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EFFECTS OF ELECTRON IRRADIATION ON LARGE INSULATING SURFACES USED FOR EUROPEAN COMMUNICATIONS SATELLITES

J. Reddy and B. E. Serene
European Space Agency

INTRODUCTION

The Orbital Test Satellite (OTS) and its derivatives ECS (European Communications Satellite) and MARECS (Maritime ECS) make extensive use of aluminised kapton for passive thermal control.

The satellites are three axis stabilised and in geostationary orbit (OTS at 10°E). The external configuration is such that the kapton is in contact with the plasma and is able to charge electrostatically.

Some time ago a test programme was initiated to establish the maximum charging potentials of these surfaces and to give some indication of the discharge characteristics (Ref. 1). The results of this work, together with results obtained by others (Ref. 2, 3) led us to believe that the discharge characteristics and the consequent material degradation would be related to the size of the charging surface. In view of the large exposed insulating surfaces on OTS it was decided to perform a series of measurements on large samples ($\simeq$ 0.5 m^2) in order to establish the discharge rates and characteristics and observe any material degradation.

TEST SAMPLES AND PREPARATION

The largest exposed surfaces which present an insulating surface to the plasma are the VHF Shield Assembly and the Antenna Dish.

The VHF Shield Assembly is shown schematically in Fig. 1. The outer layer of aluminised kapton is separated from a relatively thick sheet of aluminium foil by a thin (6 μ) layer of kapton. The thick aluminium foil is connected electrically to the satellite structure and provides a continuous ground plane for the VHF Antennas on the satellite. The complete assembly is held together by means of adhesive kapton tape. In addition to this, and in order to provide a nominal electrical connection between the vacuum deposited aluminium and the main aluminium foil, a small rivet and washer assembly is used, shown in Fig. 2. For their assembly the central kapton layer is perforated allowing the aluminium to squeeze through and so provide el. trical continuity.

The VHF Shield Assembly is completed by a number of venting holes shown in Fig. 3.

The second item under test was a sample of the structure used for the main antenna dish. A schematic of this structure is shown in Fig. 4. This antenna comprises an aluminium honeycomb on which is mounted a carbon fibre sheet which is painted with white paint, type S13 GLO. It was not certain if this paint was conductive, and even so, the electrical continuity between the carbon fibre and the honeycomb was not assured.

Samples measuring 0.7 m x 0.7 m of these assemblies were prepared and mounted on an aluminium frame. The conductive rear surfaces of the samples were connected electrically to the frame which could then be used to provide a reference point for the measurements.

TEST CONFIGURATION AND CONDITIONS

The tests were performed under an Estec contract and financial and technical management by the Deutsche Forshungs und Versuchsanstalt für Luft und Raumfahrt (DFVLR) at Porz Wahn in Germany (Ref. 6). The chamber is shown in Fig. 5 and has a conventional commercial electron gun as a source. This is followed by a scattering foil (2 μ thick) in order to achieve reasonable homogeneity over the sample area. The scattering foil details are described in Ref. 4. The beam homogeneity was measured using three simple sensors traversing the chamber in the plane of the test object.

With the incident electron beam of 25 keV (before the scattering foil) the homogeneity obtained in the plane of the test sample was approximately 30 %. The flux profile is shown in Fig. 6.

The mounted samples were suspended in the chamber and isolated from it (Fig. 7). The frame was connected by means of a dedicated wire to a ground reference point external to the chamber. This allowed measurement of the leakage current and the discharge current. The incident flux was monitored by means of a fixed sensor in the plane of the test sample. A thermistor was mounted on the rear surface of the sample to measure temperature.

In addition to the above, a commercial field mill was installed on the scanning mechanism with the intention of measuring the sample surface potential. Unfortunately, due to the flexibility of the samples the mutual attraction of the field mill and sample precluded such measurements.

The discharge current was measured using a current probe type P6022 connected to a Biomation 8000 transient recorder. A schematic diagram of the electrical configuration is shown in Fig. 8.

The samples were irradiated for eight hours at two temperatures - room temperature (approx 20^{O}) and liquid nitrogen temperature (-173^{O}C) under a vacuum of 10^{-6}torr.

The effects of illumination of the surfaces on charging were simulated by illuminating the test samples with a simple 500 watt lamp mounted outside the chamber.

The incident flux was 10 n ampères.cm^{-2}. The electron beam energy after scattering was not measrred directly but has been calculated to have the profile shown i Fig. 9. (Ref. 5 also.)

TEST RESULTS

The test results will be presented as follows:

a) Visual observations during irradiation by electrons

b) Measurements made of leakage current and discharge characteristics

c) Observations of material degradation after irradiation is completed

VISUAL OBSERVATIONS

VHF Shield Assembly

The most immediate observation made during the irradiation of the VHF Shield Assembly was that it appeared as it the entire surface discharged with the major part of the illumination being around the venting holes and the central rivet (Fig. 10). In fact two distinct forms of discharge were observed. The first already described and also smaller point discharges apparently located randomly on the sample.

Antenna Structure

The visual observations here were limited to discharges observed at a particular point on the surface. The intensity of the discharges was so low that photography was not possible.

