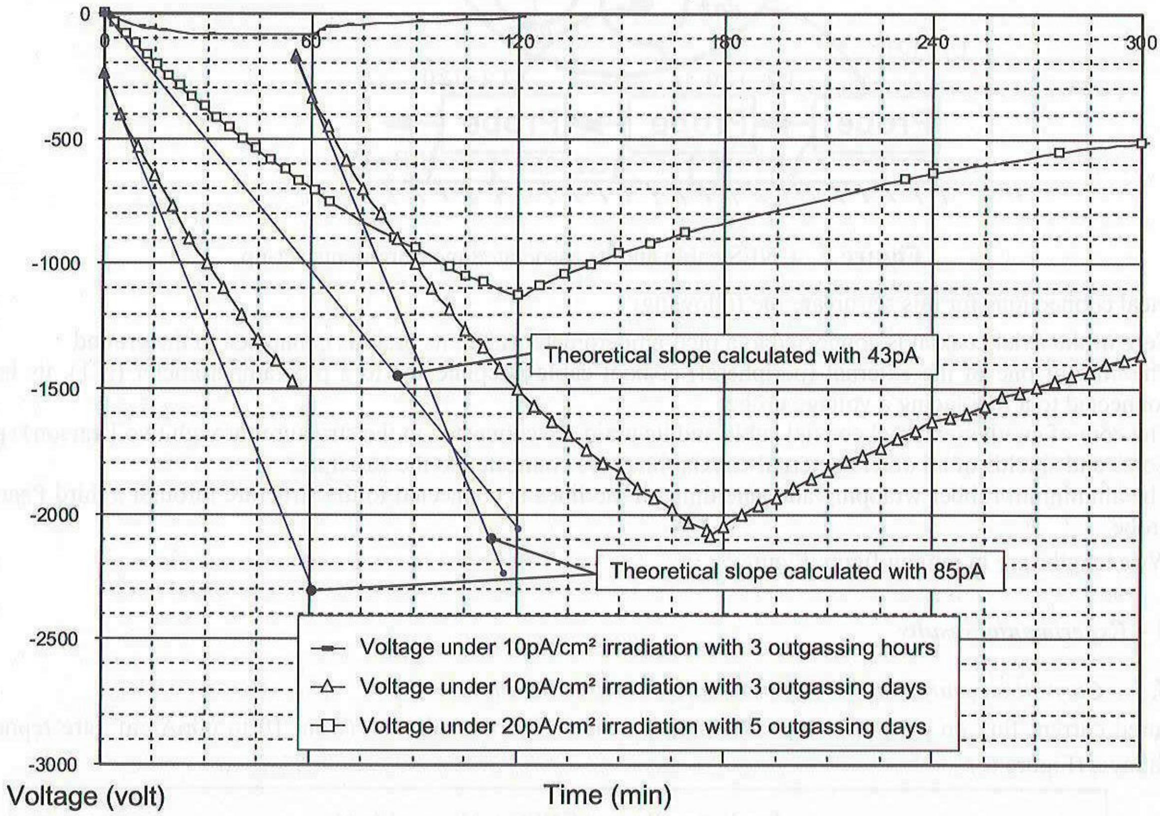

Figure 7 Braid voltage of an external cable under electron irradiation (10 and 20 pA/cm^2) versus time.

Voltages registered correspond to the charge of the coaxial capacitance (around 100pF/linear meter) under the current measured on the picoampermeter when the core is connected to the structure. It means that when dielectric around the core stores charges, the core sees a balance current which is the same as the one measured on the core with a picoamperemeter when connected to the structure.

$$V = \frac{i}{C} t(in\, s) = \frac{i}{C} \bullet 60t(in\, \min) \text{ with C=150pF}$$

Slope with 43pA $\Delta V = \dfrac{43pA}{150pF} \bullet 60 \bullet 120 = 2064\ Volts$

Slope with 85pA $\Delta V = \dfrac{85\,pA}{150\,pF} \bullet 60 \bullet 60 = 2040\,Volts$

These two slopes have been drowned on Figure 7 where we can see that it is in good agreement with measurements (in any case it is in the frame of the measurement uncertainty).

