Rad hard test of Caen HV prototype A877 for MDT and TGC performed on the CYCLONE proton beam

G. Iuvino, A. Lanza, P. Novelli*, W. Vandelli[&]

Istituto Nazionale di Fisica Nucleare, Sezione di Pavia and [*]Dipartimento di Fisica Nucleare e Teorica, via Bassi 6 - Pavia, Italy

[&]Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, via Bassi 6 – Pavia, and Dipartimento di Fisica dell'Universita' di Parma, Parco Area delle Scienze 7a - Parma, Italy

G. Passuello

C.A.E.N. S.p.A., via Vetraia, 11 - Viareggio, Italy

Abstract

A HV prototype module, A877, equipped with 8 DC-DC channels, was produced by CAEN for MDT and TGC detectors. It was tested for TID and SEE on the proton beam of UCL at Louvain-la-Neuve in March 2003. All the irradiated DC-DC channels passed the requested TID maximum level, while the on-board controller was irradiated only up to one half of the requested SEE maximum level, because of the very high TID dose that should have been accumulated. No destructive SEE was observed, but one communications optocoupler was damaged. After its replacement, the prototype was checked, and no failures were detected.

The reached NIEL level was only one third of the evaluated maximum level, and a new test, using the neutron beam, is foreseen in 2003 with the same prototype.

1. Introduction

The prototype distributor A877[1], shown in Fig. 1, was modified in 2002 by CAEN from a previous CMS design for the MDT and TGC detectors. It is equipped with 8 linear regulators (on the left in Fig. 1) and 8 DC-DC converters (to the center of Fig. 1), and provides output voltage from +2.0 to +4.0 kV with a maximum current of 1 mA each channel (for the DC-DC converters). It is driven by a master board, A876, plugged in a SY1527 (or SY2527) mainframe.

A877 is linked to A876 by means of 4 types of connections: an RG-58 cable, which provides the +4.0 kV power supply to the linear regulators, a +48VDC, which provides the power supply to the 8 DC-DC converters; a low voltage connection, supplying the distributor on-board electronics; and a communications connection, carrying the three communications signals, Clock, Sync and Data, and the power supply for the optocouplers.

The distributor A877 was tested at the Cyclone accelerator of the Universite' Catholique de Louvain (UCL) in Louvain-la-Neuve, Belgium, on March 20, 2003, following were possible the recommendations of the Atlas Policy on Radiation Tolerant Electronics[3]. The goal was to reach the maximum radiation values concerning TID and SEE for the planned HV power supply positions in the Atlas detector, which were at the time[2]:

Total Ionization Dose (TID): 230 Gy, including a safety factor of 70 with respect to the simulations;

Single Event Effect (SEE): $2*10^{11}$ h/cm^2, including a safety factor of 20 with respect to the simulations;

Non Ionizing Energy Loss (NIEL): 10^{12} n/cm^2, including a safety factor of 20 with respect to the simulations.
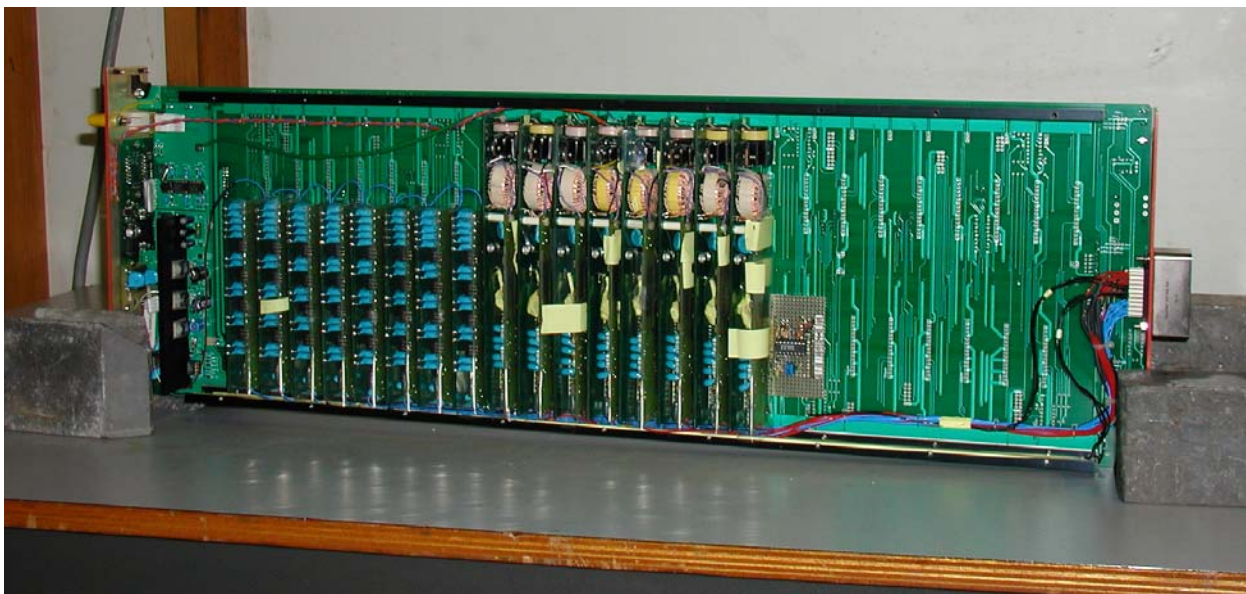

Fig. 1 – HV distributor A877

2. Test setup

A877 is composed of three sections: the first, on the left in Fig. 1, is the controller, with two microcontrollers ATMEL AT90S8515-8JC, the power supply unit, made up of three voltage regulators (1 LT1185CT and 2 MIC29302BT) and the communications unit, with 3 optocouplers (2 Agilent 2630 and 1 Fairchild 2630); close to the controller there is the second section, composed of 8 linear regulators, the small blue modules in Fig. 1; and finally there is the third section, at the center, formed by 8 DC-DC converters. The sections under test were the first and the last, because linear regulators are not able to reach our required current of 1 mA per channel with radiation tolerant components.

The available beam was 60 MeV protons, with a circular spot of 100 mm diameter. In order to precisely define the irradiated region, we used a brass collimator built by the CMS Drift Tubes Padova group, which dimensions are 85 x 52 mm^2, with a thickness of 20 mm. The DC-DC section was subdivided in six regions, as shown in Fig. 3, each one with dimensions equal to the brass collimator aperture placed with its largest dimension horizontally, and in order to avoid beam superposition the fifth DC-DC converter (DC-DC #4) was left out.

The controller section was covered by one region, obtained by placing the brass collimator with its largest dimension vertically.
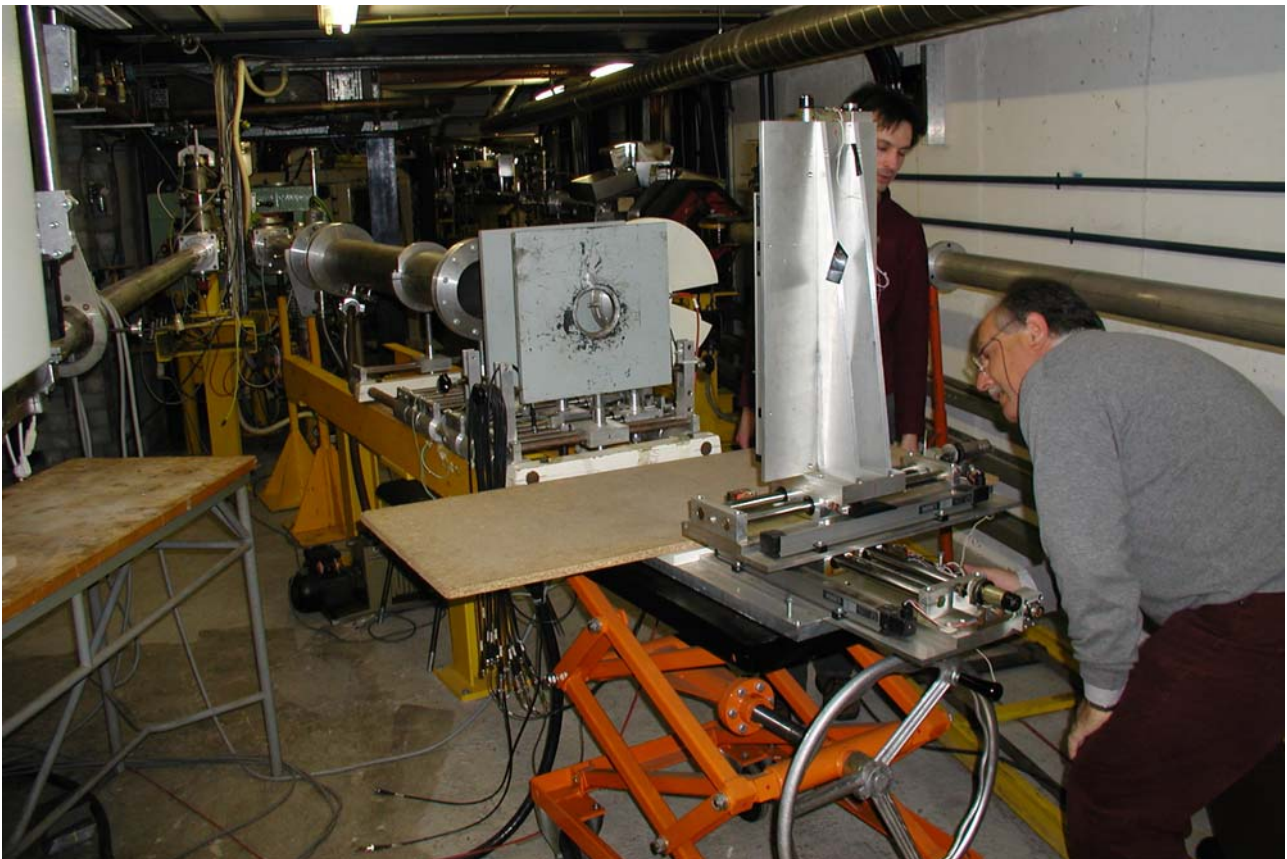

Fig. 2 – The Cyclone 60 MeV proton beam pipe, and the elevator used to center the distributor

The distributor was placed at a distance of 20 cm from the beam pipe, and centered on the beam spot by means of an elevator manually driven. It was connected to the SY2527 mainframe in counting room by means of 30 m screened cables (communications, +48VDC and LV power supplies).

All 8 DC-DC output were loaded with 5 MΩ resistors, in order to reach currents of 800 μA at 4 kV. With such value, we were able to monitor possible higher currents due to irradiation damage.
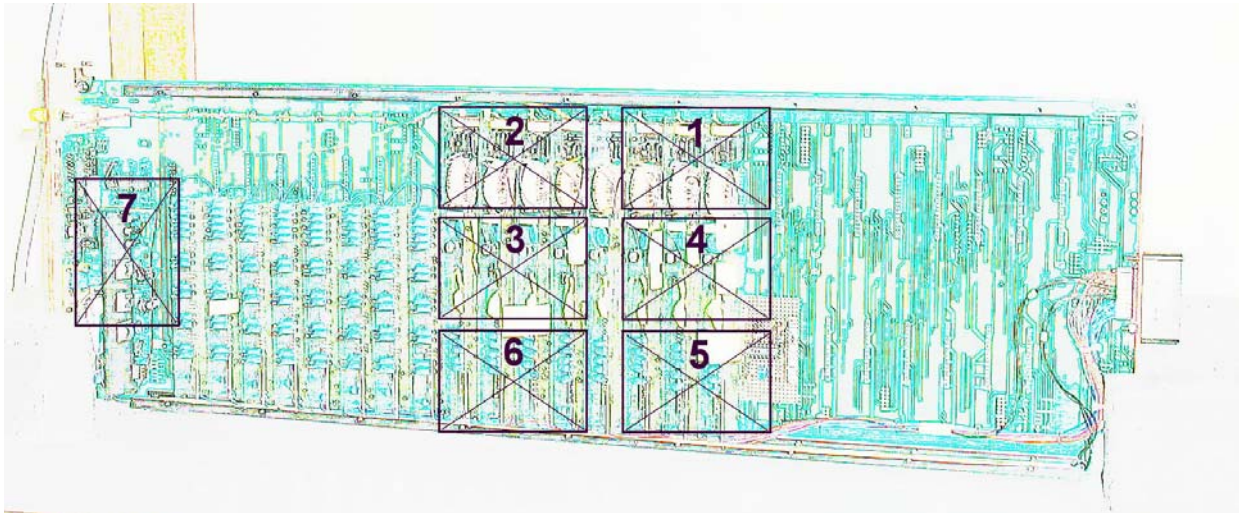

Fig. 3 – The 7 irradiated regions, as defined by the brass collimator aperture

The chosen proton fluence was 10^8 p/(cm^{2}s). We decided to perform the irradiation test of all 7 regions in two steps, the first up to an integrated fluence of 10^{11} p/cm^2, and the latter up to $2*10^{11}$ p/cm^2. The reason was to avoid controller damage, due to the very high TID dose, which could have made the distributor out of control. Microcontroller of Atlas ELMB (Embedded Local Monitor Board) belonging to the same family of the one used in A877 died before reaching $2*10^{11}$ p/cm^2 during a test performed in the same period[4]. As a matter of fact, first step corresponds to a TID dose of 145 Gy and to a NIEL fluence of $1.6*10^{11}$ n/cm^2, while second step corresponds to a TID of 290 Gy and to a NIEL of $3.2*10^{11}$ n/cm^2.

Regions were irradiated following the sequence shown in Fig. 3. Due to loss of communications described below, only the regions 1, 4 and 5 were irradiated during the second step. These regions included 3 DC-DC converters, from #5 to #7.

