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LOW TEMPERATURE RADIATION TEST OF HIGH VOLTAGE OPTOCOUPLERS FOR SPACE APPLICATIONS

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I. INTRODUCTION

Previous studies in radiation induced degradation in optocouplers at room temperature indicated that the most affected parameters were CTR and dark current (1,2). This fact is also applicable to high voltage (HV) optocoupler where the working voltage could go up to 10KV.

In space applications, optocouplers may need to work at very low temperatures. Under this low temperature operating conditions, the device degradation subjected to radiation exposure may show different behaviour compared to a standard radiation test under room temperature.

The purpose of this paper is to analyse the effects of proton displacement damages up to $8 \cdot 10^{11} p/cm^2$ and total ionisation dose up to 100Krad (Si)) at room and low temperature (i.e. 25ºC and -40ºC) on custom assemblies of High Voltage (HV) Optocouplers. The HV opto-coupler assembly, radiation setups for low temperature Gamma and Displacement Damage radiation tests are described in detailed.

II. MOTIVATION

An optocoupler working at high voltage (up to 12kV) and mounted by IRAP using a commercial optodiode OZ150SG [3] surrounded by six LEDs SFH4253 [4] will be used in the instruments PAS (Proton Alpha Sensor) and HIS (Heavy Ion Sensor) that are part of the Solar Wind Analyser Suite (SWA). The particle sensors will measure the velocity distribution of the major ionic species at a time resolution equivalent to the ambient proton cyclotron period and determine their moments (density, temperature, velocity, pressure tensor). It is designed to measure the full 3D velocity distribution functions of the major solar wind species, protons and α-particles. For the HIS instrument, it is capable of measuring ions from 0.5 to 60 keV/q, species from 3He to Fe. PAS will be operating more than 50% of the time below -20°C and at high voltage. The radiation resistance of this optocoupler was unknown and it was considered that it could be different at ambient that at the actual low operating temperature. For this reason it was decided to perform the radiation campaigns with some components at room temperature and some components at -40ºC.

III. SAMPLE DESCRIPTION

These custom optocouplers are designed to work up to 12kV, radiation testing board of each optodiode surrounded by the six LEDs is depicted in Figure 1.