Registered voltages after 4 and 5 free outgassing days under 40 and 60pA/cm² are showed on figure Figure 8 . During these experiments, we found the following results:

- After 4 free outgassing days, -2400 volts are reached in 80 min under a 40pA/cm² irradiation flux. At this voltage level, electrostatic discharges are registered. The voltage goes back to +250 volts after discharge.
- When irradiation restarts after the discharge -2600 volts are reached in 105-min. 120 min of relaxation bring the voltage from -2600 volts to -1800 volts.
- After 5 free outgassing days, voltage reaches -2400 volts in 50 min under a 60pA/cm² irradiation flux. At this voltage level, discharges occur bringing the voltage back to +100 volts.
- Other electrostatic discharges are registered when the voltage reaches again -2400 volts after 55-min irradiation with the same flux. Residual voltage after discharge is about -100 volts.

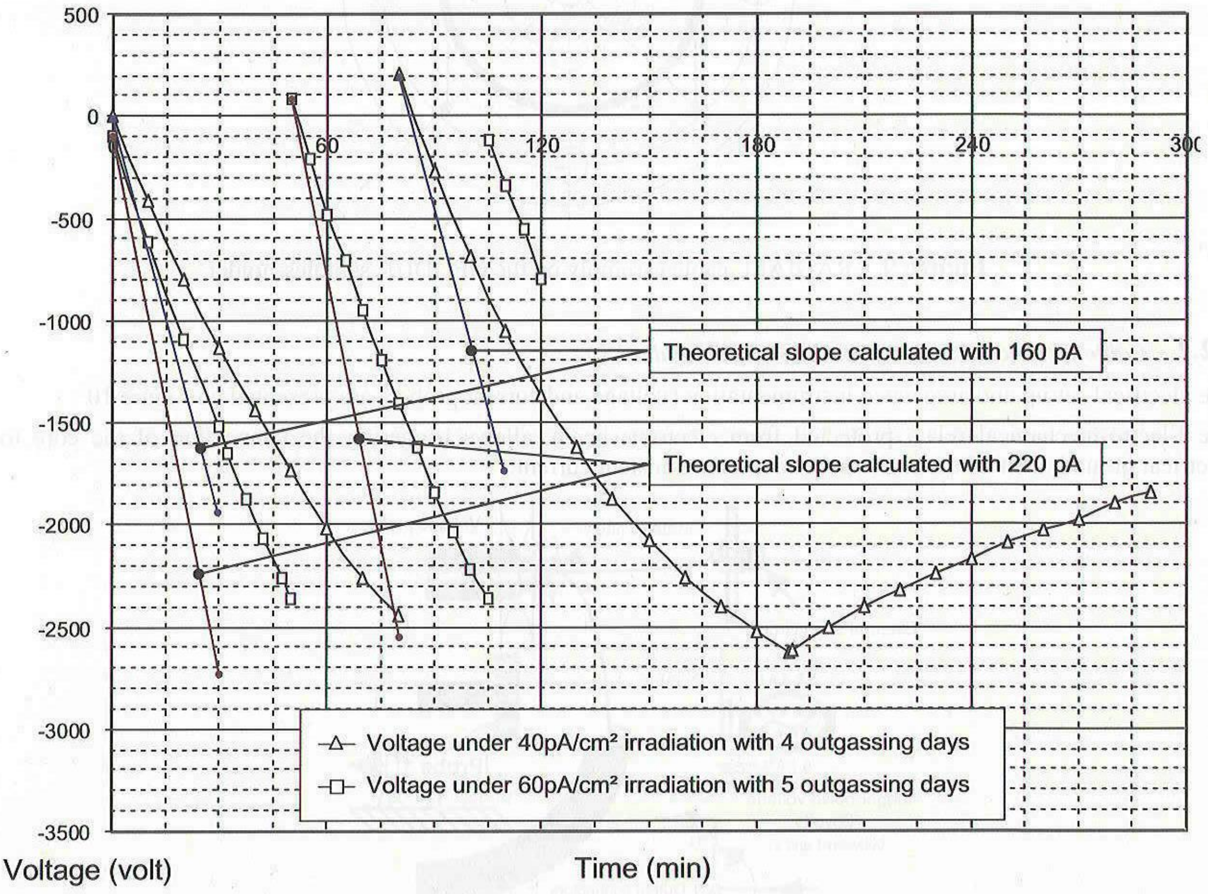

Figure 8 Braid voltage of one peripheral coaxial line under 40 and 60 pA/cm^2 irradiation fluxes.