Fig. 4 shows, as an example, the position of the brass collimator on the distributor during irradiation of region 5, while Fig. 5 shows the position and orientation of the brass collimator during irradiation of region 7. It has to be noticed that the distributor was reversed during this last irradiation, in order to keep microcontrollers and related logic in front of the beam.

Fig. 4 – Irradiation of region 5, beam comes from right.
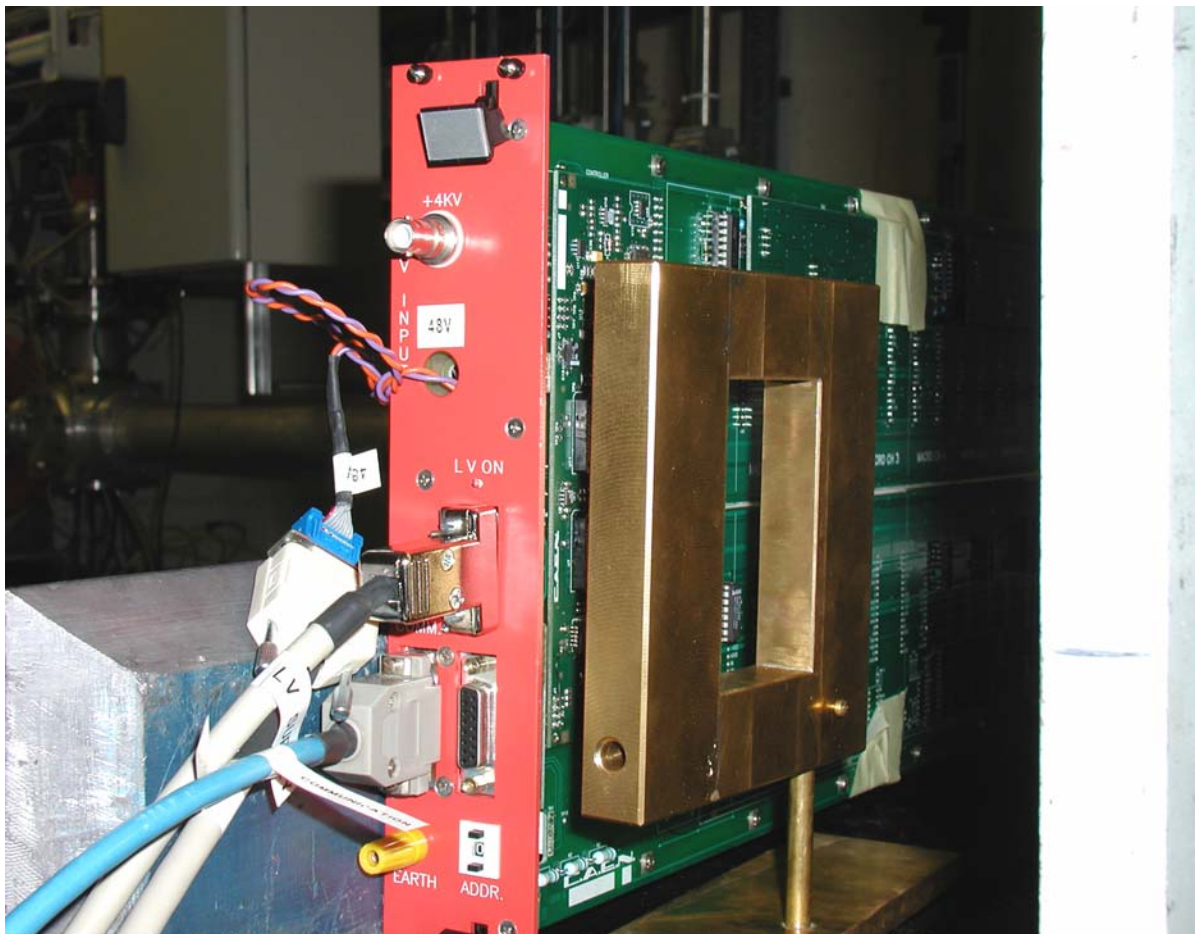

Fig. 5 – Irradiation of controller, beam comes from right
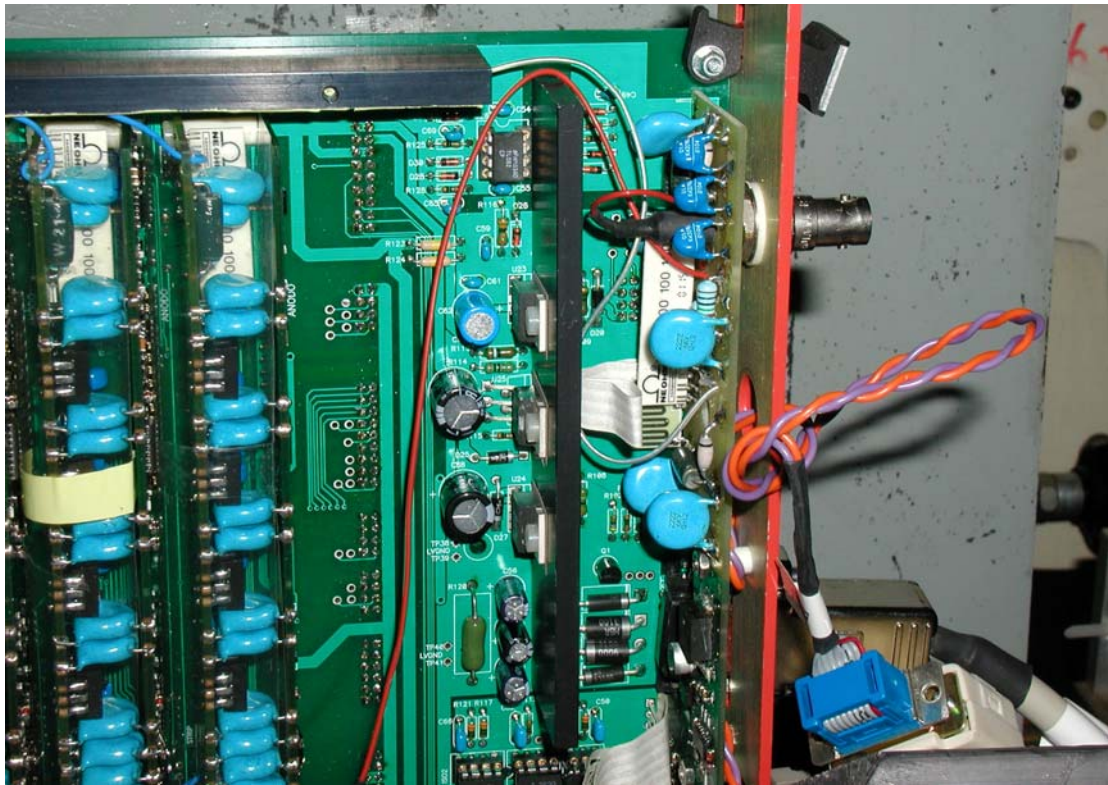
Fig. 6 – Irradiation of controller, beam comes from behind
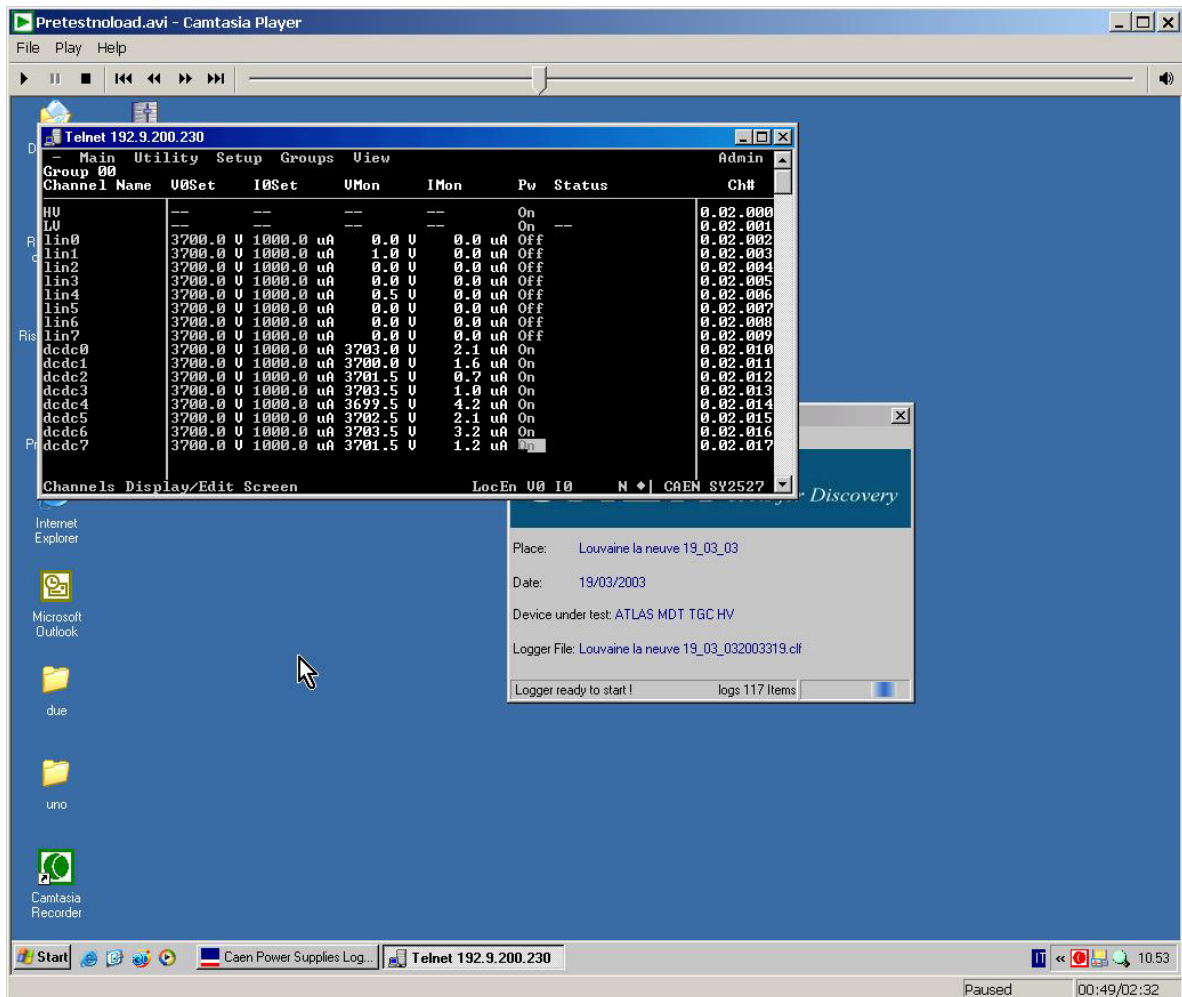

Fig. 7 – Monitor screen during data acquisition

On the other side of the distributor, as shown in Fig. 6, there are the power supply and communications circuitry, whose irradiation dose was slightly decreased by the screening effect of the pcb material.

Data acquisition was taken using a CAEN proprietary software, which allowed us to save, with a few Hz rate, all the selected parameters for every channel (Date, Time, Channel Name, Status, Vset, Iset, Vmon, Imon) in an ASCII file. Electronic log was performed with the package CamPlay$^©$ by Camtasia$^®$, which is able to record images from monitor and voices. In Fig. 7 it is shown the Telnet window of the SY2527, recorded by CamPlay$^©$, and the CAEN data logger, as they appeared on the monitor screen during data acquisition.

3. Test results

During every irradiation period the set voltage of all DC-DC channels was ramped up and down from 4 kV to 2 kV many times, in order to test the final stage of converters on different power conditions.

The set voltage (Vset) and monitored voltage (Vmon) are plotted for all DC-DC channels and for the irradiation periods of the regions 1 – 6 from Figs. 7 to 14. The X axis reports the absolute time in seconds from start of first irradiation. Plots are divided in six zones, written on bottom, which correspond to the six irradiated regions. Time in between zones was wasted for switching off the beam, moving the distributor on the next region and switching on the beam. Periods in which the DC-DC channel was not irradiated are shown in gray, while periods in which the DC-DC channel was irradiated are shown in black. Continuous line corresponds to Vset, and dots correspond to Vmon.

One zone in the plots is equivalent to a total proton fluence of 10^{11} p/cm^{2}s. It has to be noticed that each DC-DC channel was irradiated on three zones, but they correspond to three different physical regions of the same channel.

All 7 irradiated DC-DC channels showed no significant shift between set and monitored voltages, apart at the beginning and end of every one zone, where the ramp-up and ramp-down periods, respectively, are clearly visible.

Controller performance during irradiation of corresponding region (10^{11} p/cm^2) is shown in different plots, illustrated in Figs. 15 to 22. Here both set – monitored voltages and set – monitored currents are plotted, because this region is sensible to SEE. Events of this type are clearly visible as single dots outside the continuous line surrounded by a small circle, and generally happened at different times. They are due to bit upsets in the microcontroller memories, or buffers. None of that

were destructive events, the refresh of memories or buffers reestablished the correct parameter value.

Near the end of this irradiation period, the 7th, two global events happened, the first after 850 s from the beginning of irradiation, when the absorbed TID was around 88 Gy, and the second after 1200 s from the beginning, corresponding to roughly 125 Gy.

First global event, interesting all channels contemporary, was a communications loss. All channels went unplugged, the controller detected it and switched off the +48 VDC. For safety, controller switches off all channels when detecting something anomalous. This first event were recovered in few seconds switching on again the +48VDC from remote.

Second global event was again a communications loss, but without immediate recovery. First, channels ramped down, switched off by controller that detected something wrong on communications, and after few seconds channels went unplugged, as seen in Fig. 23.