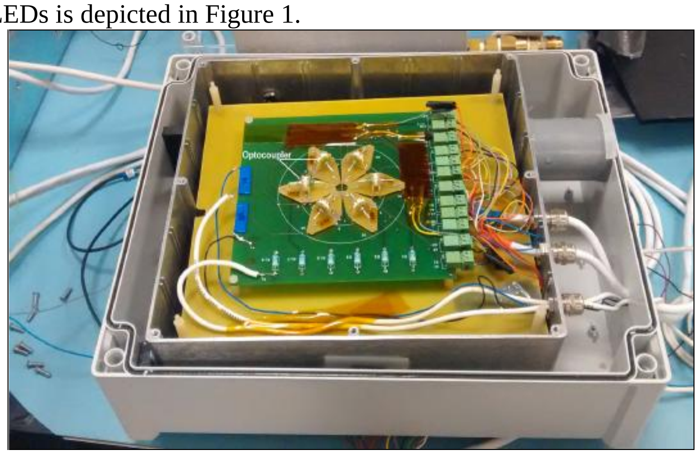


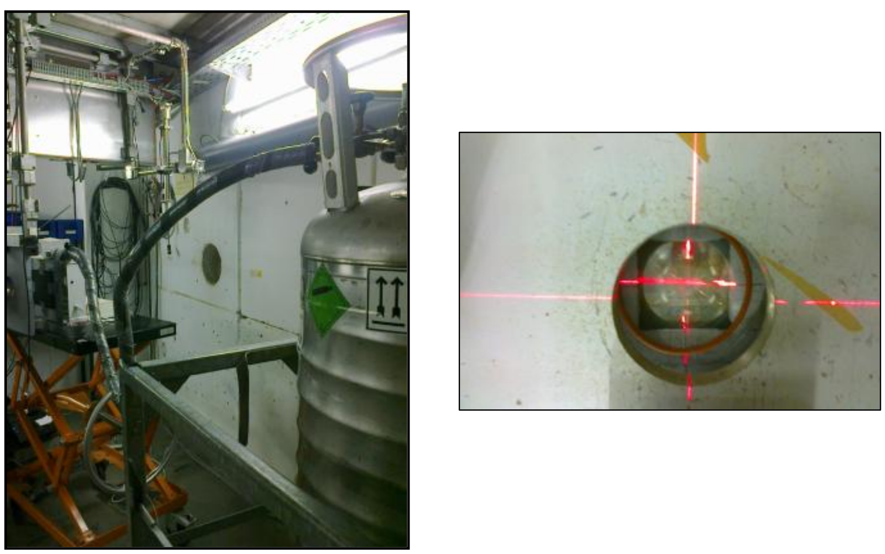
Fig. 1. Radiation testing board with the six HV optocouplers.

The radiation testing board consists of six optocouplers connected in parallel with a protection resistor of 1MΩ. During either proton radiation or gamma radiation exposure, the monitored parameter at low temperature was the Current Transfer Rate when LEDs I_F= 1 mA and optodiode V_{RWM} = 5kV.

IV. LOW TEMPERATURE RADIATION SETUP

Both gamma and proton radiation had to be performed with the possibility of keeping an optocoupler at a stable temperature of -40ºC at the radiation facility. Several cooling options were considered. Finally, it was decided to use a small chamber with a window being cooled with liquid nitrogen in a close loop configuration to allow precise PID temperature control of the samples. A small (approx. 100 liters) liquid nitrogen vessel was required near the radiation area and it was filled periodically to keep the temperature stable. Figure 2a shows the gamma radiation set up whereas figure 2b shows the proton radiation set-up at proton radiation facility.

a) Gamma radiation set-up



b) Proton radiation set-up

Fig. 2. Image of gamma and proton radiation setups with the LN2 tank.

Two calibration resistances, blue resistors on the Fig. 1, were measured at each radiation step as reference. These calibration resistances were measured at 1kV and 5kV at each intermediate step for validation of the setup.

V. RADIATION CAMPAIGN

Proton radiation campaign was performed at the Cyclotron Resource Centre at the Université Catholique de Louvin (UCL). The Cyclone is a multiparticle, variable energy, cyclotron capable of accelerating protons up to 65 MeV. Table I show proton radiation conditions applied to the HV optocouplers.

Irradiation steps:	1	2	3	4
Beam Energy (MeV)	60	60	60	60
Cumulative Fluence (p/cm^2)	$1x10^{11}$	$2x10^{11}$	$6x10^{11}$	$8x10^{11}$
Flux [$p/s\ cm^2$]	$1x10^8$	$1x10^8$	$1x10^8$	$1x10^8$
Exposure Time (min)	16.6	16.6	66.6	33.3
Temperature (°C)	-40	-40	-40	-40

Table I: Proton radiation test conditions

Gamma radiation campaign was performed at the RADLAB (Gamma Radiation Laboratory) at the Centro Nacional de Aceleradores-CNA (University of Seville, CSIC & Junta de Andalucía). The RADLAB is based on a 60Co gamma radiation source, the dose rate uniformity in the radiation field was better than 95% and the expanded uncertainty associated with the measurement is +/- 4.2%. Table II show gamma radiation conditions applied to the HV optocouplers.

	Characteristics	CONDITIONS
1	Temperature	-40ºC
2	Dose Rate	223 rad/h
3	Total Dose	109 Krad
4	Radiation Steps	20 - 50 - 109 Krad

Table II: Gamma radiation test conditions

The intermediate measurements performed after each proton and gamma radiation step are described in table III. The dark current at V_{RWM}=1kV and V_{RWM}=5kV, the forward voltage at I_F from 0 to 10 mA and the CTR (Current Transfer Rate) at V_{RWM}=1kV and V_{RWM}=5kV and I_F= 0.1 mA and 1 mA, were measured at each intermediate step.