Slope with 160pA $\Delta V = \dfrac{160\,pA}{150\,pF} \bullet 60 \bullet 30 = 1920\,Volts$

Slope with 220pA $\Delta V = \dfrac{220\,pA}{150\,pF} \bullet 60 \bullet 30 = 2640\,Volts$

Here also, the two slopes have been drown on Figure 8 and are in good agreement with measurements.

3.2 - EXPERIMENTAL RESULTS ON RADIALL CABLE

3.2.1 - *Cable mechanical assembly in the vacuum chamber.*

The mechanical assembly of the RADIALL® cable on the GEODUR sample holder is shown on Figure 9 . This one loop cable is lying flat on the sample-holder where 0,70m cable length is under irradiation. SMA End connectors are protected from irradiation beam.

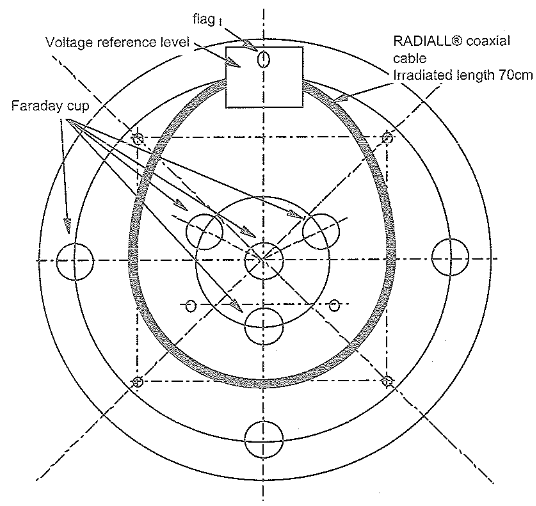

Figure 9 : RADIALL cable assembly on the GEODUR samples-holder

3.2.2 - *Cable electrical assembly on the sample-holder.*

The electrical set-up and associated instrumentation (voltage and current probes) are presented on Figure 10 .

The Electro-mechanical relay, protected from electrons beam, allows triggering the connection of the core to the electrical ground, then a Pearson® probe measures transient current.

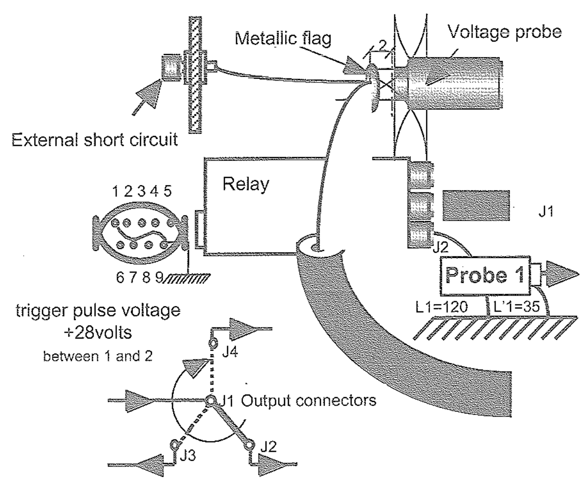

Figure 10 RADIAL® cable set-up with its associated instrumentation.

Electrical connections are the following:

- Shielding braid is electrically connected to ground through J1 relay output.
- Coaxial line core is connected, at one end, to a metallic flag facing a voltage probe and can be, at the other end, connected to ground when switching the relay.
- Cable core instrumentation can, like this, allows both voltage measurement when the switch is off and transient current measurement when the relay is switched.

All lengths are in mm in Figure 10 .

3.2.3 - *Experimental results*

3.2.3.1 - Voltage measured on the different core during irradiation.