Communications loss was partially recovered only 13 hours later, when the distributor performance after irradiation was checked. Being not able to monitor the channel status during irradiation, we decided to perform the second irradiation step, up to $2*10^{11}$ p/cm^2, only on regions 1, 4 and 5, which included DC-DC #5, DC-DC #6 and DC-DC #7.

The problem was then traced in CAEN, and the reason of communications failure was demonstrated to be only the optocoupler carrying the Sync signal. This optocoupler, visible in Fig. 24 to the right, was originally a CNY17, well known to be not a rad hard component, and it was replaced with some troubles, as shown in the same Fig. 24, with a 2630. Unfortunately, this component was manufactured by Fairchild, not by Agilent, like the other two optocouplers, and the Fairchild process is clearly (a posteriori) not rad hard.

13 hours after irradiation, the distributor functionality was checked. The 8 DC-DC channels were switched on under load, and their set and monitored voltages are shown in Figs. 25 – 32. Only the last channel, DC-DC #7, was not recovered. The cause, as verified in CAEN, was the damage of the Sync optocoupler, whose slew rate was heavily decreased. Sync signal did not last a time sufficient for reading all 16 channels, and last channel, DC-DC #7, could not be acquired. After its replacement with an Agilent 2630, also the DC-DC #7 was completely recovered.

4. Conclusions

Three DC-DC converters were irradiated up to 290 Gy, and other four up to 145 Gy, without showing any damage. The maximum specified TID level was fully exceeded by all three units. In the meantime, a revision of the Radiation Tables[5] lowered the TID maximum level to 140 Gy, so all seven irradiated units passed the new TID level.

Controller was tested against SEE up to 10^{11} p/cm^2, having known that the on-board microcontroller cannot survive to $2*10^{11}$ p/cm^2. SEE events happened, but no one was destructive. During controller irradiation, one communications optocoupler, found to be produced by Fairchild instead of Agilent, was seriously damaged, preventing the monitoring of the channel performance during the second irradiation step. After its replacement, the module was completely checked, and showed no other failures.

Accumulated NIEL was $3.2*10^{11}$ n/cm^2 for the three most irradiated channels, and only one half for the other four channels and controller. No damage was induced by this NIEL level.

In order to reach the target of 10^{12} n/cm^2, a new irradiation test, performed on the UCL neutron beam, is planned for July 2003.

Acknowledgments

References

1) Atlas MDT power supply system - Technical Information Manual, rev. 0; CAEN, 18 September 2002
2) M. Dentan: Official Atlas Radiation Tables and Extraction Tool, November 2001 available at http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm.
3) M. Dentan, P. Farthouat, M. Price: Atlas Policy on Radiation Tolerant Electronics, ATC-TE-QA-0001, July 2000.
4) F. Linde, private communication
5) F. Anghinolfi : Official Atlas Radiation Tables, in preparation.
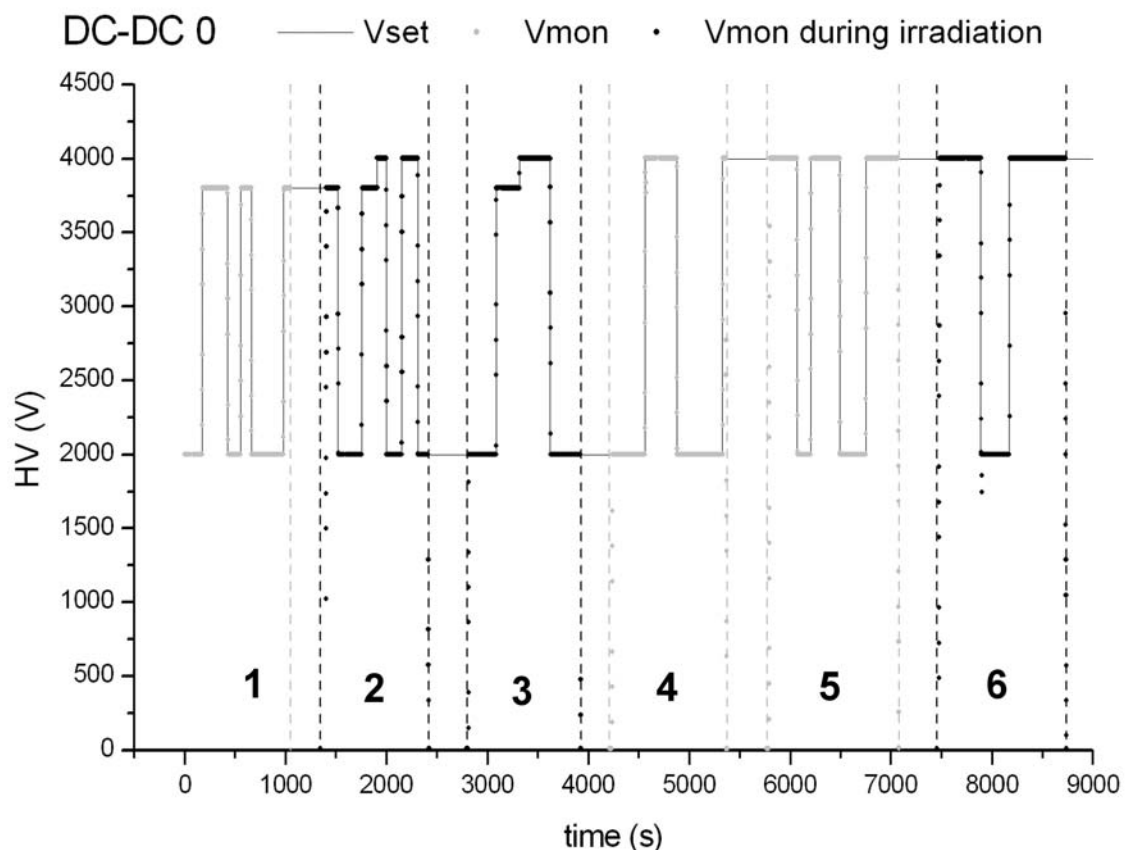
Fig. 7 – Set and monitored voltages for DC-DC #0
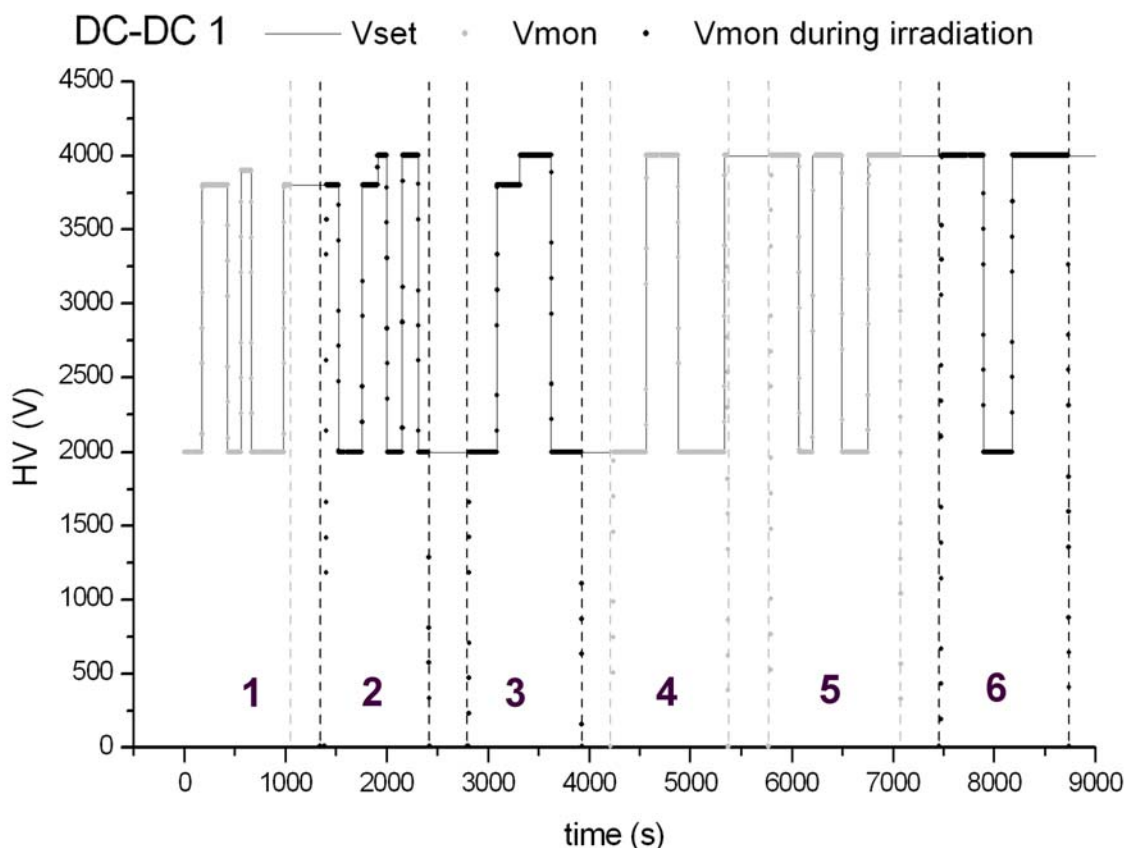
Fig. 8 – Set and monitored voltages for DC-DC #1
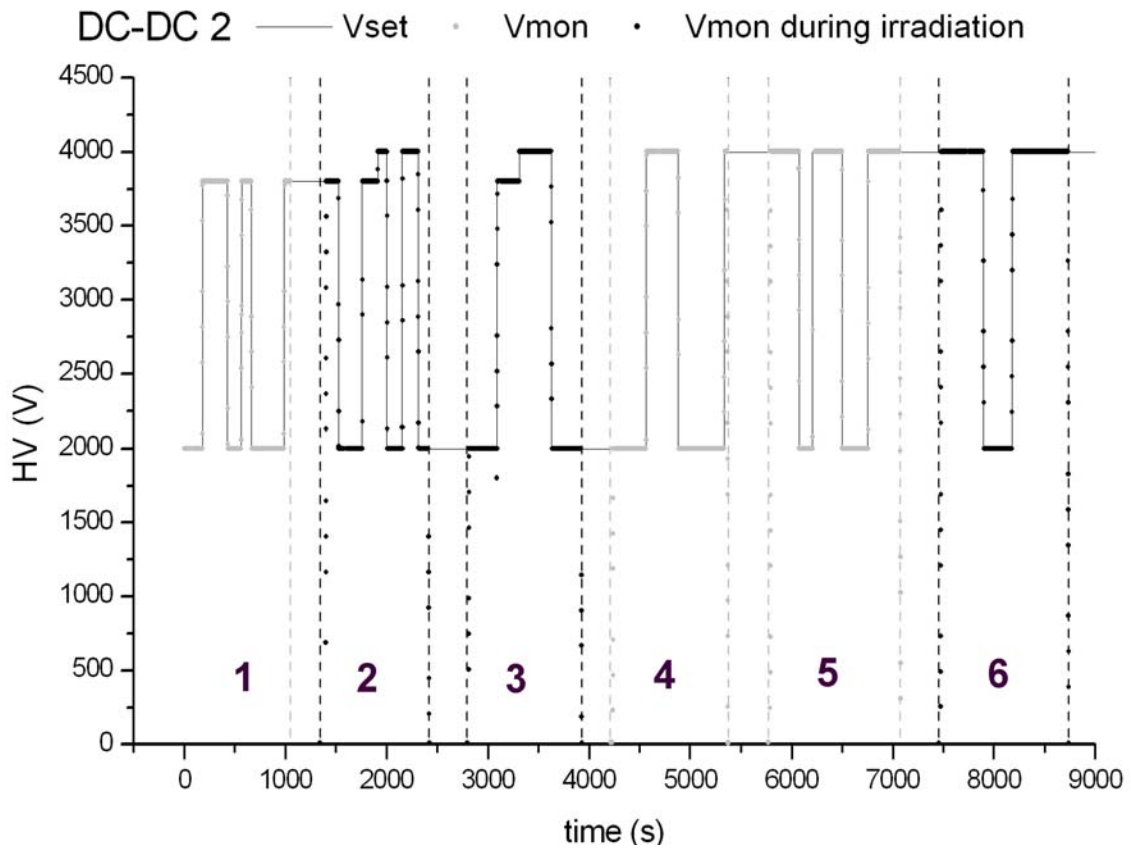
Fig. 9 – Set and monitored voltages for DC-DC #2
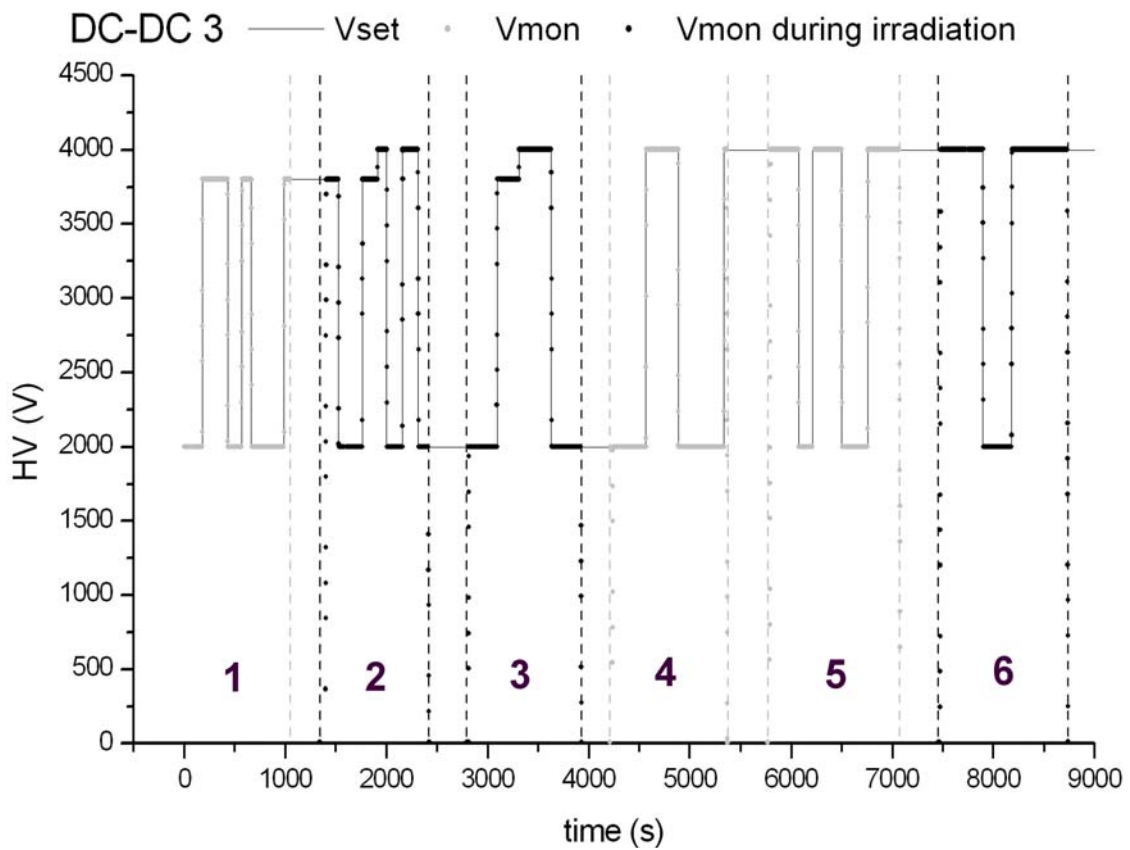
Fig. 10 – Set and monitored voltages for DC-DC #3