In addition to the discharges it was observed that the painted surfaces fluoresced with a yellow-green colour at room temperature but with a blue-violet colour at liquid nitrogen temperature. The explanation for this is not obvious.

ELECTRICAL MEASUREMENTS

VHF Shield Assembly

A plot of the leakage current versus time is shown in Fig. 11 showing the charging characteristics and the discharges. The rate of discharges is shown in Table 1 where it can be seen that the discharges became less frequent as the test proceeded.

During illumination with the lamp no discharges were observed at all.

Typical discharge currents are shown in Figs. 12 and 13. Unfortunately, equipment limitations did not allow an absolute measurement of the maximum amplitude. However, it can be seen that the amplitude may be in excess of 400 ampères with a rise time faster than one hundred nanoseconds and a pulse width of four microseconds. We should also note that the measurements were made on a ground connection several metres long which suggests that the actual maximum could be even higher.

Antenna Structure

A plot of the leakage current versus time in the antenna structure is shown in Fig 14. The rate of discharges is shown in Table 2, and here it can be seen that the rate of discharges stays constant and are only observed at liquid nitrogen temperatures.

Illumination with the lamp resulted in no change in the discharge characteristics indicating that there is little photo-emmission from this paint.

The discharge current was measured and is shown in Figs 15 and 16. It can be seen that the maximum current is considerably less than one ampère. In addition there is a pronounced 'ringing' associated with the length of the ground connection.

MATERIAL DEGRADATION

VHF Shield Assembly

The degradation of the vacuum deposited aluminium (VDA) is shown in Figs 17 - 20. As can be seen there has been considerable evaporation of the VDA in the regions surrounding the venting holes and the rivet. The evaporation of the VDA surrounding the rivet was sufficient to isolate the rivet from the VDA itself. In addition to the damage around the holes, damage was observed in the regions associated with small indentations in the VDA.

Further investigations showed that there was no degradation in the kapton itself even in those areas where VDA was evaporated.

In one instance the rear aluminium foil was actually punctured, apparently by the force of the aluminium evaporating. The area of VDA which was evaporated is estimated to be 0.3 % of the total surface area.

Antenna Structure

The only observable effect on the antenna structure surface was some discolouration of the paint in the region where discharges were observed. Closer inspection showed that the paint finish at this point was not very good and the possibility is that this defect promoted the discharges and subsequent degradation.

CONCLUSIONS

From the foregoing results it is clear that although it is capable of charging to a reasonably high potential, the effects of discharges on material property and EMI for the antenna structure are relatively insignificant.

For the VHF Shield Assembly the opposite is true. Here we have seen considerable damage to the VDA and associated with this are very large transient currents which could severely affect the system electronics.

It is difficult to assess the effects of the loss of VDA on the overall thermal design; however, a simple solution to this problem is to make the aluminum layer much thicker. This solution has been tried and the results are reported in Ref. 3. Furthermore, the need to reduce edges to a minimum by the exclusion of holes and rivets is also obvious.

With regard to the current transients solutions are somewhat less immediate. We have seen on smaller examples (0.1 m x 0.1 m) current transients of the order of thirty ampères. For samples described here we have currents of the order of several hundred ampères. Clearly there is a limit to the maximum amplitude which may be seen regardless of surface dimensions. However, it is certain that the energy dissipated in the discharge will continue to increase. The test results given here indicate a maximum discharge energy of the order of tens of joules. Such energy flowing in the satellite structure is almost certain to result in anomalous electronic behaviour.

With the present external satellite design 'frozen' with regard to thermally acceptable materials the only solution to this problem would appear to be desensitisation of all susceptible electronic circuitry.

Finally, it must be emphasised that any attempts to evaluate the charging and more importantly the discharging behaviour of materials must be made on samples which reflect accurately the mechanical configuration and more importantly the actual operational dimensions.

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Table 1 Rate of discharges of the VHF Shield Assembly

Time	Number of discharges Room temperature	LiN_2
First hour	16	18
Second hour	17	14
Third hour	7	8
Fourth hour	2	0
Fifth hour	12	2
Sixth hour	14	2
Seventh hour	1	0
Eighth hour	4	4

Table 2 Rate of discharges of Antenna Structure

Time	Number of discharges Room temperature	LiN_2
First hour	zero	$\simeq$130
Second hour	zero	constant
Third hour	zero	constant
Fourth hour	zero	constant
Fifth hour	zero	constant
Sixth hour	zero	constant
Seventh hour	zero	constant
Eighth hour	zero	constant