SYMBOL	PARAMETER	TEST CONDITIONS	UNIT
V_R	Forward Voltage	I_F = 0.1mA ; 0.2mA ; 0.3mA ; 0.5mA ; 0.7mA ; 1mA ; 2mA ; 3mA ; 5mA ; 7mA ; 10mA	V
I_R	Dark Current	V_{RWM}= 5kV V_{RWM}= 1kV	µA
CTR	Current Transfer Rate	I_F= 0.1 mA ,1 mA V_{RWM}= 5kV V_{RWM}= 1kV	%

Table III. Electrical parameters measured at each proton and gamma intermediate step.

VI. RESULTS

A. Gamma Radiation Test Results

Results of the gamma radiation test have shown that there was no optocouplers degradation. For example the dark current at low temperature was obviously lower than at room temperature, but it showed no degradation during the low temperature radiation test. It clearly recovered the same value when measured during annealing stage at room temperature.

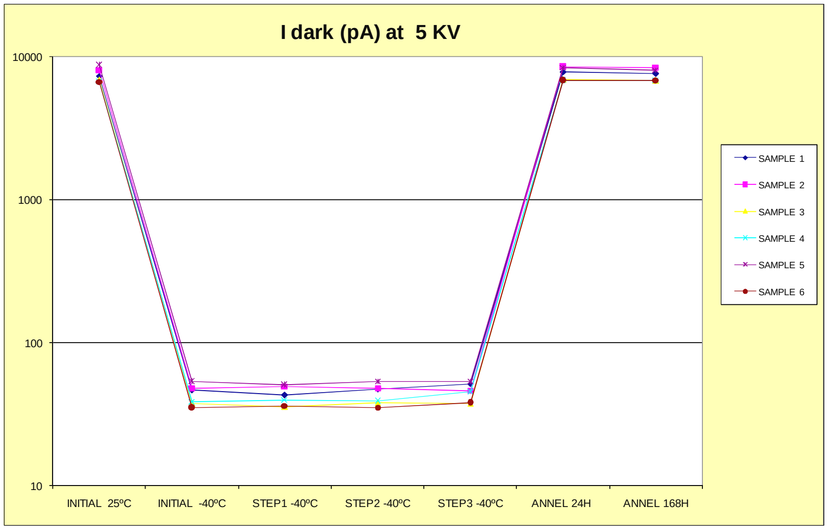


Fig. 3. Dark current evolution measured after each gamma radiation step.

The following picture shows the CTR evolution after each gamma radiation step. It did show no degradation. All the other results obtained were similar in the sense that only variations with respect to different temperature was observed, but no gamma radiation related degradation has been noticed.

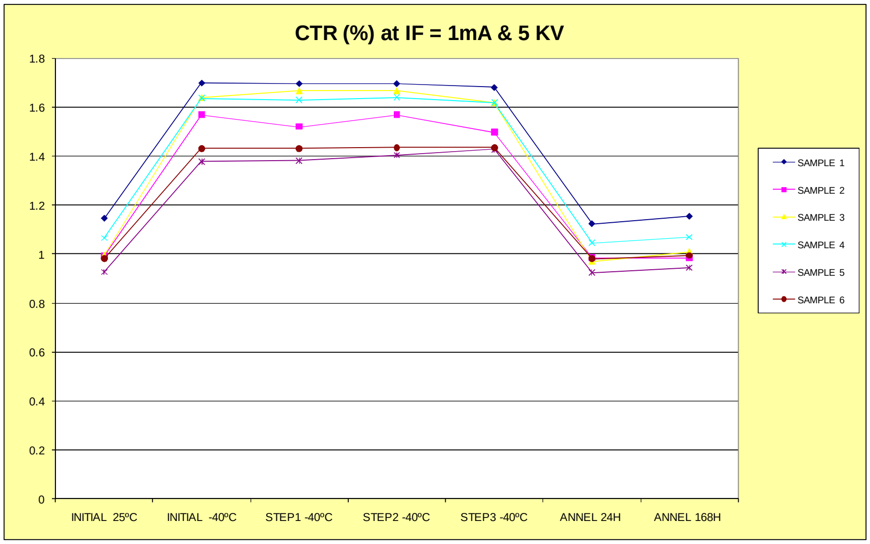


Fig. 4. CTR (at I_F=1mA and V_{RWM}= 5KV) after each gamma radiation step.

