METEOSAT SPACECRAFT CHARGING INVESTIGATION

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SUMMARY

A number of phenomena observed on the first orbiting METEOSAT satellite have, after analysis, been attributed to spacecraft charging effects. The investigation programme consisted of design analysis, correlation of anomalies with space environmental data, on-ground tests with an engineering model spacecraft, tests on the validity of improvements and, finally, installation of suitable monitors for the second improved flight satellite.

INTRODUCTION

METEOSAT is a spin-stabilised meteorological satellite in geostationary orbit containing as the main payload a scanning radiometer.

A first satellite (METEOSAT-1) was launched in November 1977 from Cape Kennedy, Florida, U.S.A. The satellite met the mission performance requirements in spite of a number of anomalies, mostly spurious status changes, which have been the subject of investigations for almost three years. However, the low number of such status changes and the type of perturbations caused did not really justify major investigation. It became necessary to investigate these phenomena in detail, however, in view of

- potential irreversible degradation,
- operational impacts,
- improvements for future satellites.

Spurious Status Changes in Orbit

About 150 status changes have been observed in three years orbiting which could be attributed to spacecraft charging effects. Correlation with local time, sun attitude, eclipses could not be established but correlation with magnetic activity indices of Leirvogur, Lerwick, Friedericksburg and the general planetary index Ap showed good correlations, particularly with magnetic activities occurring two days prior to the anomalous events (Ref. 1).

Certain trends concerning the affected subsystems could be observed over the first two years after which the spacecraft operations were reduced due to an on-board failure owing to which less anomalies could be detected. Status changes were still observed during the third year in a corresponding proportion.

Finally, one status change (which was equally likely to occur) was only observed once after two and a half years in orbit.

Satellite Design Features

Following consultations with experts, the satellite design was reviewed with respect to differential charge built up capabilities and the noise immunity protection of interfaces.

Outer Surfaces

About 80% of the outer surface of the satellite are not conductive, e.g. solar cell cover glasses, second surface mirrors and black paint. The large metallised surfaces of the thermal shields are not grounded, the main reason being that no cost-effective qualified solution was available for grouding these surfaces.

The main surfaces concerned (Fig. 1) are

- antenna thermal shield, forward thermal shield and afterward thermal shields,
- antenna and shunt second surface mirrors,
- solar panels.

The material (Fig. 2) used for the thermal shields is Kapton of 25µm, aluminised on both sides. The edges of the thermal shields are reinforced. The second surface mirrors have a similar material: FEP Teflon-coated aluminium mirror.

The largest single grounded capacitor is formed by the forward thermal shield sections with about 350 nano farad per section.

Command Interfaces

The satellite contains a centralised telecommand decoder which provides individual telecommands to the units. In the case of low power commands, this requires a telecommand amplifier which is characterised by the noise immunity, threshold level and its gain. The decoded telecommands have a duration of 13 ms.

The zero level is $0 < \text{zero} < 0.7$

The one level is $2.2 < \text{one} < 5V$.

There are about 250 telecommands, 80 of which are "low power commands". The performances of the telecommands amplifier of the various equipment show a considerable difference concerning this noise immunity. Status changes could be observed only on those interfaces where low noise immunity amplifiers drive TTL logics rather than relays (Fig. 3). Typical noise immunity figures for the affected circuitry are

5V	330µS	Type 1
5V	10µS	Type 2
5V	1µS	Type 3

In the last case the interface is however not a telecommand interface but an interface to a protection system.

All units passed system level tests.

Grounding Concept

As for many other satellites, the grounding system for METEOSAT is a multiple grounding system. The low impedance of the structure interconnects the grounding points with a resistance of less than 10 ohms in most cases. Most of the units which showed status changes were, in fact, double grounded as concerns the command interface.

Simplified Analysis

Assuming the status changes were caused by ground currents generated by the arc discharges of the large outer surfaces, one can determine the order of magnitudes for charge voltage, ground current, duraction of pulse and, in the case of METEOSAT, arrive at a discrepancy. In the most favourable case, the thermal shield has to charge up to more than 3KV and all discharge current has to pass the interface decoder-telecommnad amplifier as a single pulse (Fig. 4). Whereas it appears to be more realistic that the discharge pulse will not be rectangular, only a small fraction of the discharge current will pass the particular interface and the discharge will not be to zero volts.

Current Injection Test

Due to the discrepancies in the simplified analysis and to also obtain a better understanding on the real mechanism for the status changes, and finally to test the effectiveness of improvements, it became desirable to perform a test with an electrical model of the satellite and to simulate the effect of discharges by a high tension capacitor and a spark chamber. The test set-up (Fig. 5) enabled the following test parameters to be varied :

- injection points,
- change voltage (500 - 6000V),
- spark gap (0.1 - 10mm),
- current limiting resistor (0, 1, 10, 100 Ohm),
- polarity,
- shielding of spark chamber (with/without).

The capacitance of the storage capacitor was .47 micro F. The satellite was either "open" (dummy solar panels, dismounted), or "closed".

Test Experience

Initial setting up problems was due to the monitoring and sensitivity of test equipment to the discharger and the coupling of the umbilical connector cabling. In the configuration finally used, the spacecraft was completely disconnected from all items of equipment, was operated on its on-board battery and was controlled by the VHF TM/TC system.

Test Results

The current injection test reproduced a number of status changes, some of which had already been observed, some not. The most frequent status changes in the radiometer scanning control could not be reproduced. Generally the results were in line with the course analysis, that is the test parameters had to be very favourable (high voltage and current levels, injection points close to the equipment) in order to cause status changes.

The test could also establish that the modifications introduced to increase the noise immunity had no negative effect but failed to establish a real gain. On the whole the test proved that the satellite was quite immune to structural currents - it was felt that the status changes may be caused differently.