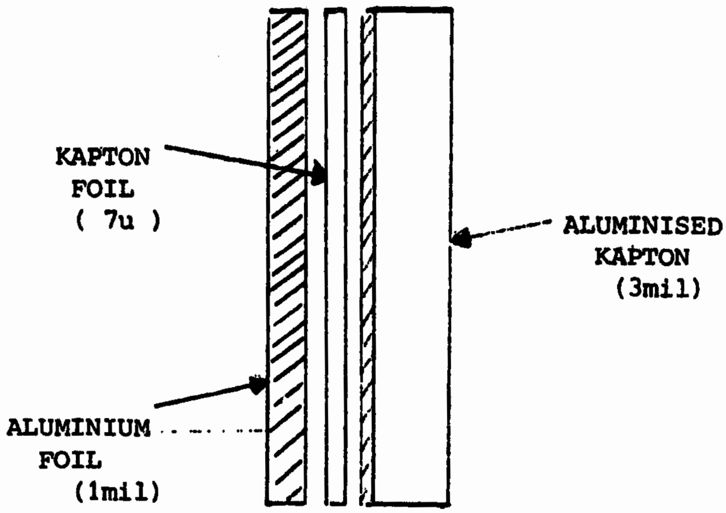

Fig 1: VHF Shield Assembly schematic

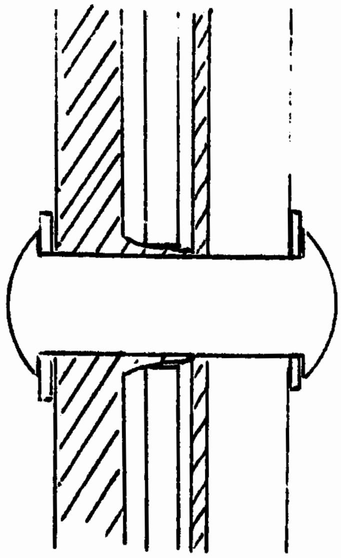

Fig 2: Rivet Assembly

Fig 3: Overall blanket view

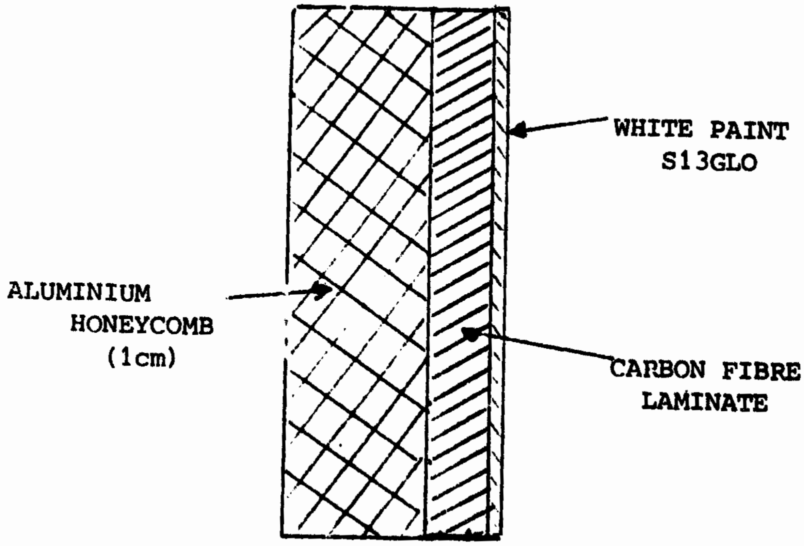

