THE DISCHARGE DETECTOR EXPERIMENT

Antonio Ciccolella - Johannes Wolf
EUROPEAN SPACE AGENCY — ESTEC
Postbus 299 — NL2200 AG Noordwijk; Tel.: +31 71 565 5461; Fax: +31 71 565 4999; email: jwolf@esa.int

Abstract

The Discharge Detector Experiment (DDE) aimed to **investigate the internal discharges** caused by **charging effects** on spacecraft in **GEO** is described. The DDE has been funded by ESA and is currently running on a Russian spacecraft **Express 14**. The Experiment has been in **operation** for **more than one year** but **no discharges** have been recorded so far. This is an indication that in GEO the **reason for unexpected failures** or temporary degradation/loss of function can **not be levied against the occurrence of internal dielectric discharges**. The fact that the DDE is still fully operable also proves that it is possible to successfully run Commercial off the Shelf (COTS) hardware in space for a period of at least one year.

Introduction

It is becoming progressively more important to protect spacecraft from in-orbit environmental effects that can jeopardise their operations and prevent the achievement of mission objectives. This is particularly necessary in the present climate of tighter budgets and closer public scrutiny.

The electrostatic discharge (ESD) induced by the natural space environment is a major threat to spacecraft systems. ESD takes place when electric fields, caused by differential or deep dielectric charging, exceed the breakdown voltage of an insulator and a discharge current flows for a brief period. The resulting transient discharge current/field can interfere with a spacecraft s electronics, with effects ranging from temporary upsets to permanent failures.

Current thinking is that internal discharges of electrostatic energy caused by deep charging of dielectric materials placed inside the spacecraft are potentially damaging to internal electronics. If these occur close to sensitive circuits where there is a high probability of their producing electromagnetic pulses that will have a detrimental effect. These discharges are certainly more harmful than those occurring on the exposed insulating surfaces of a spacecraft such as thermal blankets, solar arrays.

The ESD tests currently performed on spacecraft at both equipment and system level are, in general, not fully representative (in terms of level, risetime, pulsewidth, energy) of the electromagnetic effects caused by electrostatic discharges occurring in orbit. Hence these tests do not guarantee absolute immunity of the spacecraft from an ESD threat, as has been already proven by the anomalies and failures that still take place in orbit, despite successful completion of conventional ESD test activities. Furthermore, tests performed on ground do not address the problem of the internal ESD that remains an area of great concern.

To investigate the dynamics of environmentally induced ESD in situ, a Discharge Detector Experiment (DDE) has been funded by ESA. This experiment has been designed for mounting on a spacecraft where it will capture the characteristics of an electrostatic discharge as it occurs in orbit. The experimental data thus obtained will initially help to improve the protection techniques and test characteristics used and lead to more reliable spacecraft.

Experiment Description

The DDE consists of two probe boxes outside and an electronics box inside the Russian Spacecraft Express 14. The probe boxes contain a dielectric sample, mounted on a sample holder with shunt (see Fig. 1) and an electric field probe (see Fig. 2).