A further review of the candidate discharge current sources revealed that the radiometer mirrors were not grounded. The main mirror of the radiometer telescope has a reflector of about $1000cm^2$ on a glass structure coated with THF_4. The closest structural element has a distance of about 20mm. Simulating a discharge of this surface by current injections into the telescope structure could, in fact, reproduce new status changes.

It was further thought that a real, illuminated solar array might make the satellite more sensitive to arc discharges and the test set-up was changed accordingly. There was no change in the test performance, however.

Finally, a direct charging-up of the thermal shields was tested. Apart from deteriorating the thermal shield, this test did not produce any new results.

Conclusions

A current injection test is time-consuming and costly. For METEOSAT this test took five weeks to carry out with four operators to control the satellite and perform the testing. The spacecraft, built for currents of maximum 15A, was subjected to transient currents exceeding a hundred times this value without suffering any failure, and only rarely were status changes provoked. This test, if performed as an acceptance test, could have demonstrated the satisfactory immunity of the satellite.

Sample Irradiation Test

In parallel to the current injection testing, an electron irradiation test programme was initiated in order to establish the charge and discharge characterics of the satellite surfaces and also to verify the validity of the parameters for the current injection test.

Thermal Shield

The first sample subjected to an irradiation test was a 20 x 20cm thermal shield in two versions - one with an ungrounded outer surface and the other with a grounded outer surface as foreseen as an improvement for the second flight model. The irradiation was performed with energy levels of 5, 10 and 20KeV and currents of 0.1 to 1.25 (nA/cm^2). On the first sample discharges were initally observed at low potentials (500V) rising to about 2000V with continuous discharges. The relative low potential seems to be due to edge effects, in particular field emissions. The effect of ultra violet illumination on the charging properties was also investigated. Under test conditions the ultra violet illumination did not prevent the charge build-up and consequent arcing events, but had a reducing effect particularly with low incident angles (Ref. 2). The test set-up enabled the determination of the discharge currents. Typical values were 10A for 500nS which is far below the expected value of about 100A for 500nS and 1KV charging voltage.

Second Surface Mirrors

The second surface mirrors were irradiated in a similar tests. The SSM showed discharges starting from 15KeV ($1nA/cm^2$); typical discharge currents were 15A and 500nS. Again the discharge currents were lower than expected. What was surprising, however, was a strong signal at the pick-up antenna and the fact that discharges seemed to appear in holes rather than at the edges. See Ref. 3 for further detail.

Radiometer Mirror

A spare scanning mirror, smaller but similar to the primary mirror, was used for this test. As concerns the charging properties, this mirror showed a zener effect on its surface potential at around 5KV (Ref. 4). Discharges could not be discovered. It was further noted that the surface potential was rapidly discharged in the presence of ultra violet illumination.

Conclusions

The discharge currents of the outer surfaces are far below the values required to produce the levels applied for the current injection test. The simple model for the differential charge build-up and current injection due to arc discharges does not seem to be valid.

Electron Irradiation Test

The investigations carried out so far have not revealed the real mechanism of the status changes but, on the contrary, have created doubts on simple explanations. Therefore the possibility of performing a full scale space simulation test including electron irradiation was investigated; this test was finally performed. To simplify the test set-up and to reduce the cost, the following restrictions had to be applied :

- passive satellite : to avoid the need to power the spacecraft and to reduce the test team and equipment.
- no sun simulation : to avoid the need for cooling the shrouds and since no valid simulation of ultra violet light was available.
- no thermal control : to simplify the test set-up.

The sole aim was to study the behaviour of the outer surfaces and to attempt not to reproduce anomalies.

The instrumentation to monitor the surface behaviour consisted of

- surface potential probes
- electric field antennae
- photographic equipment.

The spacecraft was in addition equipped with a probe to monitor the primary mirror potential. The test parameters were

- satellite grounding	: (free floating or ground resistors).		
- motion simulators	: zero spin or .5 rpm.		
- satellite attitude	: (-23 to 23).		
- irradiation	: acceleration	voltage	5 to 30KV
	flux density	InA/m^2	
	target disc	3m diameter.	

The test set-up (Fig. 6) shows the location of the equipment.

Test Results

When irradiated, the surfaces would charge up rapidly and arcing was observed starting at energy levels of about 7KeV on most surfaces. The arcing events were frequent, typically .1 to 1 events per second (Fig. 7). Prior to the test and according to the theory, it was expected that larger surfaces would produce considerably larger discharges. This difference in amplitude could not be observed by the electric field antennae nor by visual observations.

Occasionally cascades of arcs were observed which could, by their combined effect, better explain the status changes. As an interesting detail, the test could clearly identify the rapid arcing of a repaired thermal shield which proves the general suitability of the test.

The test confirmed the basic results of the sample irradiation test which showed already that the larger surfaces did not produce discharges corresponding to their capacity. As a main result, the test demonstrated that under substorm conditions the satellite is virtually covered with arc discharges. This makes it difficult to explain the very low number of actual status changes.

In a last phase, the effectiveness of grounding the outer layer of the thermal shields was tested and improvement foreseen for the second flight model. Figure 8 shows that a general attenuation rather than a reduction in number of discharges takes place based on the electric field measurements. This could mean that the satellite reduces the electric field variation but not necessarily that the arc discharges are less violent. The fact that the number of arc discharges is hardly affected also confirms that the thermal shields have a minor contribution to the overall arc discharge activities.

Conclusions

The test did not provide a clear understanding of the mechanism leading to status changes but demonstrated that arcing activites can be very intense even if only small surfaces are involved. Grounding of part of the satellite does not prevent arcing but could reduce it.

Satellite Design Improvements

Since improvements sometimes make things worse, particularly if the cause of a problem is not fully understood and also due to the advanced state of the hardware, the number of modifications introduced to the second METEOSAT flight spacecraft were limited to

- grounding of the thermal shield,
- improvements of critical interfaces,
- incorporation of charging monitors.