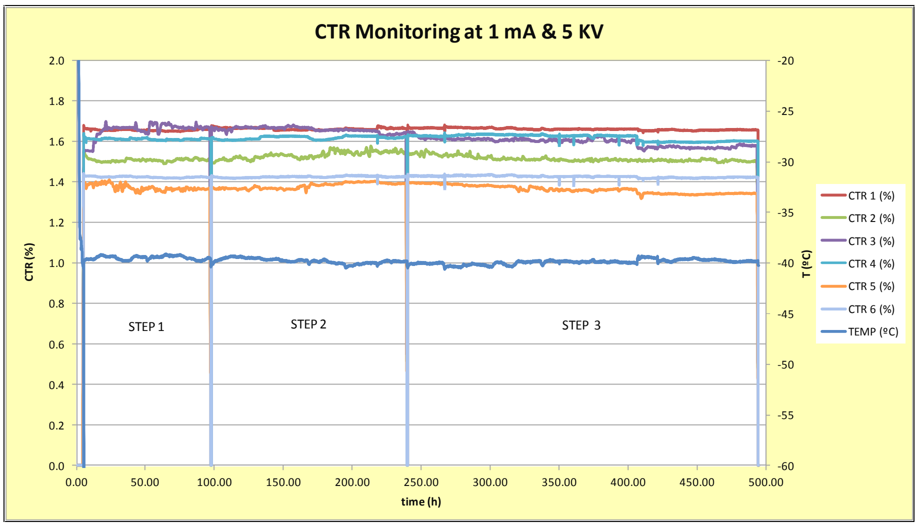


Fig. 5. Time Evolution (min) of the CRT during gamma radiation.

Figure 5 shows the CTR monitoring during gamma radiation at -40ºC considering also the time for intermediate measurements. The vertical lines indicate the moment of ending each radiation step. CTR values clearly indicate the no degradation of all optocouplers during gamma radiation exposure.

B. Proton Radiation Test Results

However, the proton radiation tests have given rather more interesting results. In this case, there is real optocouplers degradation. The device degradation has been found to be different at low temperature (-40ºC) and at room temperature. As an initial summary, the table below shows the main results obtained:

PARAMETER		CONDITIONS			
		TEMP 25ºC	TEMP -40ºC		TEMP25ºC
		Initial	Initial	Final	Final
DARK CURRENT (pA)	At 1KV	2224.5	19.3	101.1	17343.3
	At 5KV	4404.7	27.3	263.0	39598.3
CTR at 0.1mA (%)	At 1KV	0.056	0.149	0.053	0.048
	At 5KV	0.101	0.287	0.102	0.089
CTR at 1mA (%)	At 1KV	0.564	0.857	0.377	0.249
	At 5KV	1.037	1.654	0.721	0.454

Table IV: Comparison of main electrical parameters results at two different temperatures.

Table V presents the CTR percentage reduction which was calculated from the above data at the indicated conditions. Note that for a LED forward current of 1mA results at 25ºC and -40ºC are equivalent, but for lower LED forward current of 0.1mA results at 25ºC and -40ºC are completely different as CTR reduction at -40ºC is almost 5 times higher than the CTR reduction at 25ºC.

PARAMETER		% CTR Reduction at 25ºC	% CTR Reduction at -40ºC
CTR at 0.1mA (%)	At 1KV	14.29	64.43
	At 5KV	11.88	64.46
CTR at1mA (%)	At 1KV	55.85	56.01
	At 5KV	56.22	56.41

Table V: Comparison of CTR reduction at two different temperatures

Figure 6 shows the CTR monitoring during proton radiation at -40ºC considering also the time for intermediate measurements.