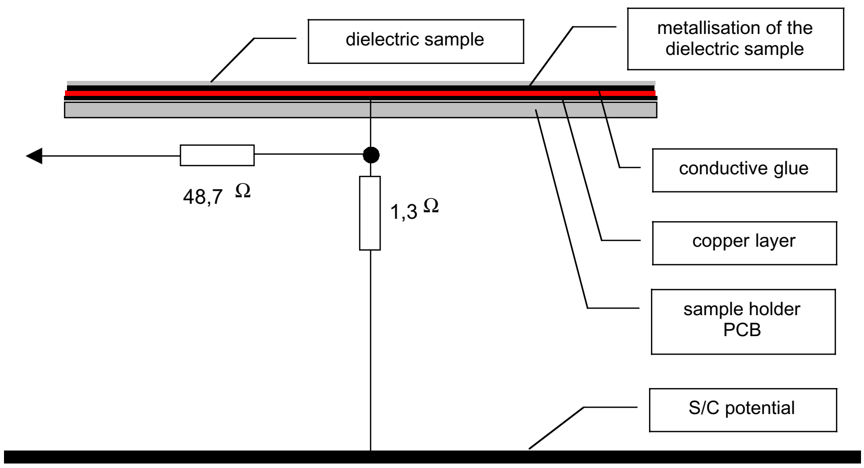

Figure 1: Dielectric sample set-up

The dielectric sample is 100 m Mylar foil, metalled on one side and glued (using conductive glue) to a sample holder with shunt and matching resistors. In case a discharge to the S/C structure occurs, the current through the shunt will cause a voltage drop that is detected by means of a peak detector circuit. In case a surface discharge appears between different charged areas of the dielectric sample, the resulting transient electric field will be sensed by the electric field probe placed close to the sample. Also in the case of a discharge to the structure appearing, the electric field probe will sense the transient electric field produced.

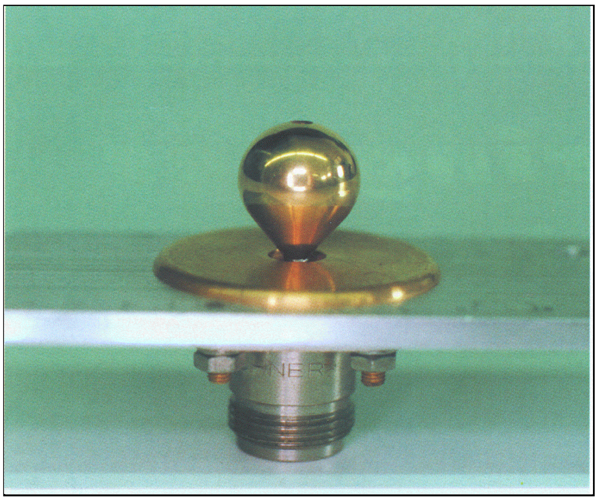

Figure 2: Electric field probe (D-dot antenna)

The rise time of the discharge transients is of primary importance in any study of disruptive consequences of an electrostatic discharge. The DDE has been designed to measure rise times as short as 1 ns, imposing demanding requirements on the components used in the experiment. The broadband electromagnetic probe is a miniature D-dot antenna 17 mm long, suitably shaped and optimised (see Fig. 2). When tested in a GTEM cell, it exhibited a flat frequency response up to 3 GHz. Both, simulation and measurement have also meticulously characterised the probe s electromagnetic behaviour inside the metallic box.

The probe boxes are slightly different: one of them is open on the top, i.e. not covered with thermal blankets, while the other one has an aluminium top cover and is further covered with thermal blanket. The thickness of the closed box s top cover is chosen to have a nearly equivalent shielding factor to the thermal cover of European spacecraft. Since the host spacecraft is hermetically sealed and pressurised, placing the boxes inside the spacecraft would affect the dynamics of the discharge (which is pressure-dependent) and thus introduces a high degree of shielding due to the pressurised container. The results obtained would not be representative of European spacecraft which are usually not pressurised. (The DDE probe boxes are therefore mounted externally)

Parametrical analysis and test of the optimum thickness of the wall of the external box and the type and the size of dielectric material have been performed using the facilities of the Novosibirsk State University. Semi-rigid cables to the hermetically sealed feedthroughs in the spacecraft wall connect the probe boxes to the electronics box.
The block diagram of the DDE is shown in Figure 3.