Grounding of the Thermal Shields

The technology applied uses grounding straps glued to the outer layer with conductive adhesive. So far this design showed only problems during vibration testing due to insufficient stress relief. This was improved in a later version.

Improvements of Critical Interfaces

Since the sensitive interfaces consisted in all cases of low noise immunity amplifiers and TTL logics modification (Fig. 9) consisted of the use of relays with high immunity amplifiers. Non-critical interfaces have not been modified and can be considered as reference for the orbital behaviour.

Charging Monitors

The modifications will not exclude arc discharges and possibly status changes in orbit.

To monitor the space environment and the arc discharge activity, the satellite was equipped with two monitors :

- electrostatic analyser :

  This instrument is provided by the Emmanual College, Boston, USA. It was developped for the DMS Programme and is called SSJ /3. It detects and analyses electrons in the energy range of 50eV - 20KeV, by employing a low and a high level channel. The aperture points into space with an inclination of 45°. The basic instrument (Fig. 10) consists of

  . instrument aperture
  . deflecting electrostatic field
  . exit aperture
  . channeltron multipliers and counters.

- electrostatic-discharge monitor :

  This monitor is designed to detect and analyse the electromagnetic interferences caused by discharges. It provides over one observation period (one telemetry format; 25s) the detection of

  . peak value of highest spike picked up
  . number of events exceeding the background noise and their total duration
  . level of the background noise itself.

  The instrument is an in-house development by the Agency's technology centre ESTEC. The block diagram (Fig. 11) shows the automatic setting of the threshold, the event timer and counter and the peak detector. The input to the instrument is provided by a small pickup antenna.

FINAL CONCLUSIONS

Performance data of the second flight model, in particular in conjunction with the monitor data, may well show that further improvements are required, such as grounding all outer surfaces. Present grounding methods for conductive SSM are under investigation and the overall impact of a requirement for a unipotential outer surface on manufacture is presently being assessed.

It is felt however that a better understanding of the arcing phenomena could lead to more efficient solutions.

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3. Levy, L, Sarrail, D: Essais de Claquage d'une Portion représentative de SSM de METEOSAT. Centre d'Etudes et de Recherches de Toulouse, France

4. Levy, L, Sarrail, D: Essais d'Irradiation d'un miroir de METEOSAT pour la Détermination de l'Influence de l'Eclairement Solaire sur son Comportement Electrostatique. Centre d'Etudes et de Recherches de Toulouse, France.

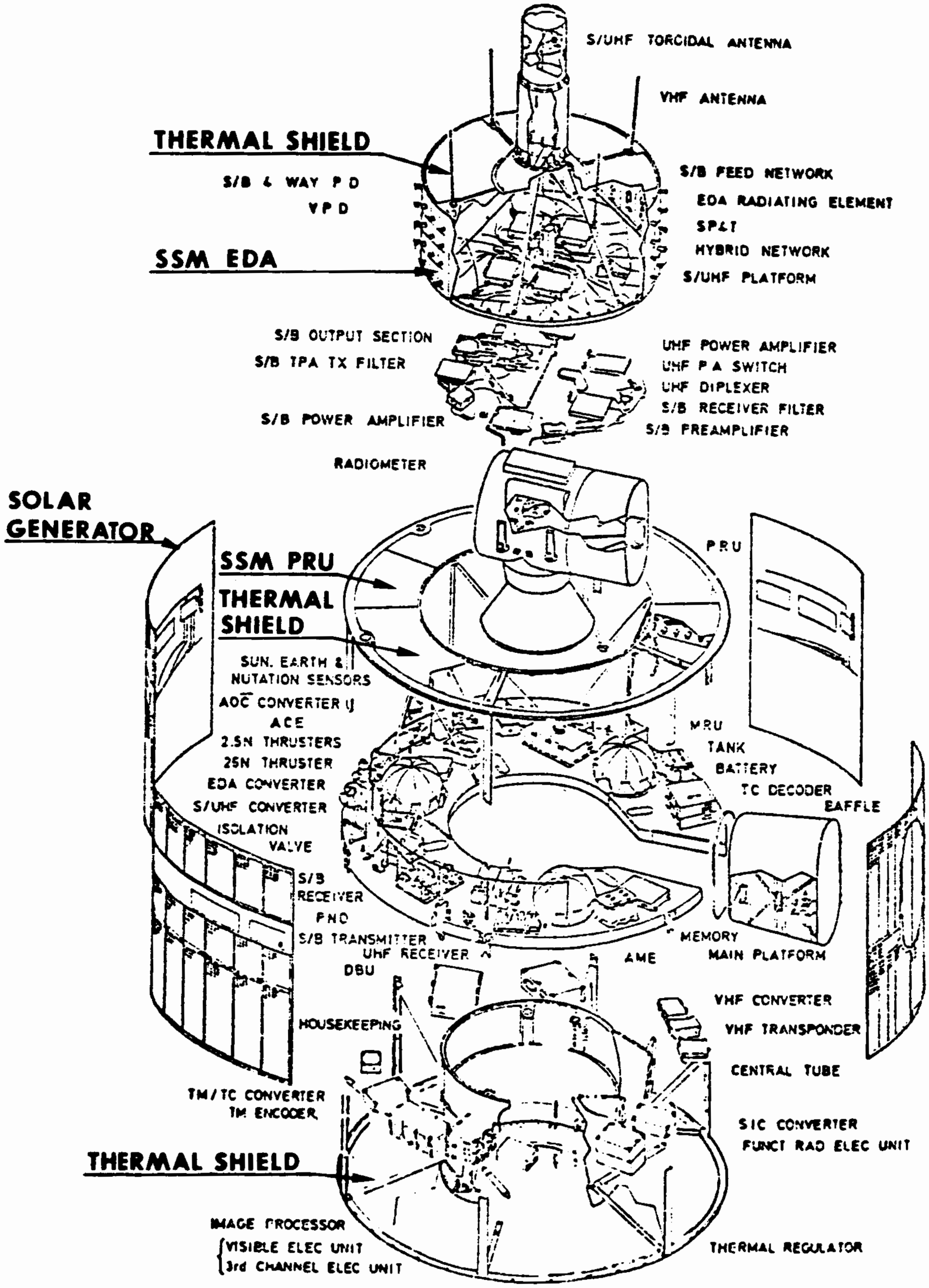
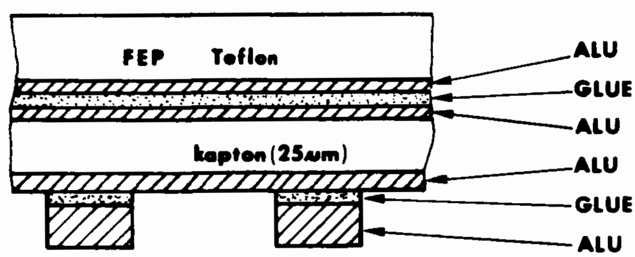