Core voltage changes versus time under a 40 pA/cm^2 irradiation flux are presented in 0. Transients are registered after 4 free outgassing days.

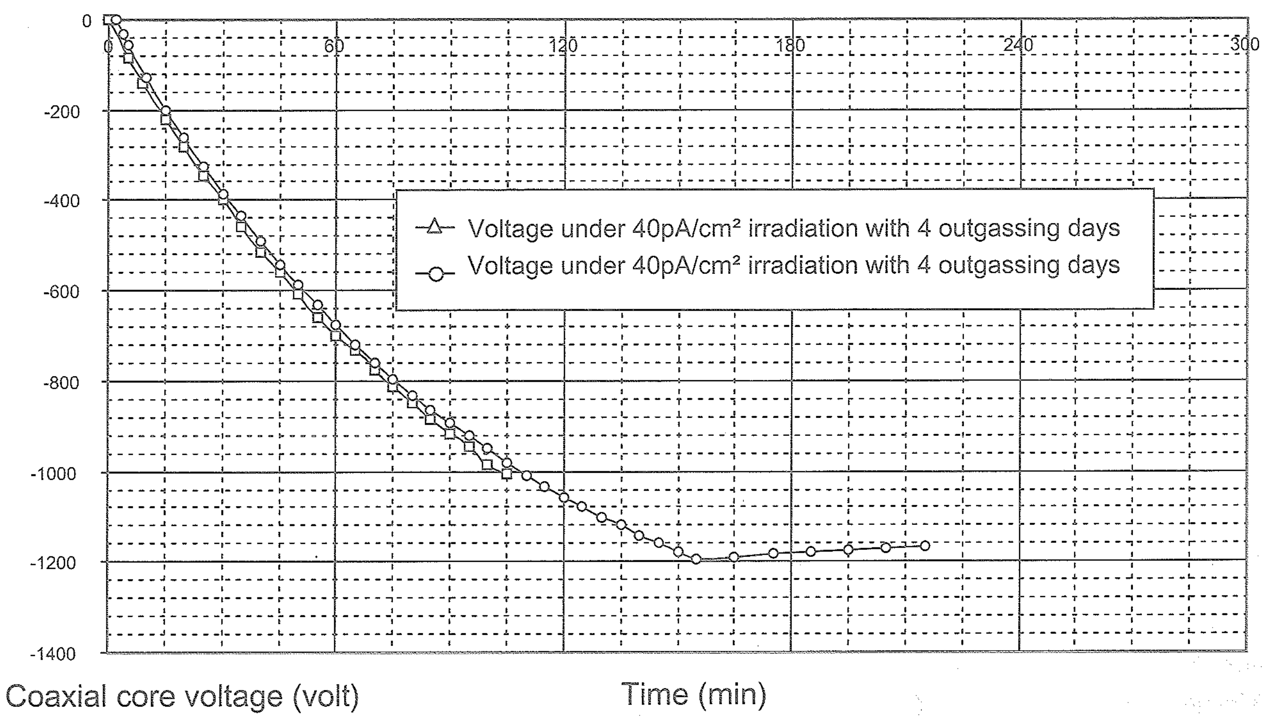

Figure 11 Core voltage variation versus time under a 40 pA/cm^2 irradiation flux Radiall® coaxial cable.

3.2.3.2 - Discharge measured.

After 2.5 hours irradiation, the voltage is around -1200 volts. The relay that allows connection between the cable core and the ground through a Pearson probe is switched at -1000 V threshold level. A current obtained during one of these commutations is shown on Figure 12 . One can see on this figure that this transient current lasting 250 ns is oscillating between + and – 8 amperes. After each switch, irradiation induces exactly the same voltage slope (see 0) and transient currents (see Figure 12).