11
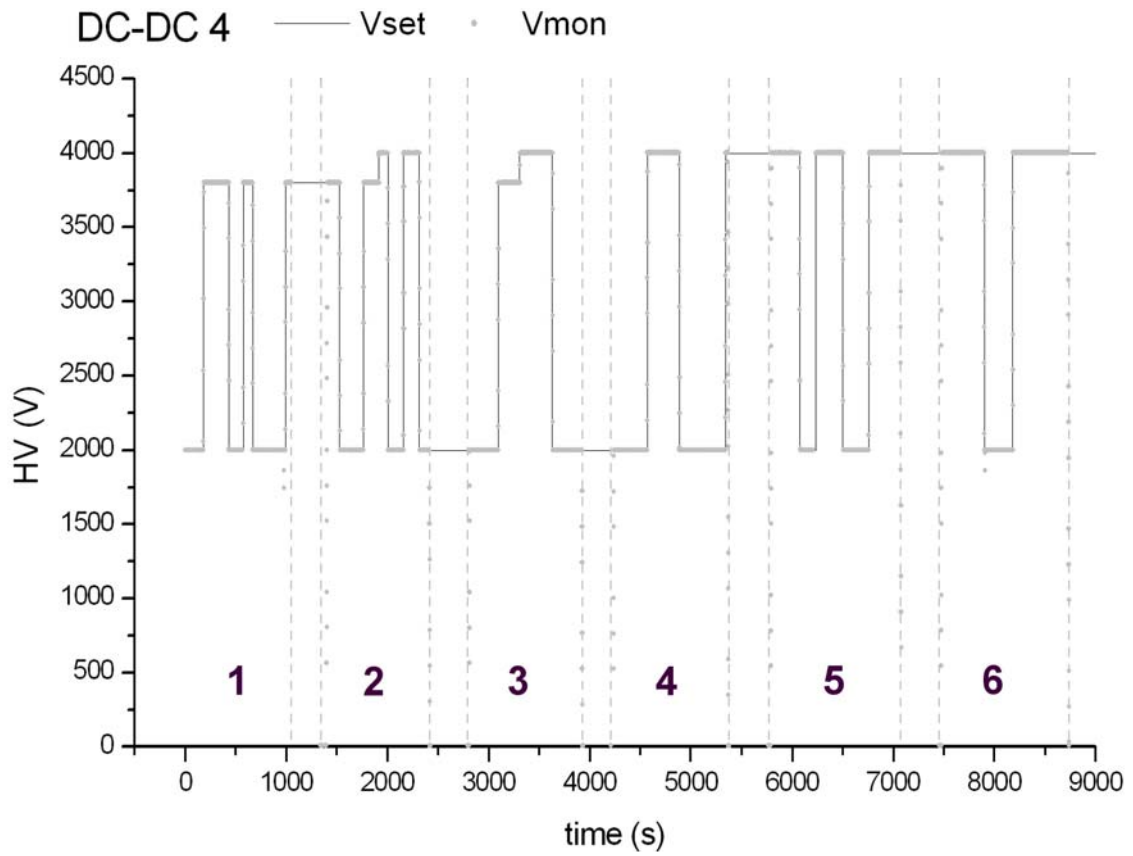
Fig. 11 – Set and monitored voltages for DC-DC #4
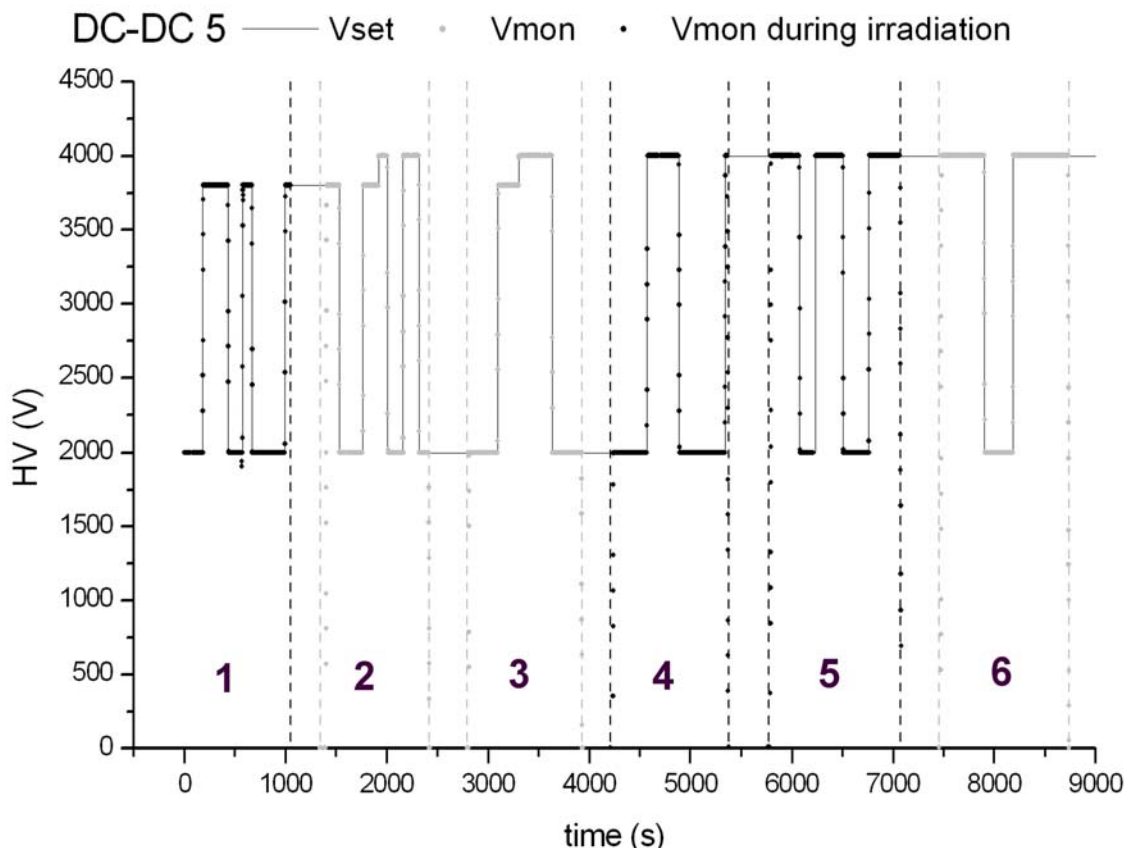
Fig. 12 – Set and monitored voltages for DC-DC #5
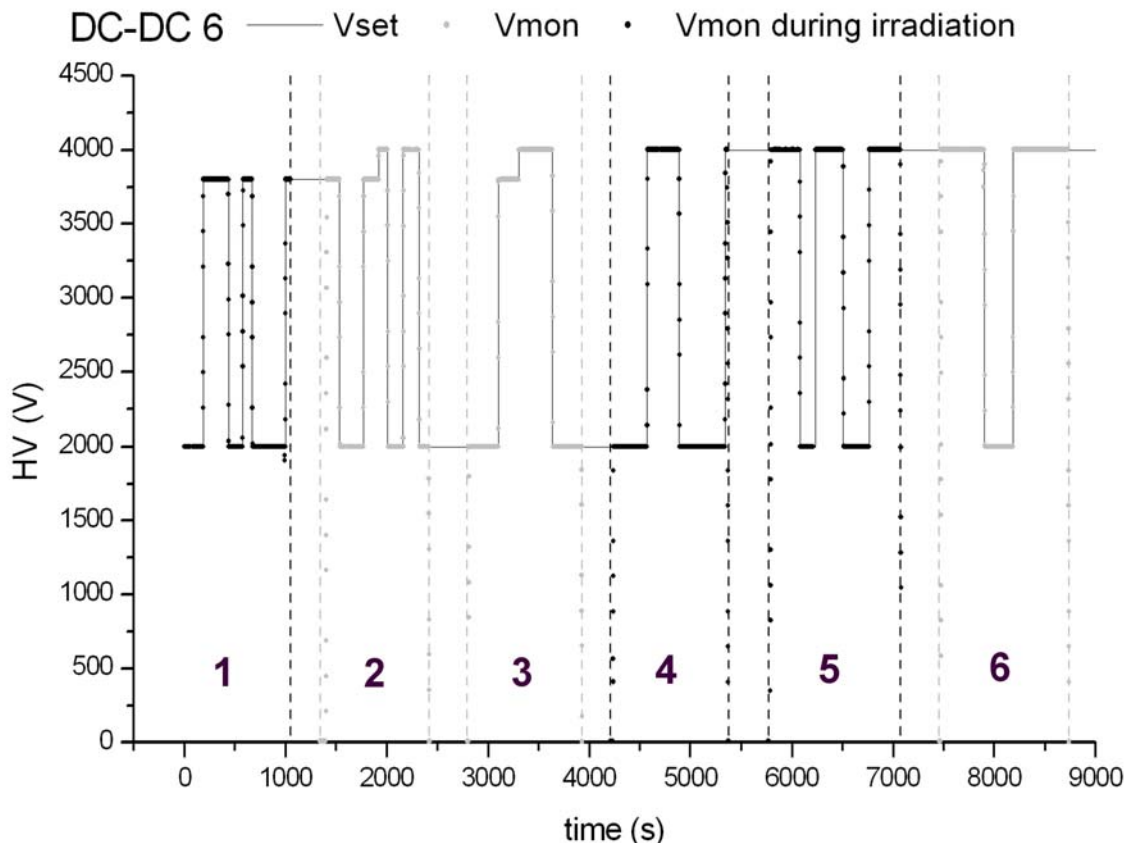
Fig. 13 – Set and monitored voltages for DC-DC #6
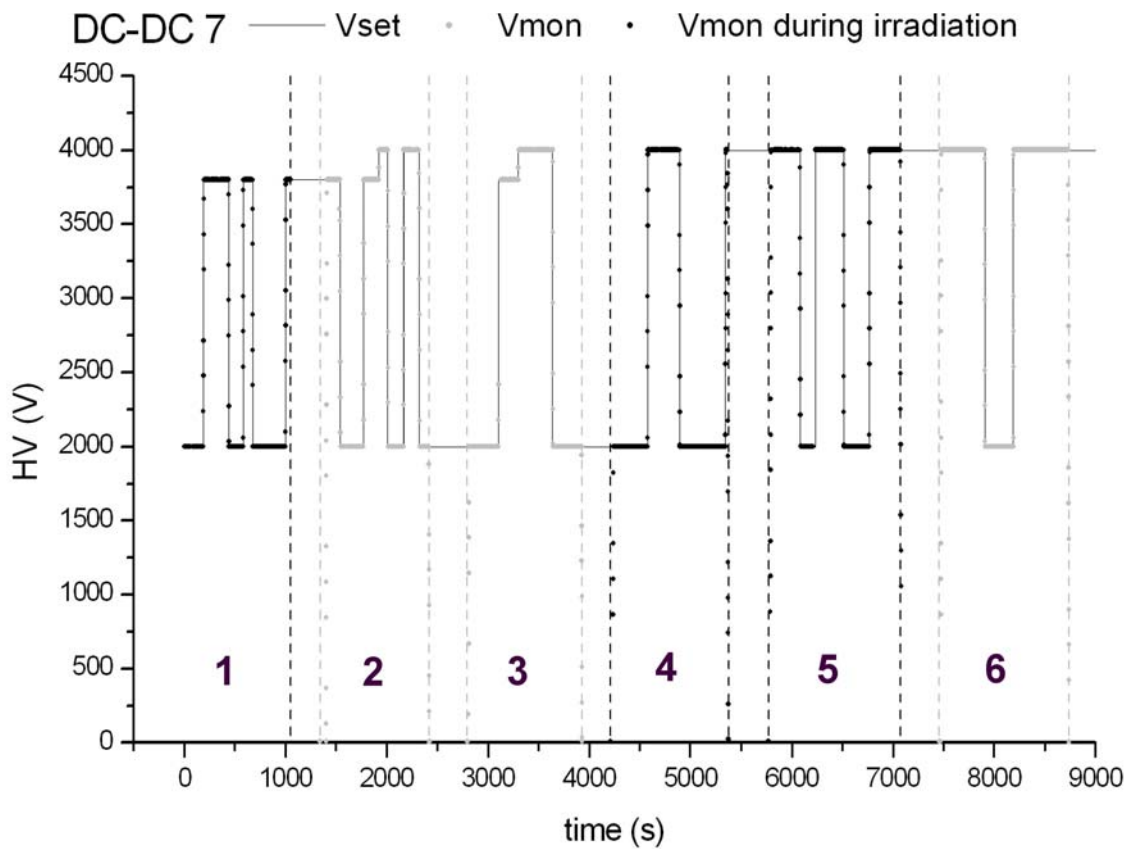
Fig. 14 – Set and monitored voltages for DC-DC #7
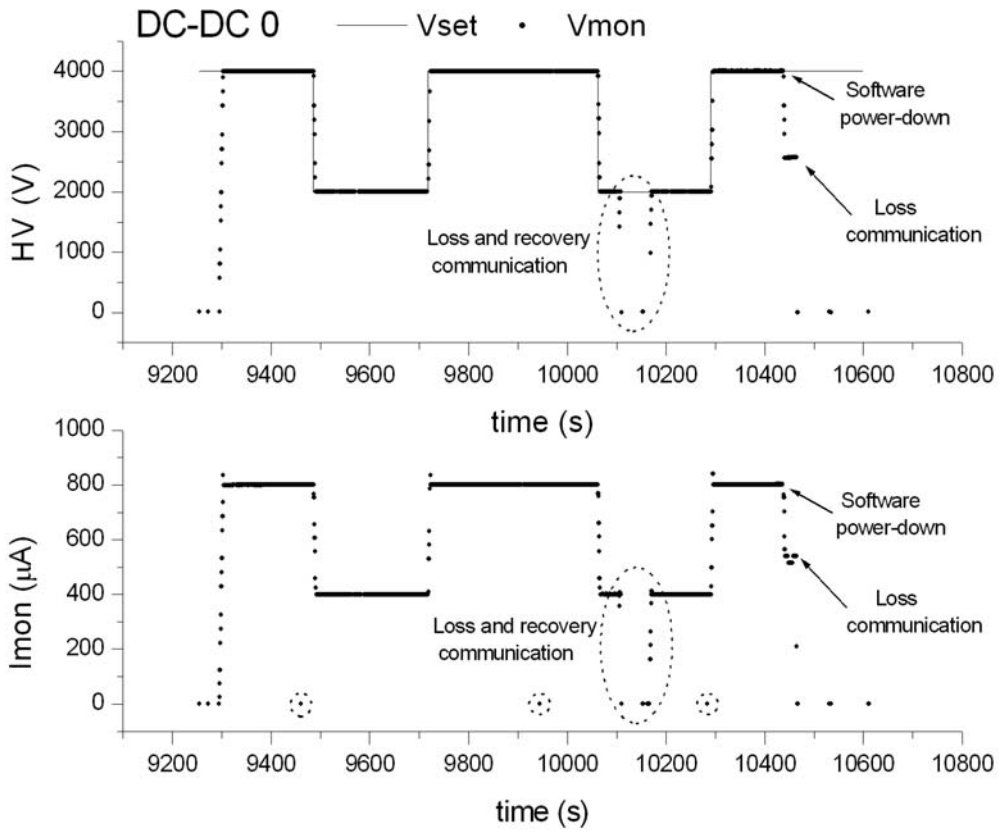
Fig. 15 – Set and monitored voltages and currents for DC-DC #0 during controller irradiation
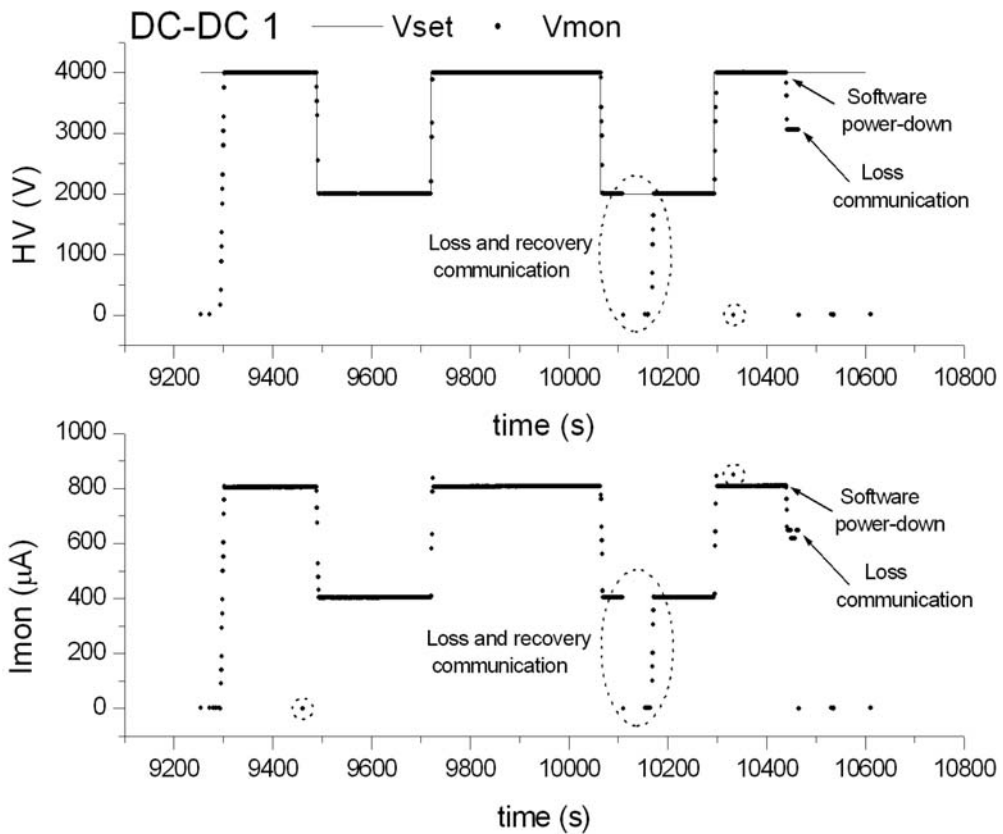
Fig. 16 – Set and monitored voltages and currents for DC-DC #1 during controller irradiation