Figure 1. - Satellite configuration and outer surface.

Second Surface Mirrors



Thermal Shields

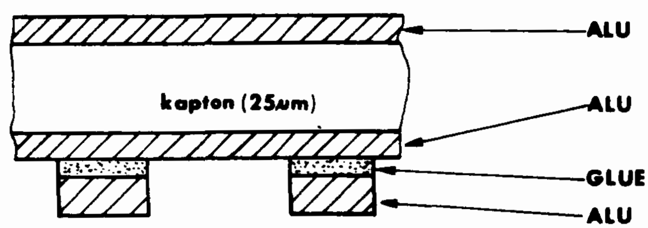


Figure 2. - Thermal shields and second-surface-mirror material.

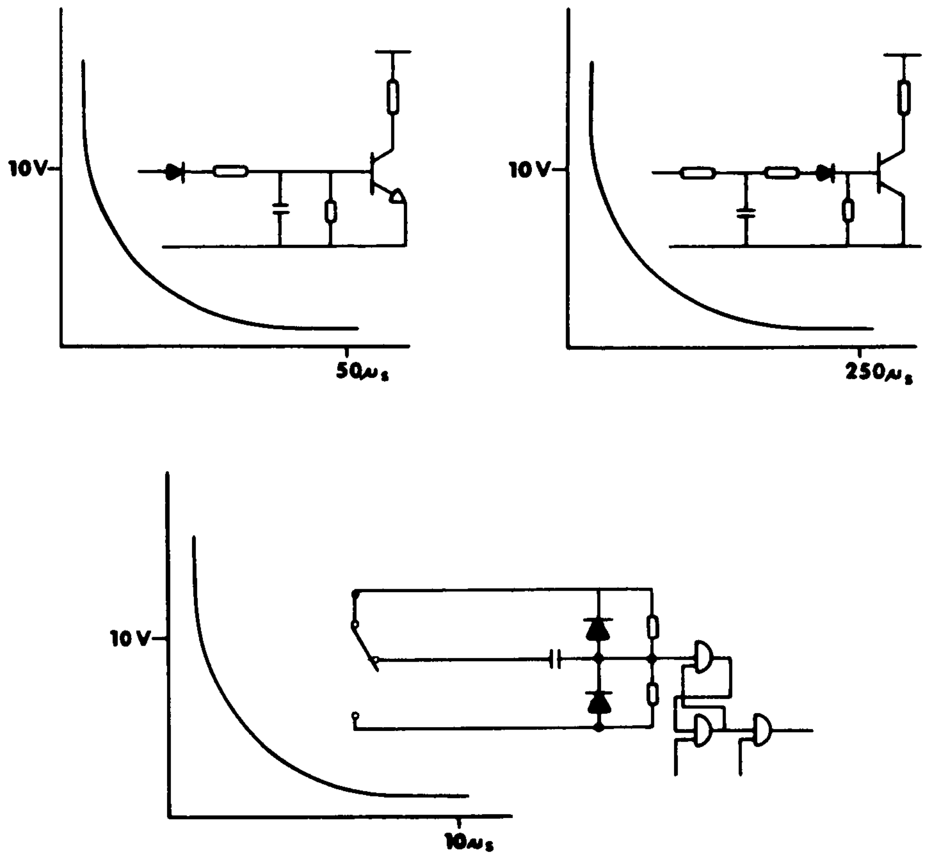


Figure 3. - Command interfaces and noise immunity.