Fig 4: Antenna Structure schematic

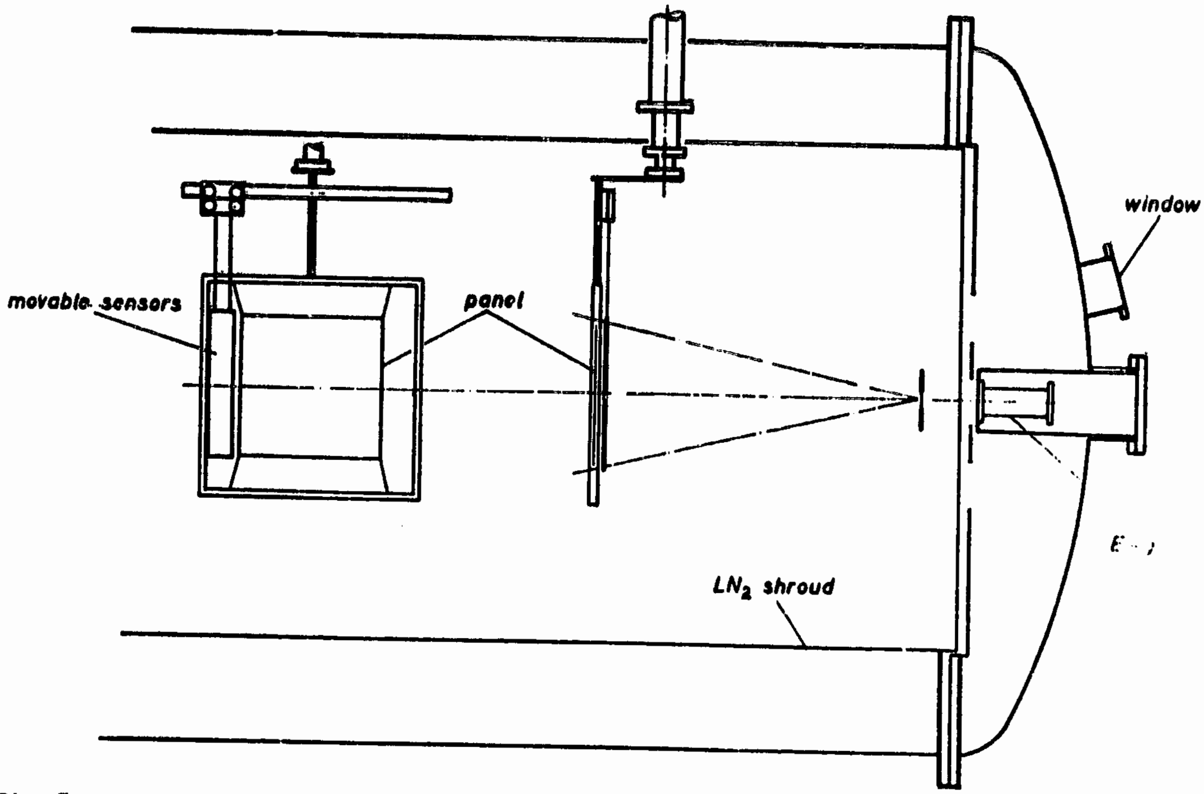

Fig 5: Vacuum chamber

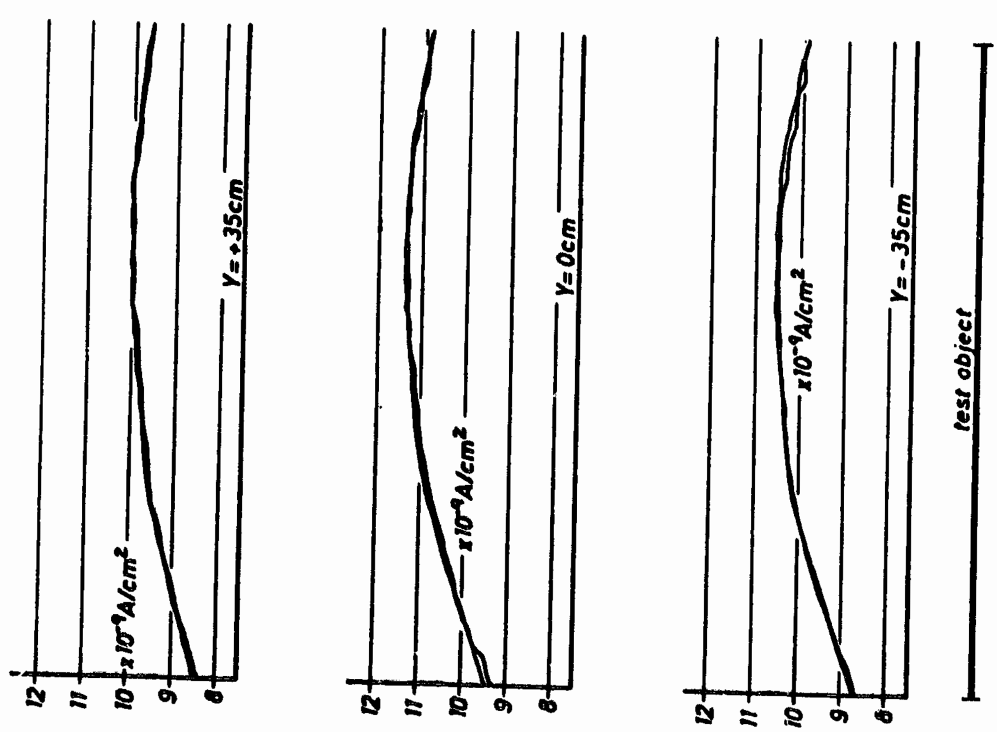

Fig 6: Flux profile

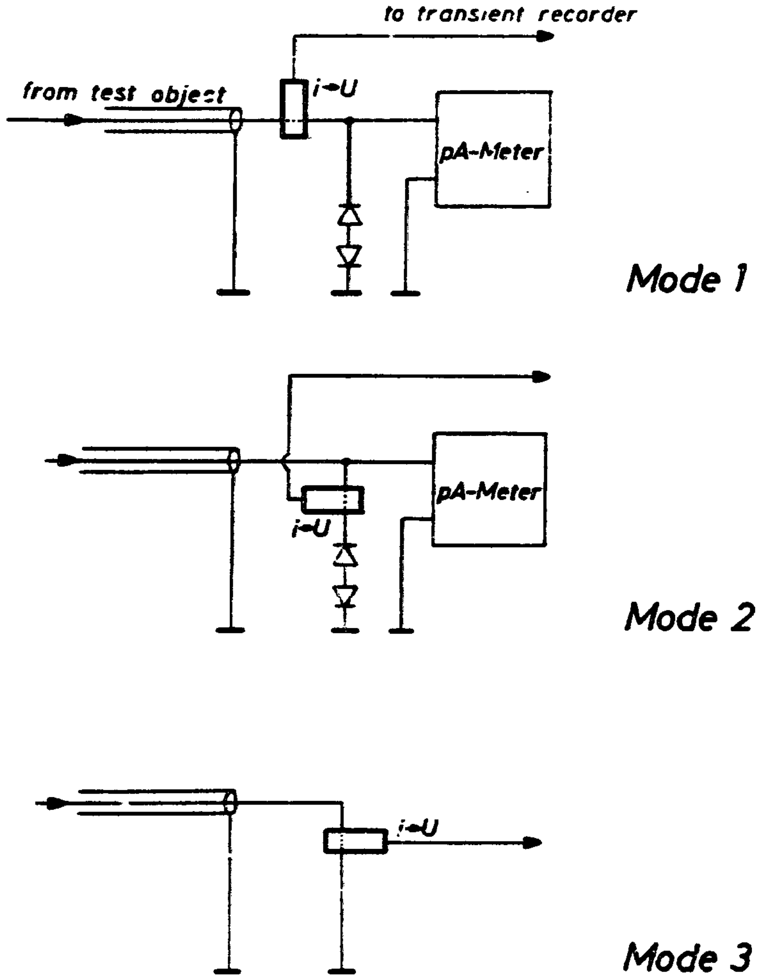

Fig 8: Electrical schematic

Fig 7: Sample mounting