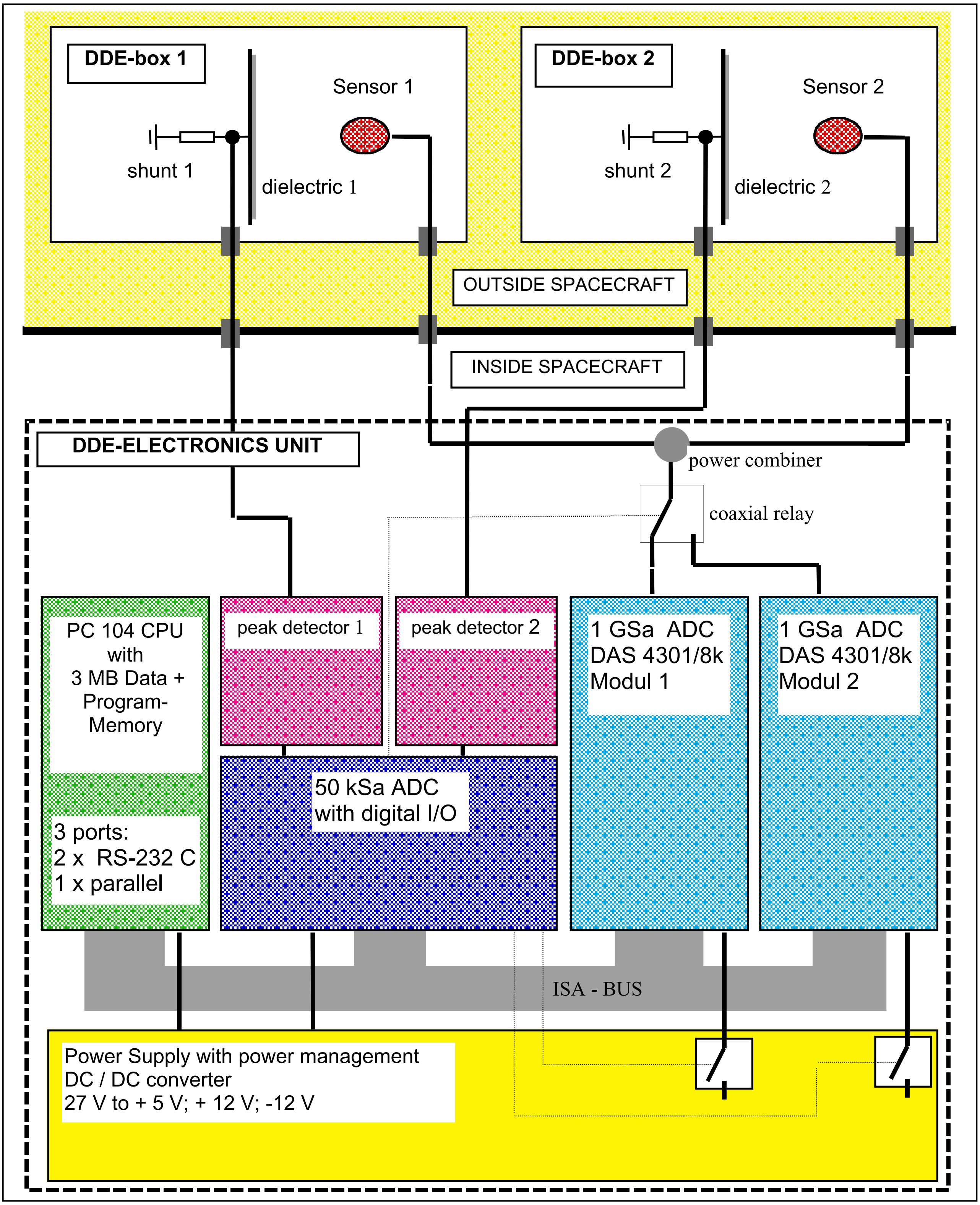

Figure 3: Discharge Detector Experiment functional block diagram

The signals from the electric field probes are consolidated by means of a signal combiner (assuming that there is only one discharge event at one time in one box) and fed to an 1 GSa 8-bit analogue to digital converter (ADC). This offers the possibility to implement a redundant converter without exceeding the requirements regarding weight, power and dimensions. In order to decide in which probe box an event has occurred, the information available from the analogue peak detectors is used.

The high speed ADC is operated in a free running mode, where a trigger freezes the acquired data in memory and initiates the readout from the processor into the onboard non-volatile Flash memory. Thus also a pre-trigger information is available which ensures that the complete slope of the transient is captured.

The analogue peak detectors are able to store the peak of the input voltage for a period of time, which allows the slow 50 kSa ADC to convert the analogue peak value into a digital word. This is also stored in the non-volatile Flash memory together with date and timestamp of the event. The peak detectors trigger the conversion of the slow ADC. So this ADC can also be used to acquire housekeeping data for the DDE.