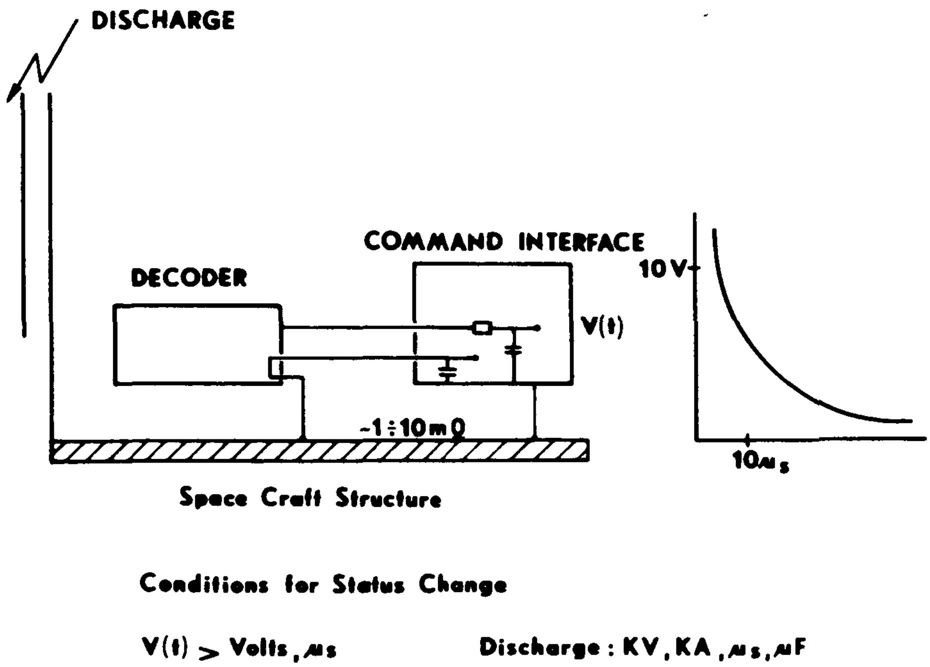


Figure 4. - Simplified analysis for status changes.

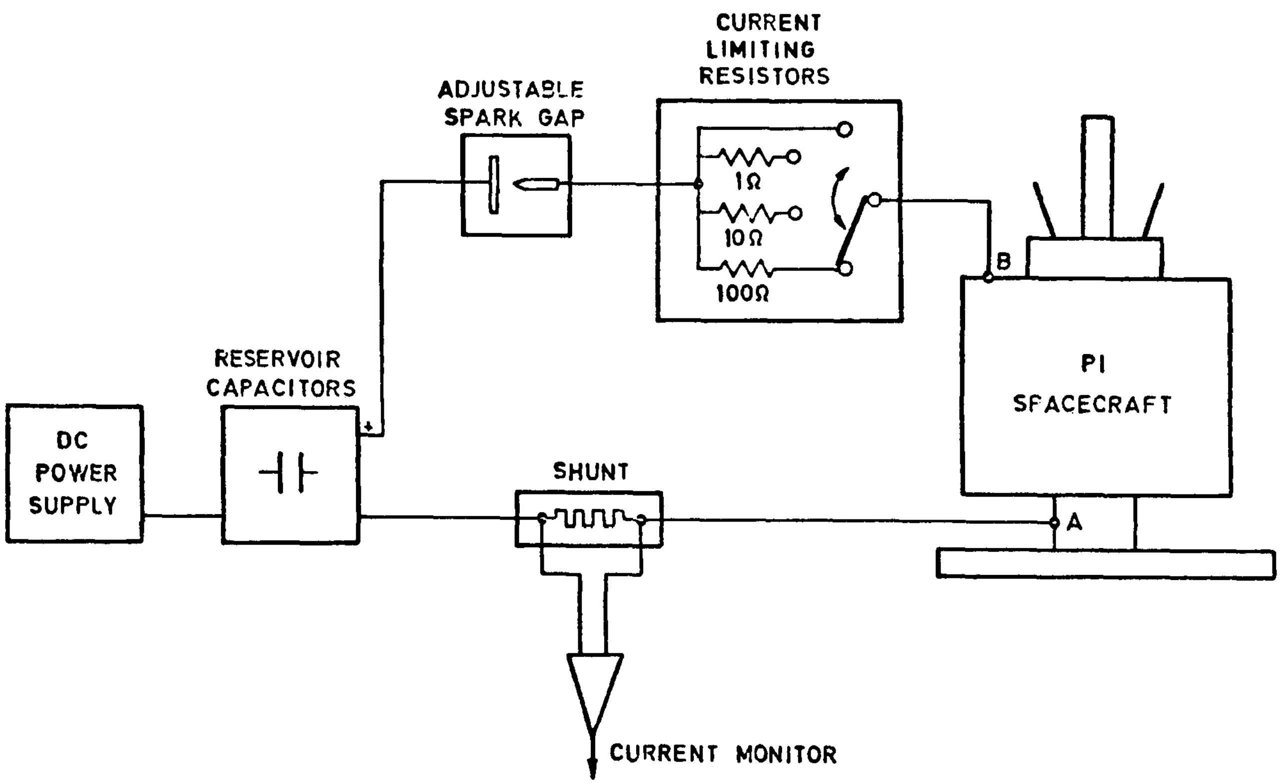


Figure 5. - Current injection test setup.

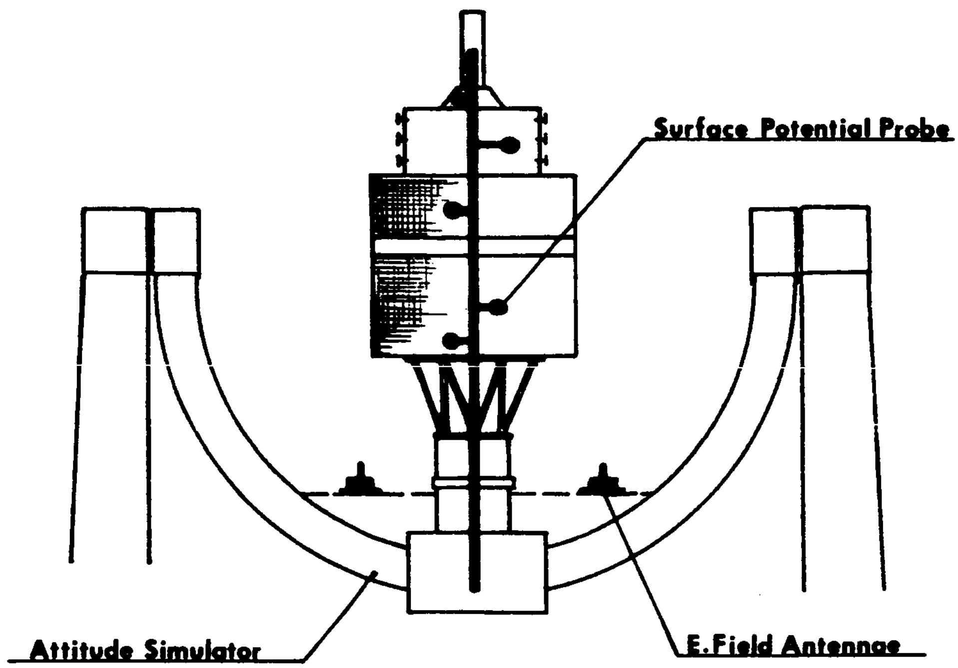


Figure 6. - Electron irradiation test setup.