14
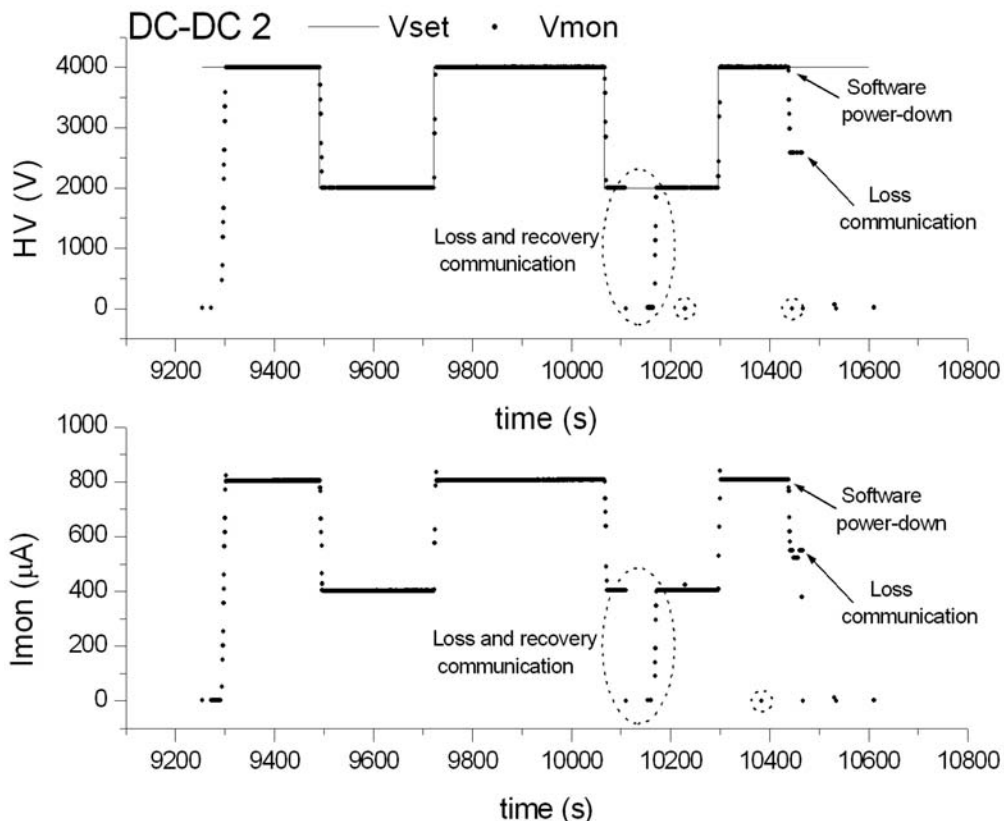
Fig. 17 – Set and monitored voltages and currents for DC-DC #2 during controller irradiation
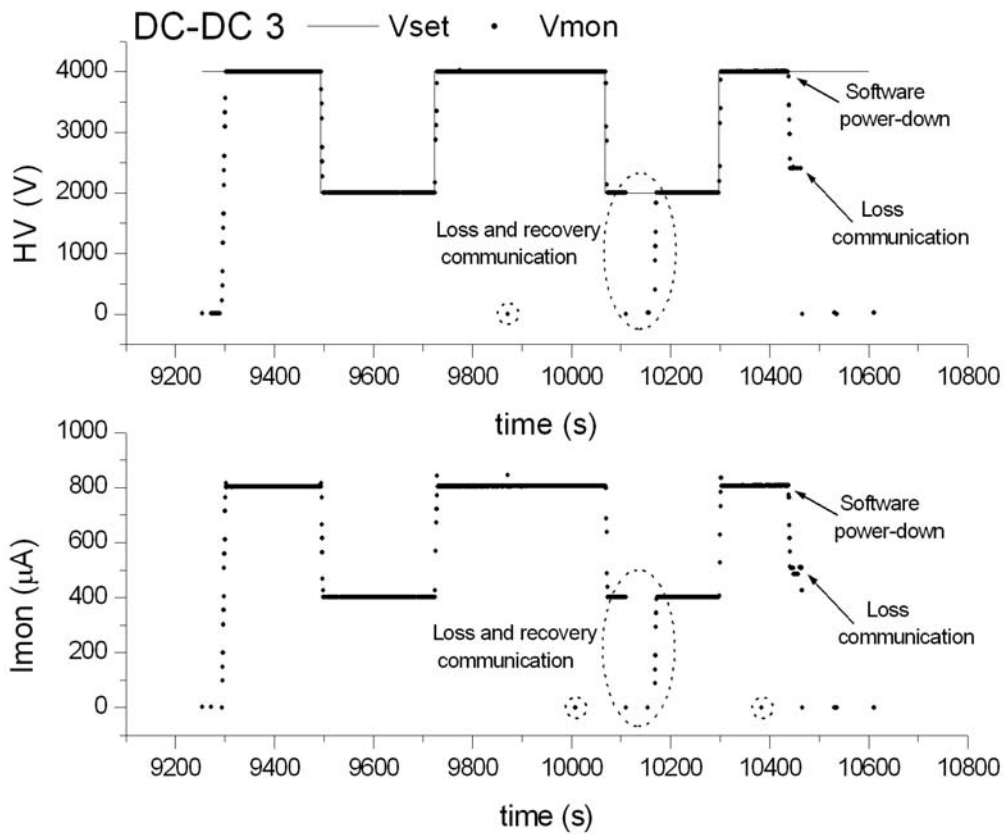
Fig. 18 – Set and monitored voltages and currents for DC-DC #3 during controller irradiation
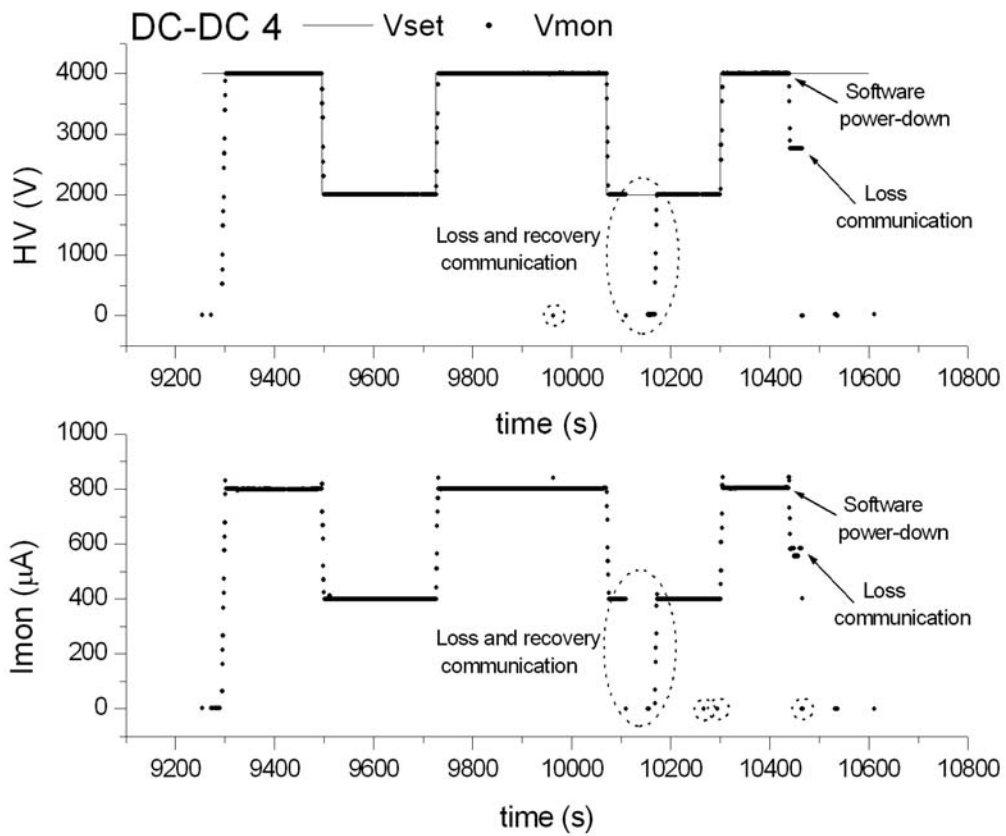
Fig. 19 – Set and monitored voltages and currents for DC-DC #4during controller irradiation
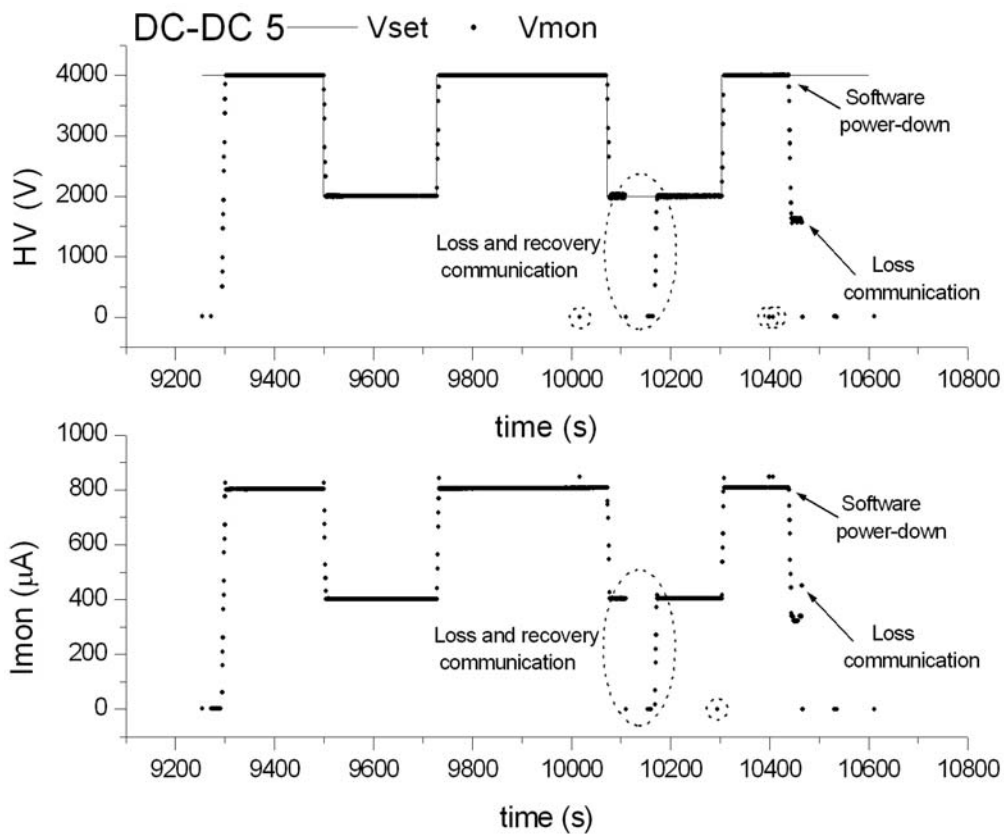