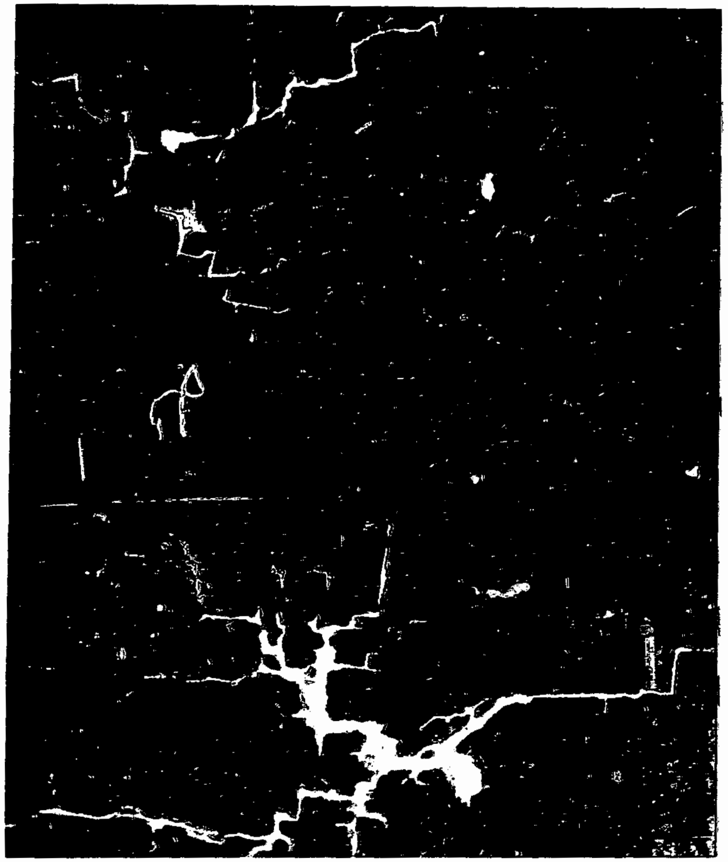

Fig 10: Typical discharge

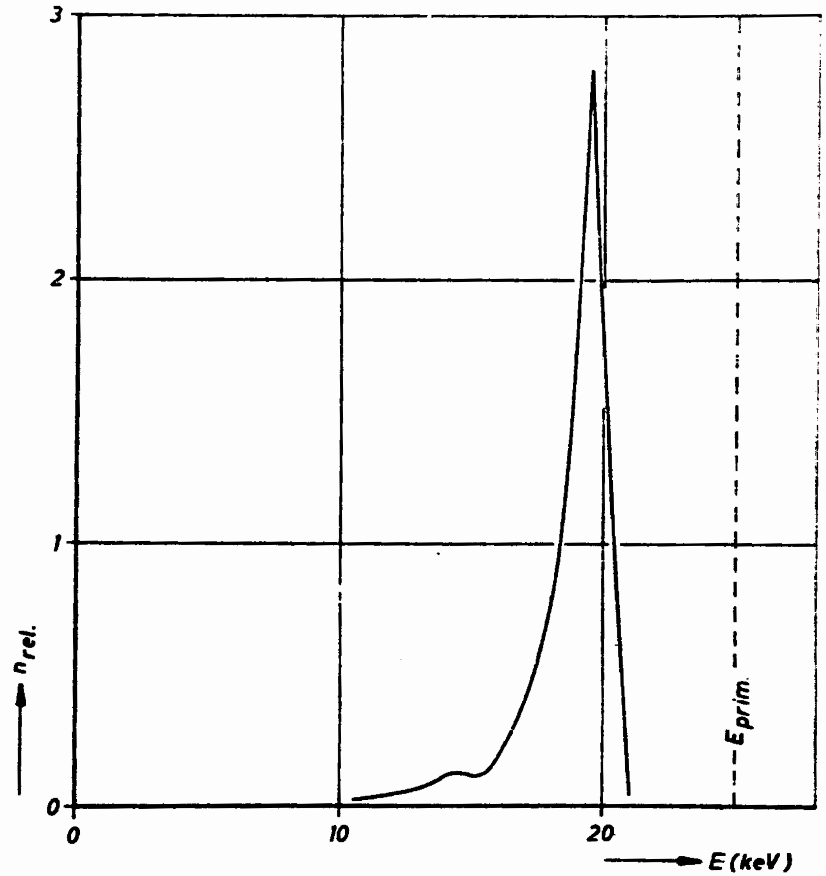

Fig 9: Electron energy profile

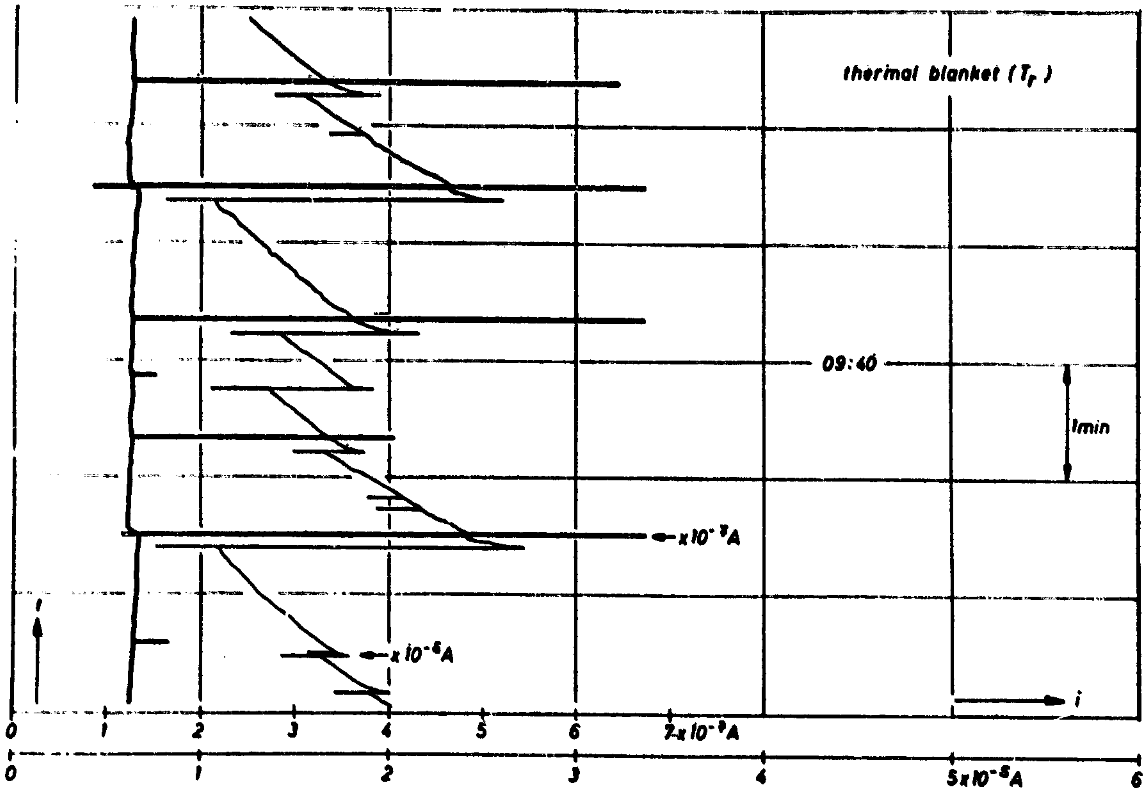

Fig 11: Leakage current - VHF Shield Assembly