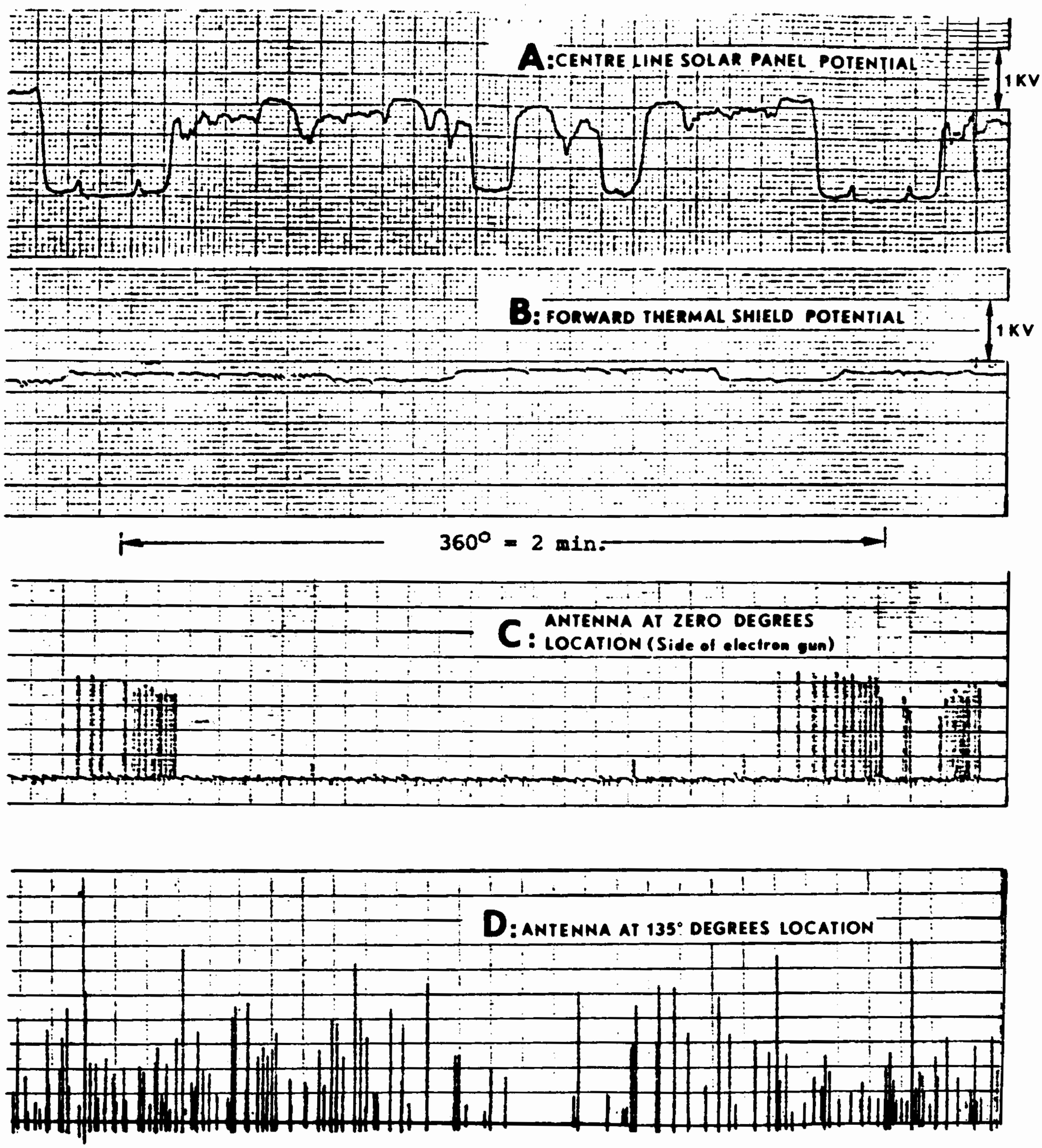


Figure 7. - Typical discharge events under electron irradiation.