Fig. 20 - Set and monitored voltages and currents for DC-DC #5during controller irradiation
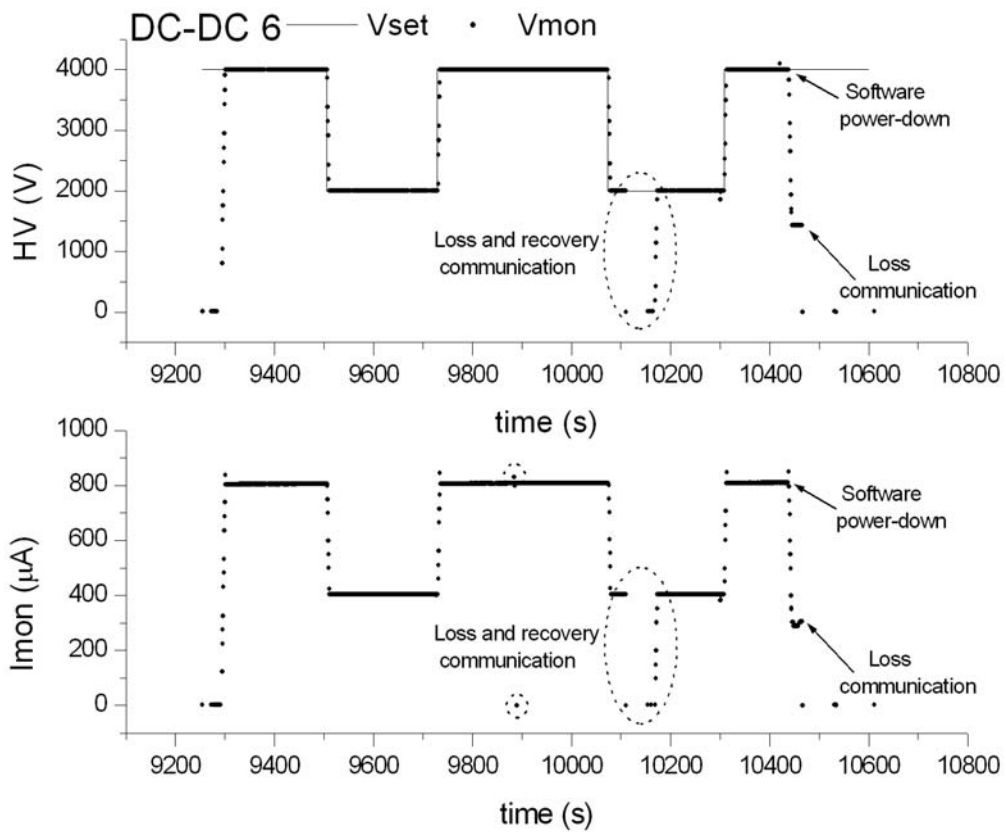
Fig. 21 - Set and monitored voltages and currents for DC-DC #6during controller irradiation
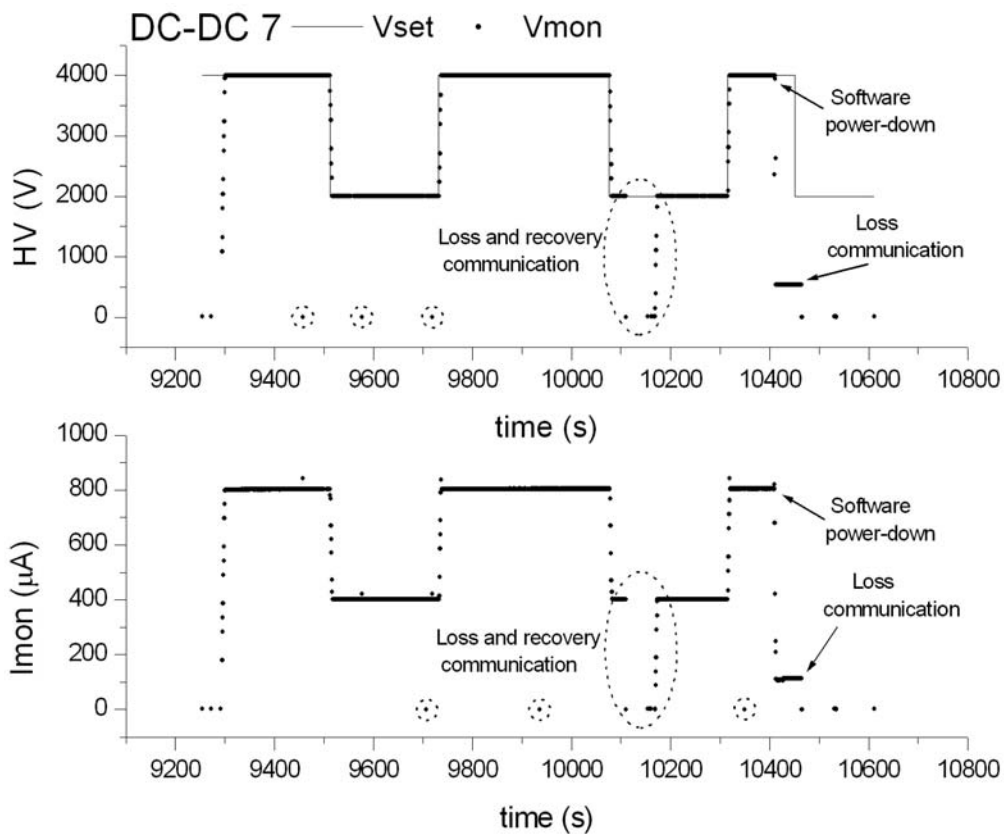
Fig. 22 – Set and monitored voltages and currents for DC-DC #7 during controller irradiation
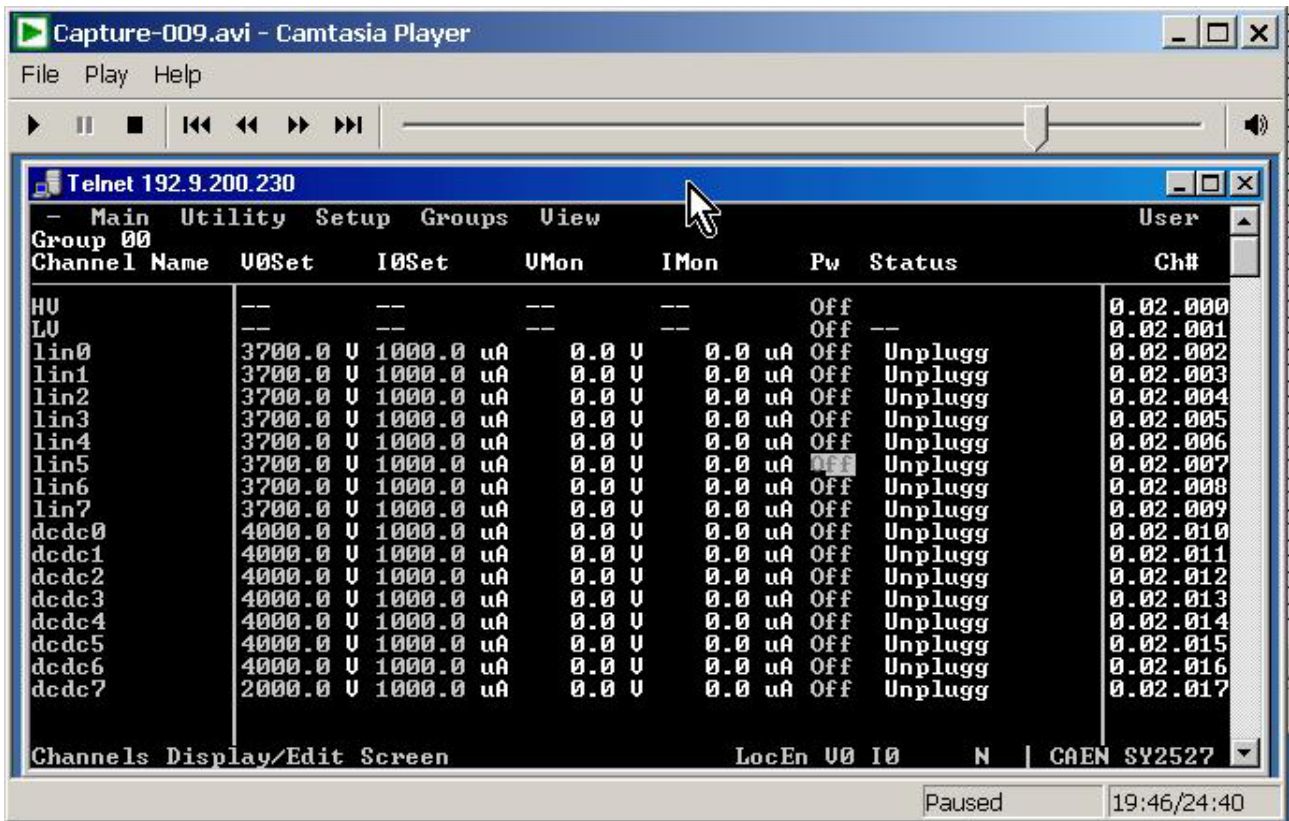