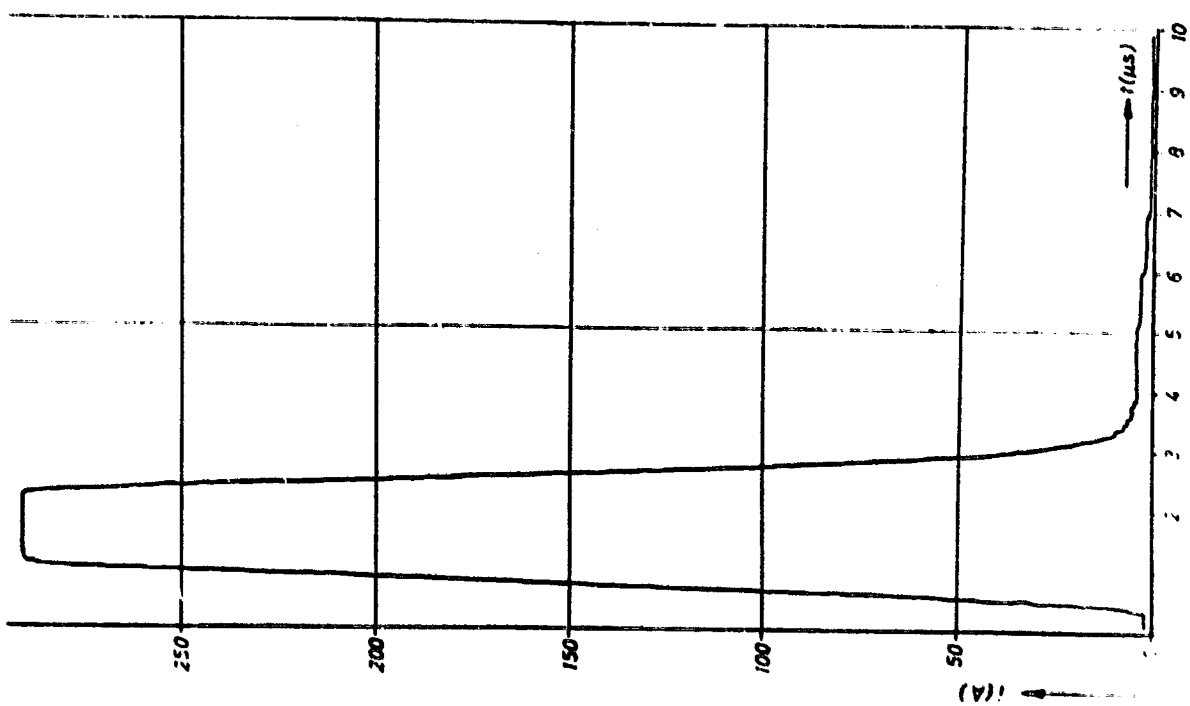

Fig 12: Current discharge-VHF Shield Assembly

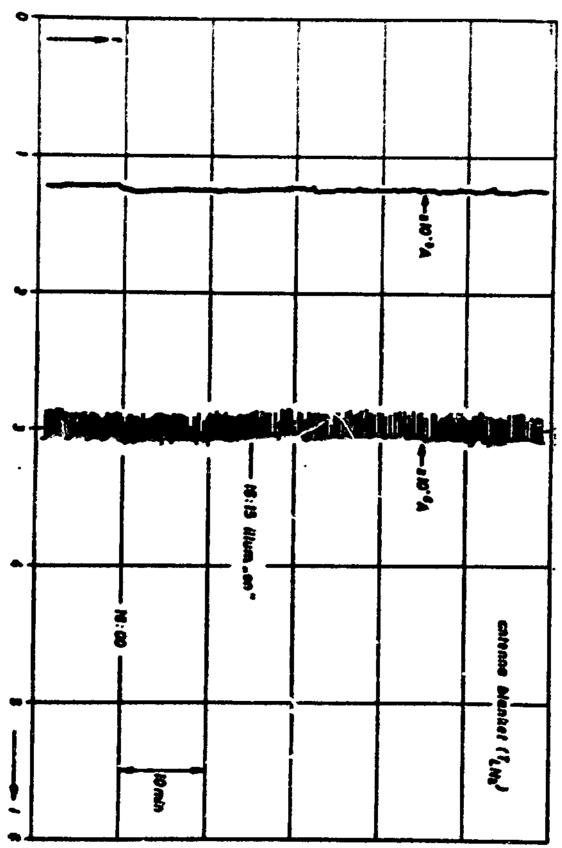

Fig 14: Leakage current - Antenna Structure

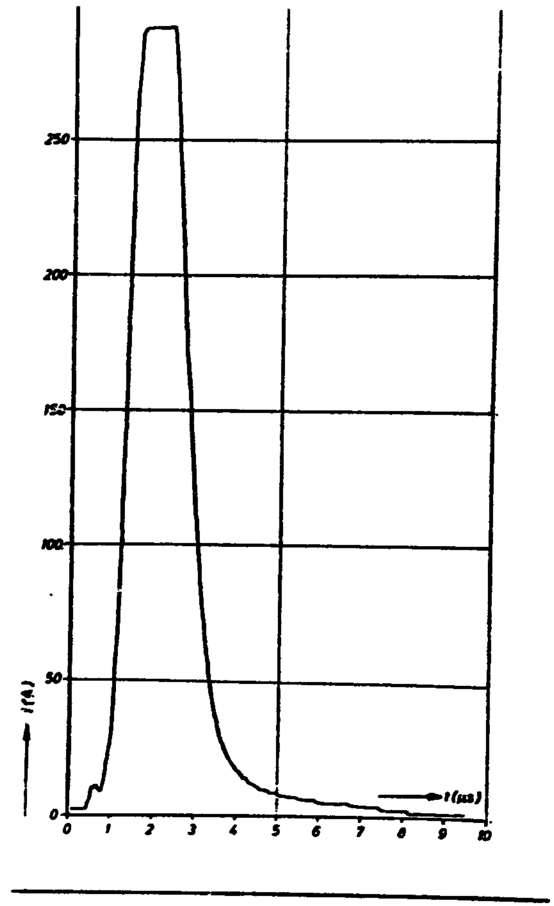