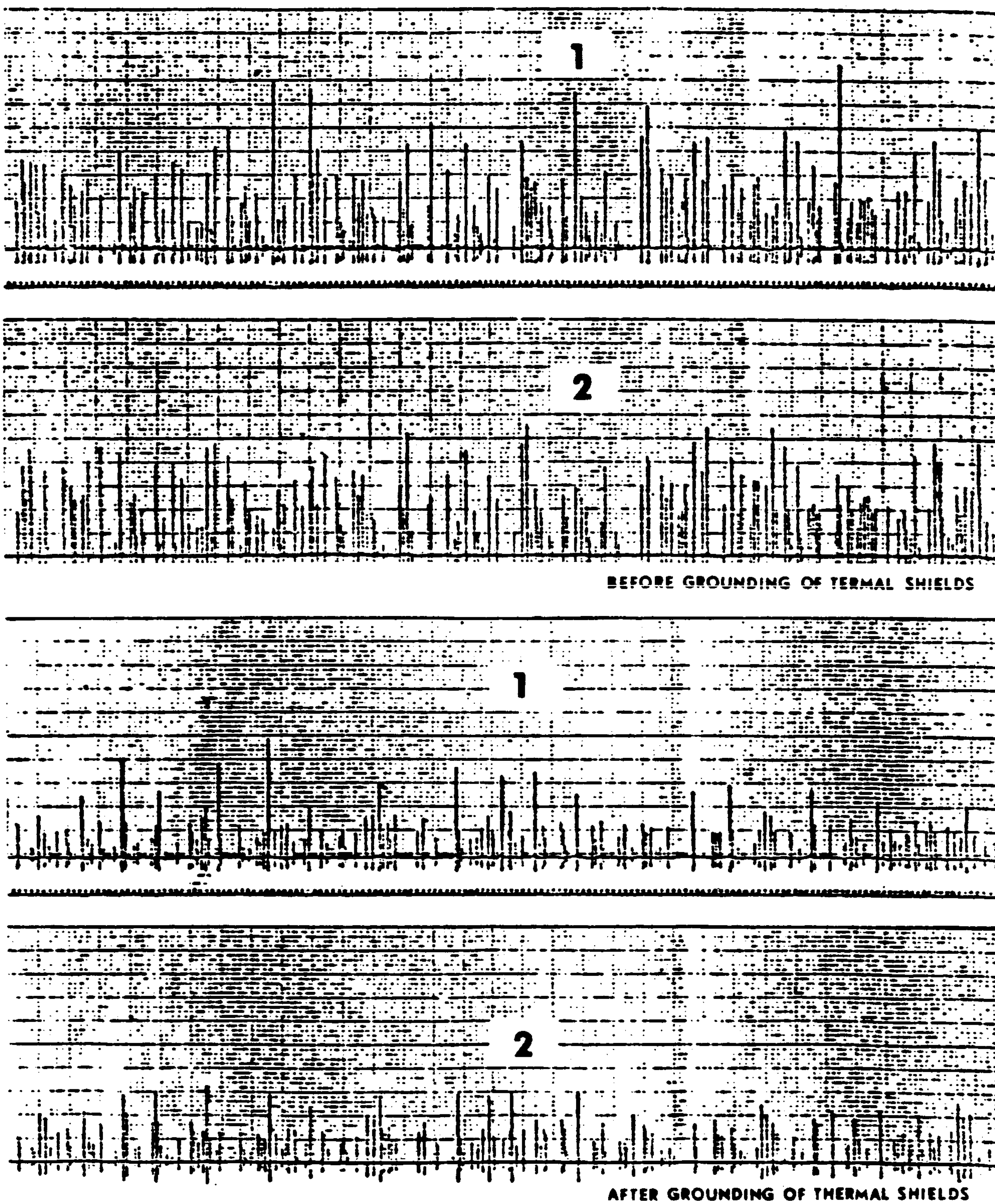


Figure 8. - Effect of grounding thermal shields.

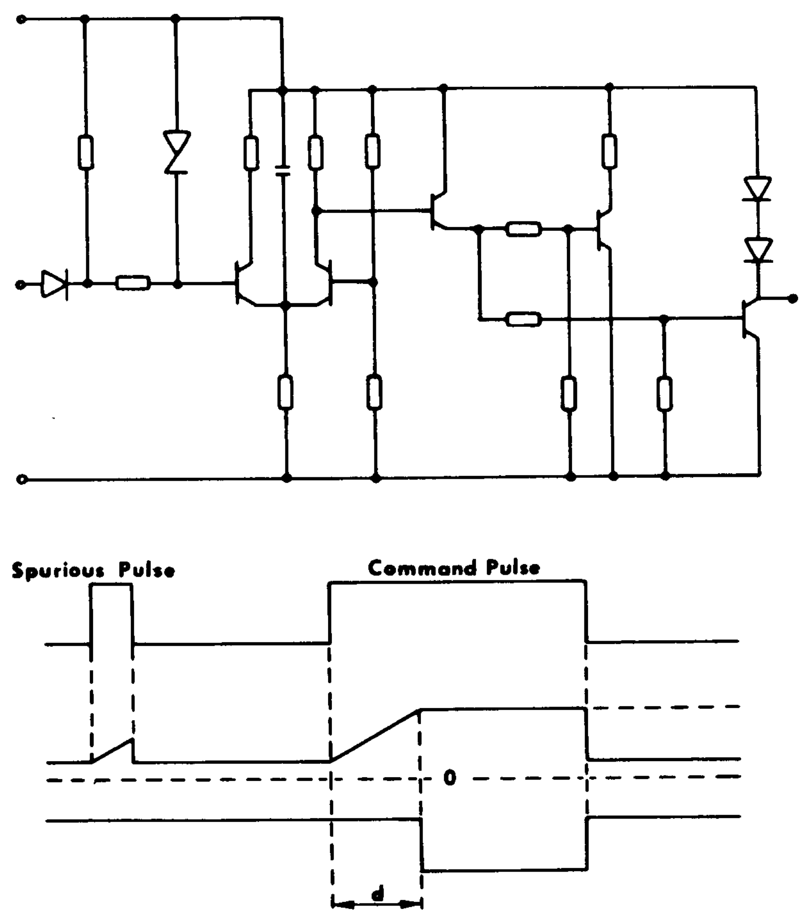


Figure 9. - Improved command interfaces.