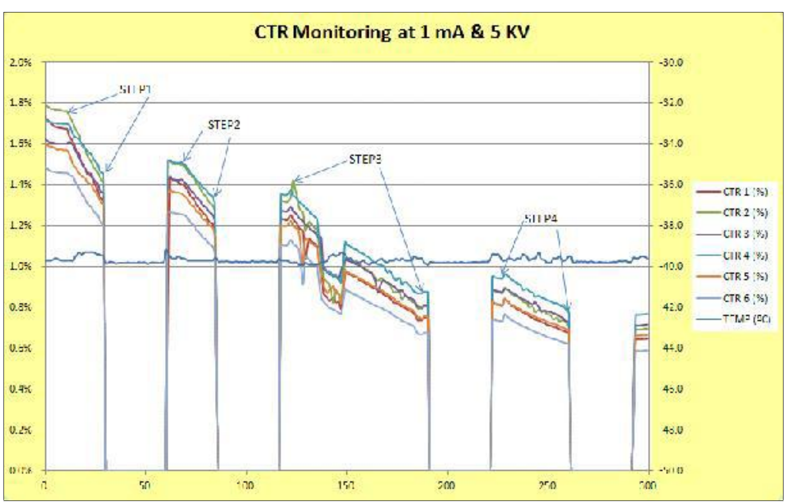


Fig. 6. CTR Time Evolution (min) of the CRT during proton radiation

The arrows at each step indicate the moment when the proton radiation started and when it was removed. It was detected some annealing effect after each radiation step. CTR degradation during the test had a similar rate in all steps. However, this rate was different for some minutes during the 3rd step. It is believed that the cause of this change was that the flux was unintentionally increased up to $2x10^8$ p/s/cm^2 during those minutes. Although, the final step fluence was $6x10^{11}$ p/s/cm^2 as specified in the test plan procedure.

The graph below shows the dark current evolution measured at each intermediate step. Note that the first and the last measurements were taken at 25ºC while the other measurements were taken at -40ºC. These results are not uncommon as the dark current strongly depends on the temperature.

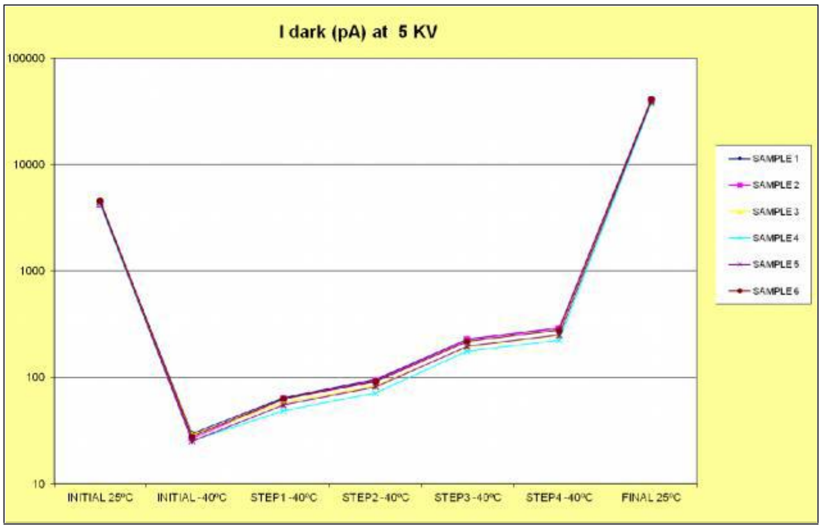


Fig. 7. Dark current plot measured at intermediate steps (Vertical axis scale is logarithmic).

Although the CTR was monitored during the entire proton radiation, it was also independently measured at each intermediate step. The CTR reduction at low temperature was confirmed also at room temperature when the samples were characterized at the end of the radiation and the measured values were compared with initial data. The following picture shows this CTR variation at I_F=1mA and V=5kV.