Fig 13: Discharge current - VHF Shield Assembly

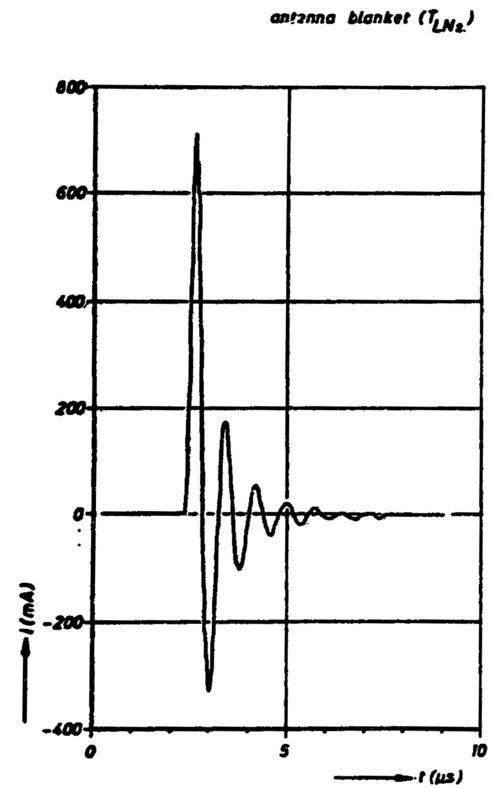

Fig 16: Discharge current - Antenna Structure

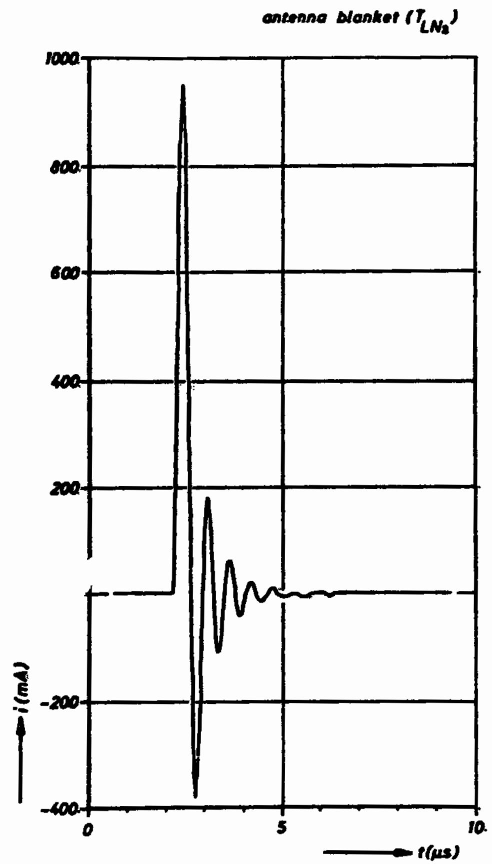

Fig 15: Discharge current - Antenna Structure