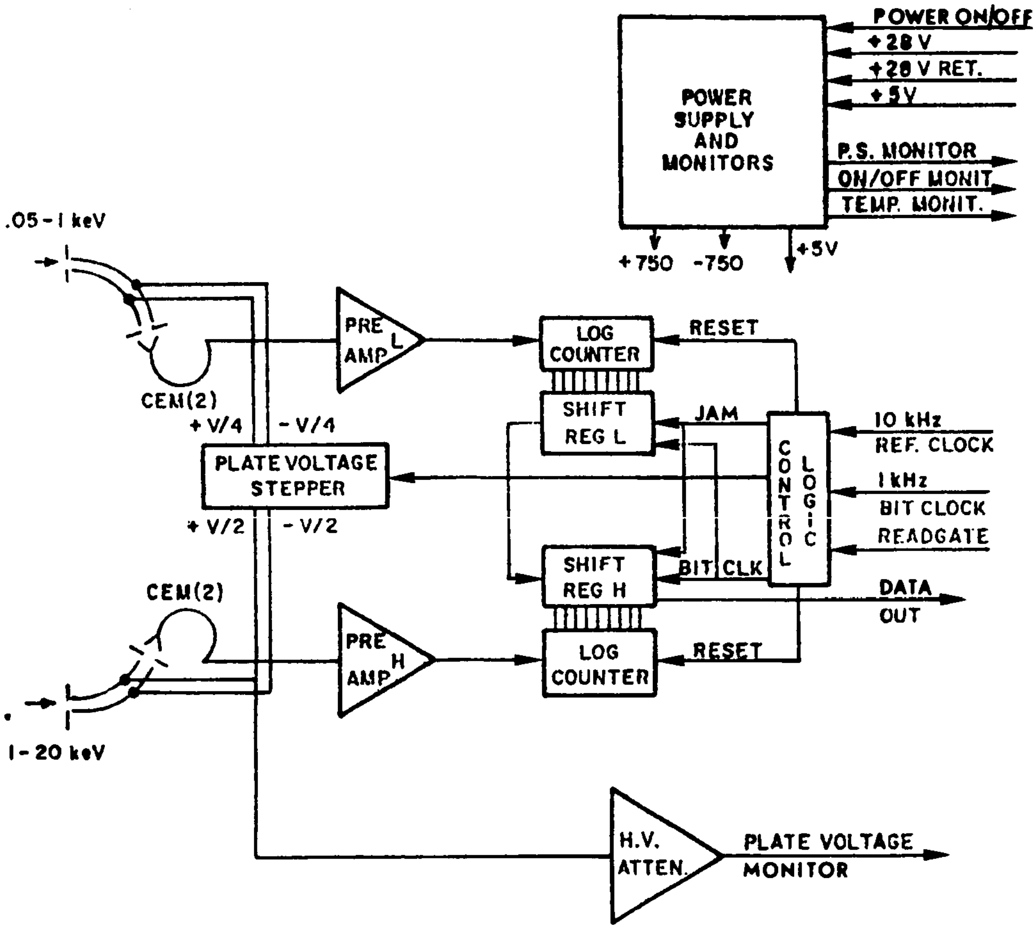


Figure 10. - Electrostatic analyser SSJ/3.

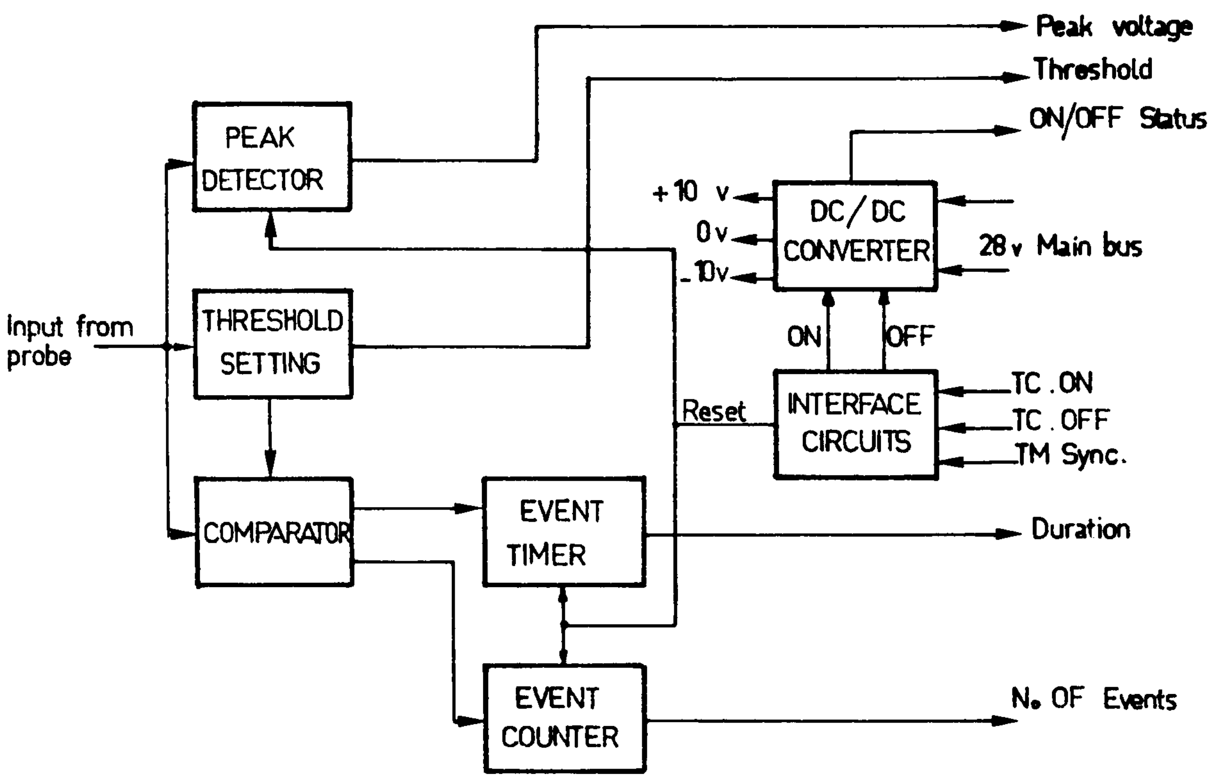


Figure 11. - Electrostatic event monitor.