Fig. 23 – Main remote window at the time of second communications loss
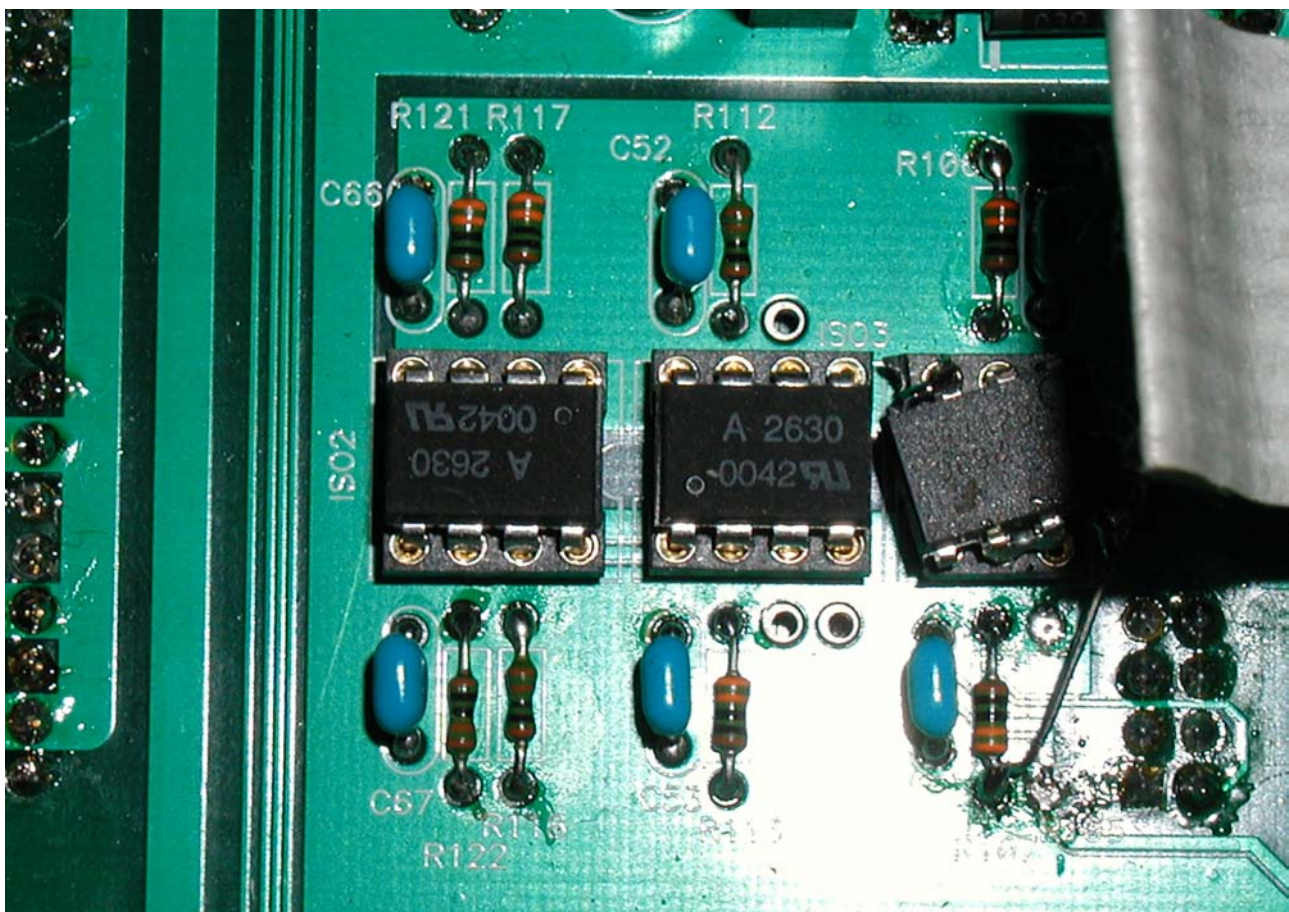
Fig. 24 – Communications optocouplers
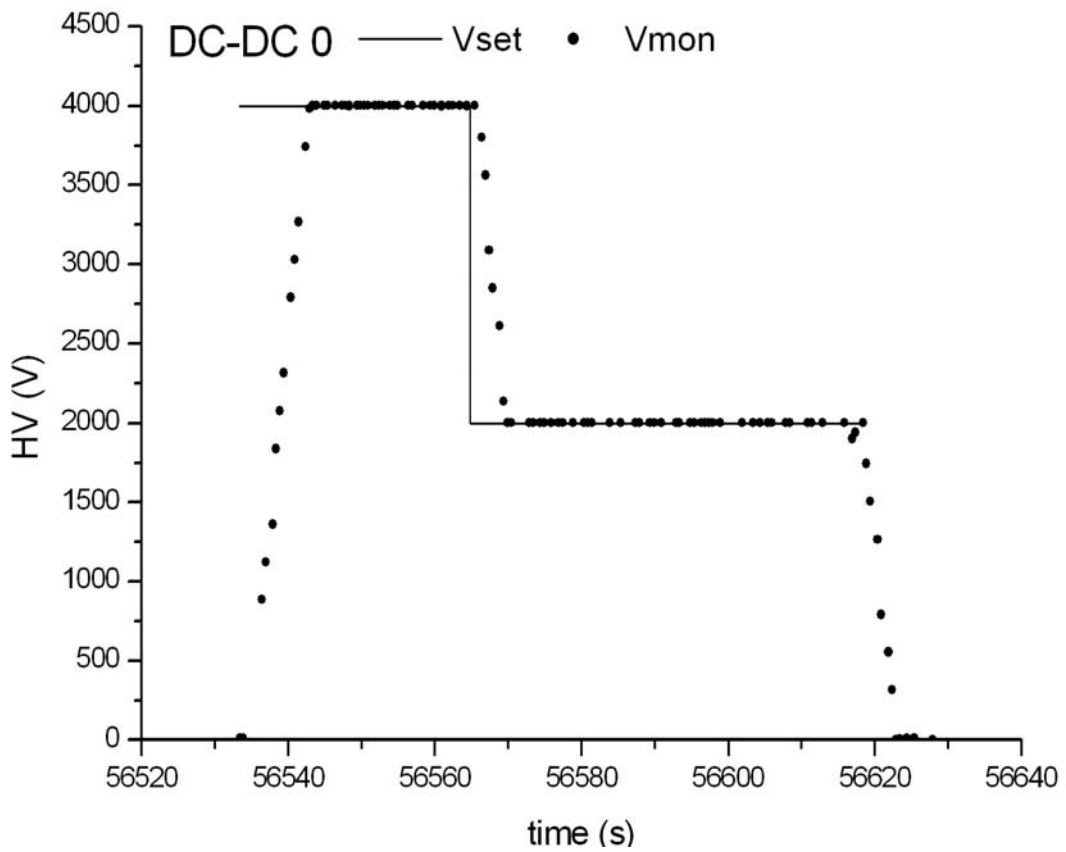
Fig. 25 – Set and monitored voltages of DC-DC #0 after irradiation
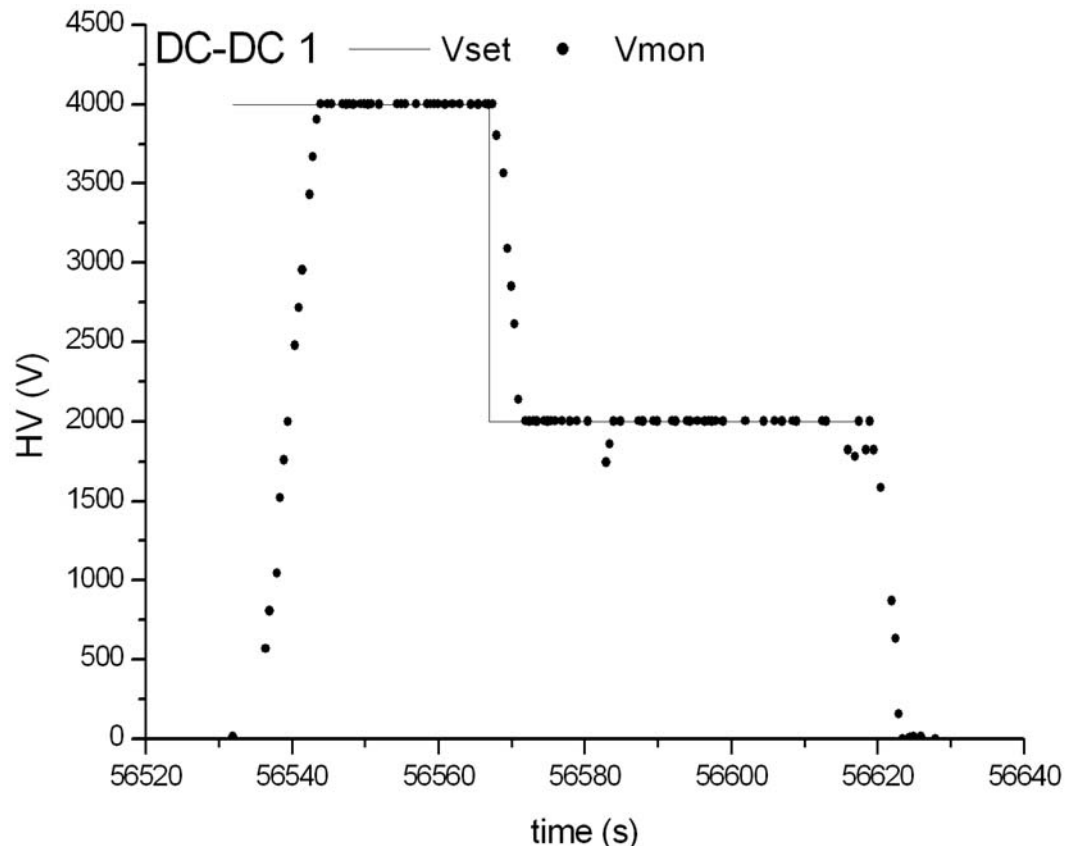
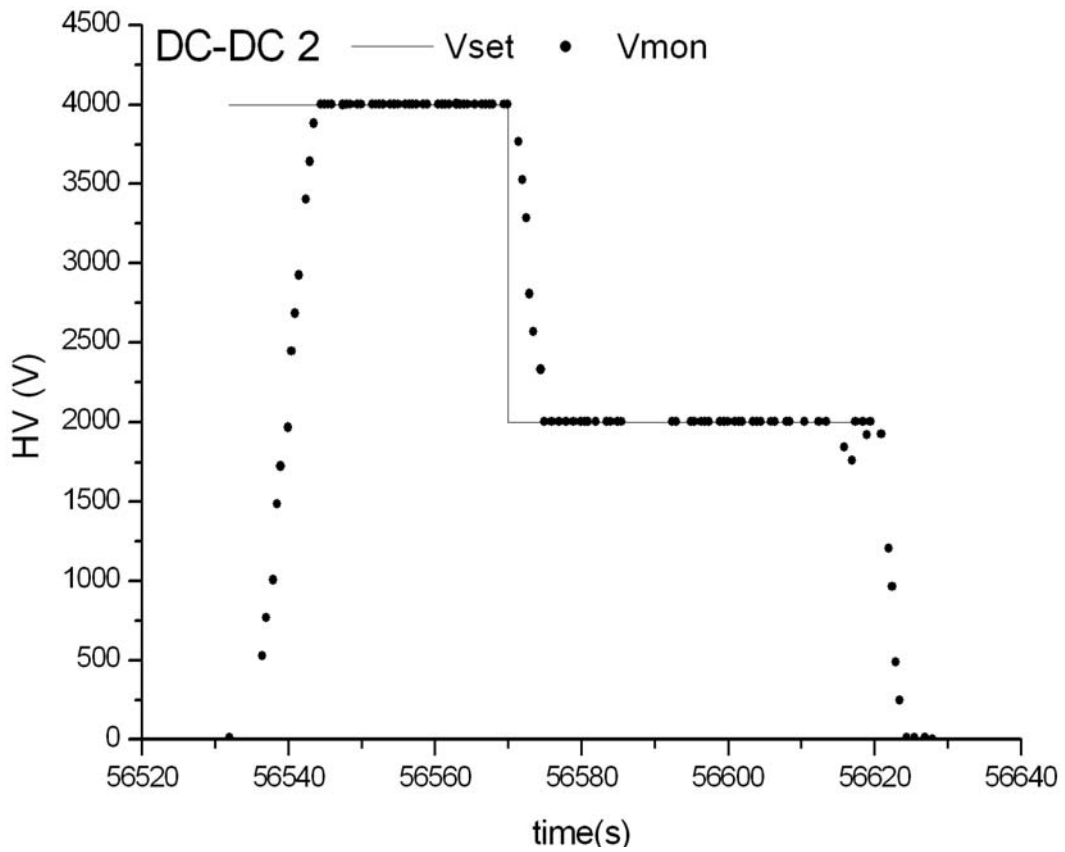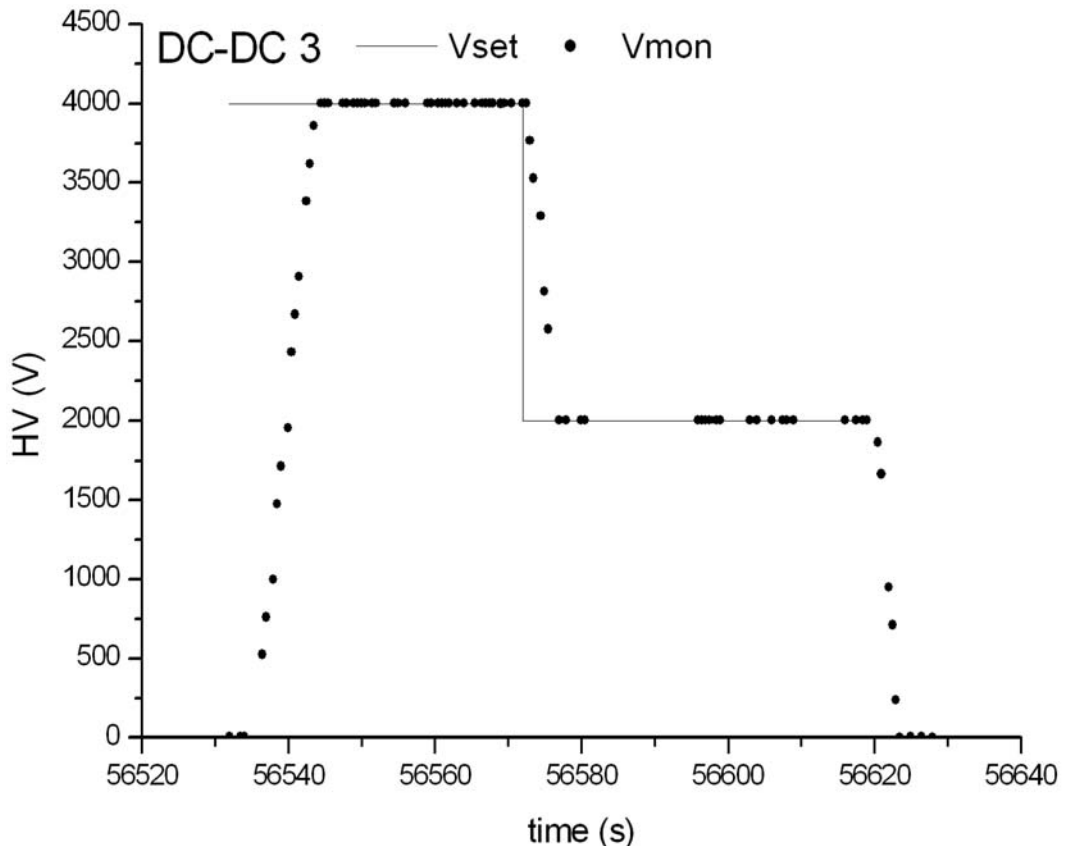Fig. 26 – Set and monitored voltages of DC-DC #1 after irradiation