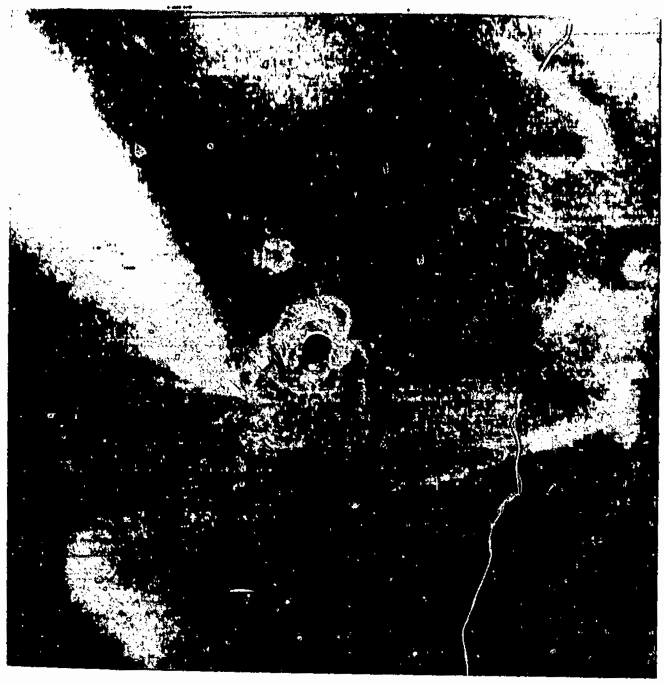

Fig 17: VHF Shield Assembly degradation

Fig 18: VHF Shield Assembly degradation

Fig 19: VHF Shield Assembly degradation

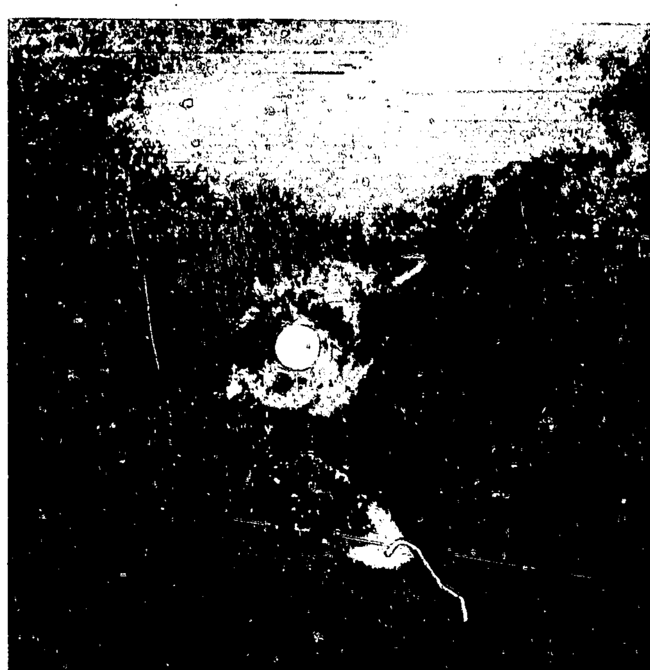

Fig 20: VHF Shield Assembly degradation