For the DDE no space-qualified parts have been used. During the design special care has been taken to achieve a maximum reliability by applying reasonable design margins and to foresee redundancy to the maximum extent possible. This is also especially important for the software design. Several mechanisms are implemented to increase the software reliability. The processor board used provides also an hardware-watchdog, which is supported by the software. The DDE software has been extensively tested over a period of 8 months, using it also for the hardware tests (mechanical, thermal, performance and EMC).

Command and Data Transfer

The transfer of command and data is performed via a special designed Russian interface box to the telemetry system of the spacecraft. Since the detailed interface to the Russian telemetry system was not available for the Experiment design it was decided to implement such an interface box and to have a simple ASCII-protocol between DDE and interface box. This makes it possible to send commands as a very simple text and to read the downloaded data using a simple text editor. The transmission between spacecraft and ground control is in binary format according to the Russian telemetry format. The downloaded data are then converted into text format and provided on an FTP server. Commands for uploading to the DDE will be sent to this FTP server too, converted into binary format, transmitted to the spacecraft and then send to the DDE via interface box.

This approach had the advantage of having a well-defined data and command interface which was completely independent with respect to changes of the Russian telemetry system and which not required detailed knowledge about the Russian telemetry system.

By means of software program developed for the operation and testing of the DDE on ground the downloaded data can easily be converted into a graphical representation.

Operation of the DDE

Express 14 has been successfully launched in March 2000. Soon after the spacecraft entering its planned orbit the DDE was successfully switched on the first time in space. During the first phase (duration of about two months) the telemetry to the spacecraft was performed every 10 days. The preloaded data of the DDE have been able to be downloaded successfully. Then the Experiment was set into its acquisition mode. After putting into operation all payloads on board Express 14 the telemetry sequence was reduced to once per month. Since the Experiments non-volatile Flash memory has enough capacity to store up to 8000 events, the low frequency of telemetry sessions is no problem. With short interruptions due to switch off during

Status	
Date	25/04/01
Time	07/30/00
Status	0
MEM_index	0017
Transfer	0016
ACQ status	0
sel. ADC	0
ADC gain	03
ADC TRG	020
ADC Slope	1
ADC about	0010
ADC CLK	020
ADC samples	0070
Thresh. 1	0100
Thresh. 2	0100
DAS4300	0000
PC-LPM error	0000
Controller	0000
RS232 error	000
ST Date	25/04/01
ST Time	07/29/25
PC pwr up	0000
PC-LPM stat.	0000
DAS4300	1500
5P voltage	5075
12P voltage	1191
12N voltage	1190
Temp1	0212
Temp2	0219
Temp3	0240
Temp4	0229
reboot error	1
PkDetOffs1	00004

Figure 4: DDE status information

several spacecraft positioning operations the DDE has been operating for 14 months. There has been no discharge event recorded so far. The functionality of the DDE is checked in several ways: there are sequential self-tests, which are performed automatically from the DDE every hour and reported to the status block. The hardware watchdog prevents the DDE software from hanging. During each telemetry session to the DDE also the complete status information is downloaded. Figure 4 shows the contents of the DDE status block as displayed by the DDE software. Beside date and time information there is the general status displayed, all acquisition parameters as gain, trigger level, acquisition clock, number of samples to store per acquisition, threshold levels for the peak detectors, error status of the fast ADC board, the slow ADC board and the controller, status of the serial communication, followed by the information generated during the last self-test. Temperatures are measured on the fast ADC board (hot spots) , on the DC/DC converters and the side wall of the DDE box. The internal supply voltages are measured and the status block also contains information that the watchdog caused the DDE to reboot.

The following table shows the orbit parameters (GEO):

Orbital period	86146 s + 15 s
Inclination	0 — 0.2 grad
Eccentricity	0 — 0.001
Inclination in longitude	± 0.3 grad

Conclusion

The fact that the DDE has not recorded one single discharge event over a period of at least 14 months suggests the conclusion, that the observed and reported malfunctions of spacecraft in GEO can not be traced back to effects of deep electric charging as per current thinking. This is more likely a secondary effect of surface discharges on the solar panels caused by surface charging due to the penetration with plasma and electrons from the solar wind. Nevertheless the DDE proves that it is possible to operate non space-qualified COTS equipment in space for a reasonable period of time.