Fig. 27 – Set and monitored voltages of DC-DC #2 after irradiation

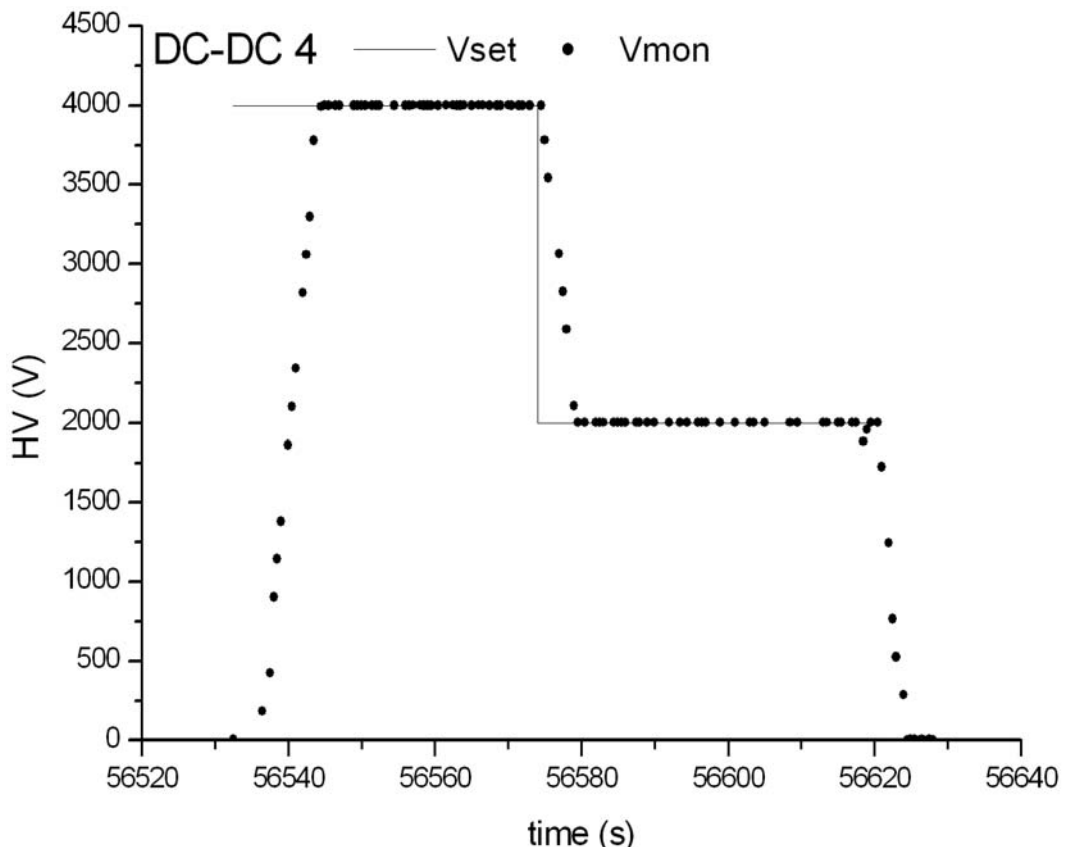Fig. 28 – Set and monitored voltages of DC-DC #3 after irradiation

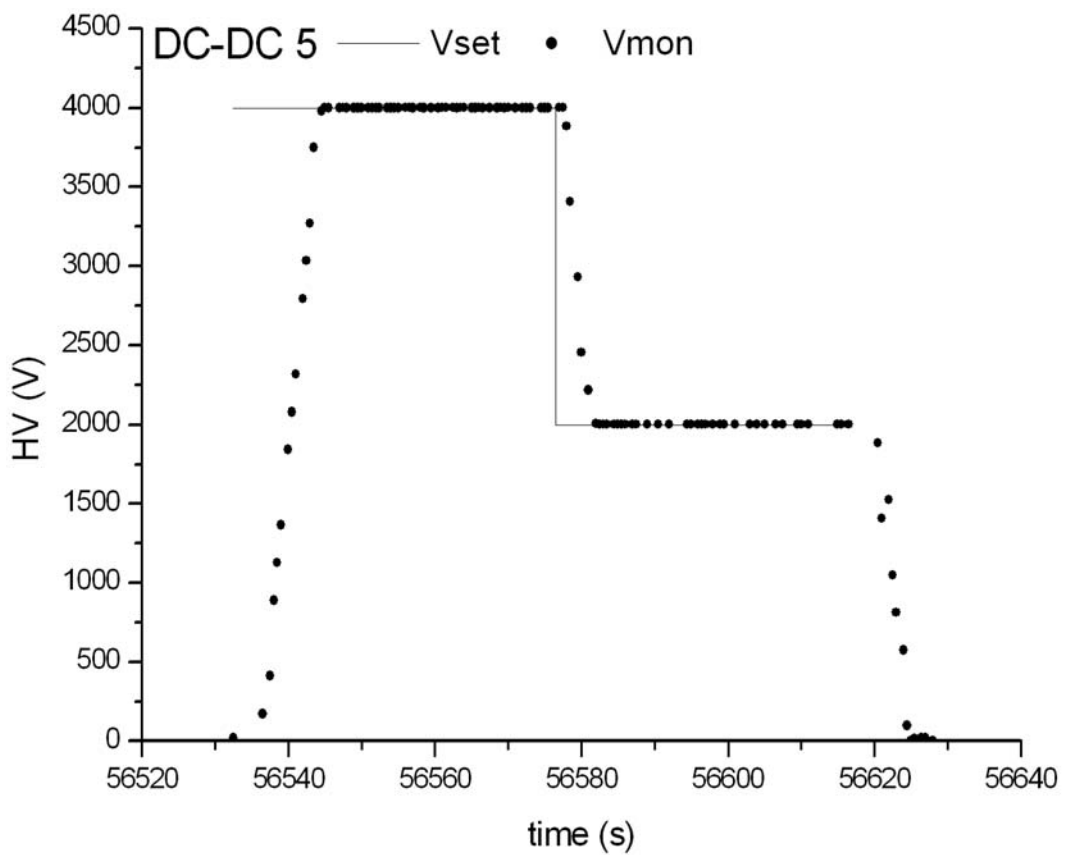Fig. 29 – Set and monitored voltages of DC-DC #4 after irradiation

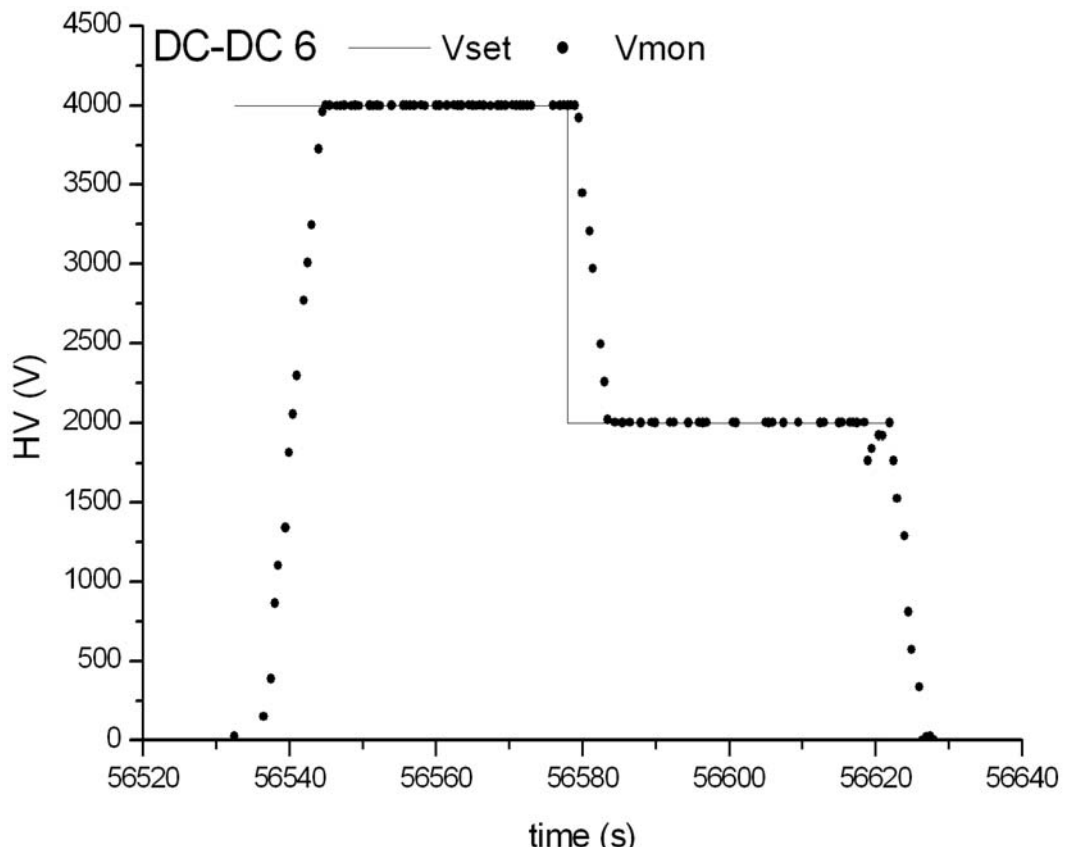Fig. 30 – Set and monitored voltages of DC-DC #5 after irradiation

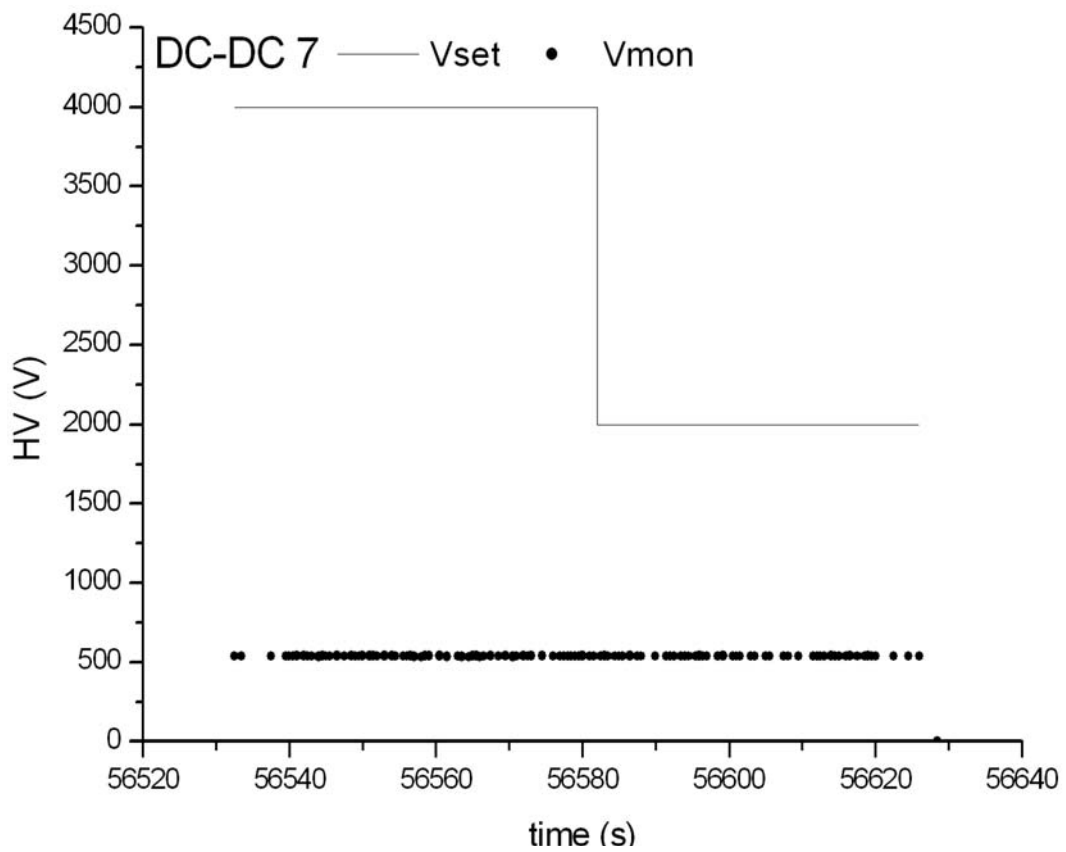Fig. 31 – Set and monitored voltages of DC-DC #6 after irradiation

Fig. 32 – Set and monitored voltages of DC-DC #7 after irradiation