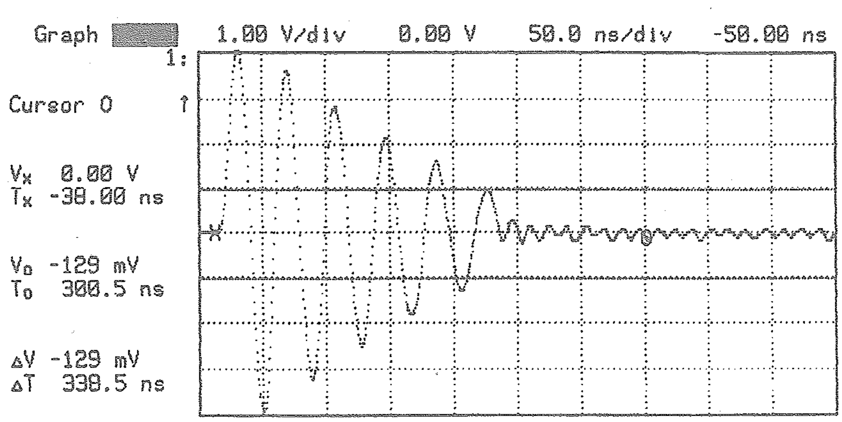

Figure 12 Current transient monitored on a Pearson probe during a discharged triggered when switching relay (charging potential: -1000V – probe transfer function 1V=2A).

4 - STUDY RESULTS SYNTHESIS & CONCLUSION

From the experimental results on CNES and radial cables

A few peculiar points have to be underlined

- During the irradiation, electrons are not directly collected on the cable core but all around in the dielectric
- The preliminary outgassing period affect significantly voltage levels.
- Core registered currents during irradiation depend strongly on the connecting mode of the shielding (floating or connected to the ground). In fact when the shielding is connected to the structure, electrons flow more easily to the structure and the capacitive influence between electrons embedded inside the dielectric and the core is lower than when the shielding is not connected to the structure. Thus current collected on the core and voltage are higher.

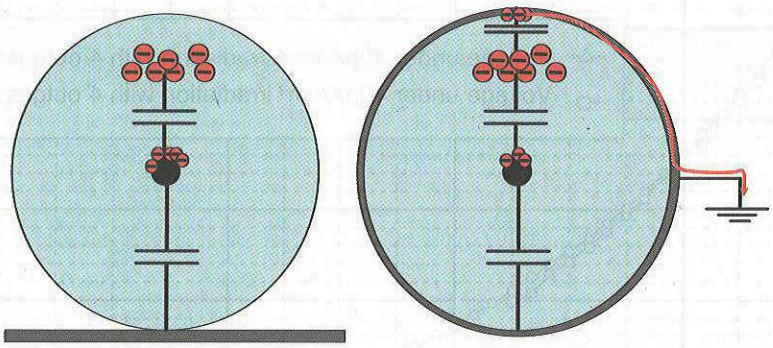

Figure 13 Influence of the shielding connection to the structure.

In the best electrical configuration, where the shielding is at the ground, the voltage reached by the core is yet critical (this measurement configuration has not been reproduced in this article). Hence for a 40pA/cm²flux a -320 V voltage is measured on CNES cable whereas it reached –1200 V for Radiall® cable.

With just a few hours of orbital position cables are exposed to the stringent conditions.

The interpretation of these results must consequently be rather considered as: to make representative testing of what happen under orbital conditions it is mandatory to let the cable under testing being largely enough outgassed to promote worst conditions of measurements that could have been otherwise let on seen.

The shielding connected mode deeply influences the current level on the core during irradiation.

So far on RF cables used between switches need for charge collecting resistors on each cable that could temporarily be floating along with the commutation schemes.

In the same way, a satellite for which operators would change the orbital position (for example, the satellite has been sold to an another country or when there is operational changes or for maintenances reasons or when switching on redundancy or to be furtive and so on), coaxial cables cores always must be connected to the structure through a bleeder resistor. Otherwise, even in the case where coaxial cores have been let ungrounded during some few minutes only, switching will induce damageable transient current for electronic device connected to.

5 - REFERENCES

[1] R&T CNES – Etudes de structures polarisées ou chargées en présence de plasma. Etudes de phénomènes d'arcs déclenchés en orbite. RF/4730.00 ONERA DESP Octobre 1999 René REULET, Daniel SARRAIL, Bernard DIRASSEN, Denis PAYAN.