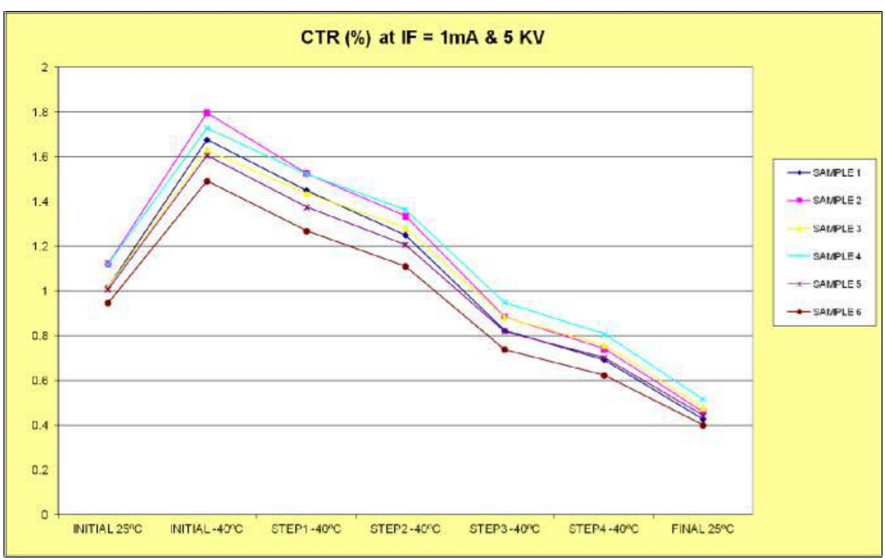
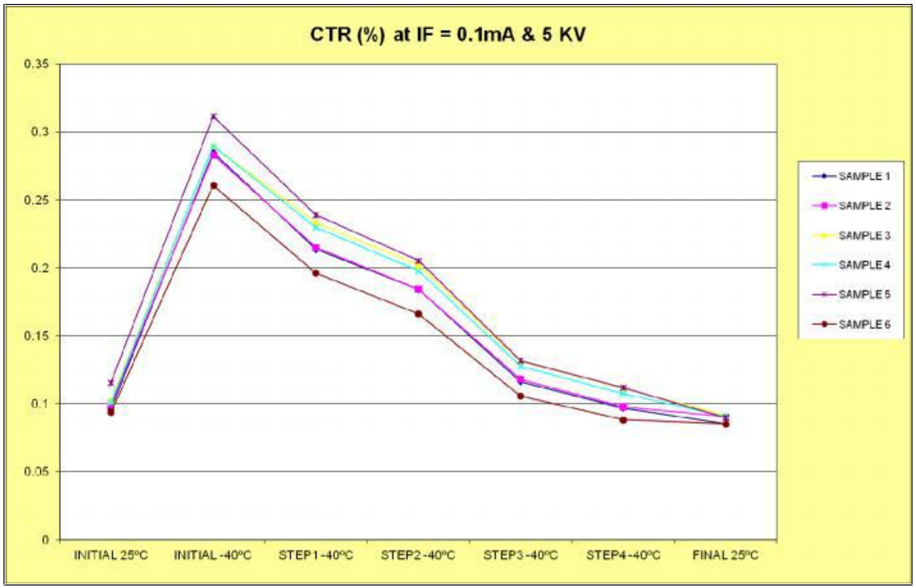


Fig. 8. CTR evolution measured at each intermediate step.

However, when LEDs forward current was lower as shown in figure 9, the CTR degradation was much higher at low temperature than at room temperature. This fact shows the necessity of testing the radiation at the operational temperature because it could lead to different behavior.



VII. CONCLUSIONS

The studied optocouplers did not show any degradation under gamma radiation testing, however, some important remarks should be made regarding proton radiation test. Those remarks are summarised as follows;

- A reduction of CTR and an increase of dark current were observed.
- The reduction of CTR is higher at low forward currents (0.1mA) and at -40ºC, and it is lower at low forward currents (0.1mA) at 25ºC.
- The radiation induced reduction of the CTR at -40ºC for low forward current (0.1mA) (almost 65%) was roughly 5 times higher than the reduction at 25ºC (i.e. between 11.8% to 14.2%).
- The CTR degradation is not dependent of the high output voltage level obtaining similar behaviour at output voltages of 1kV and 5kV.
- The dark current at 1 & 5 kV increases but all measured values are lower than the specification limit (<1 µA).
- All samples work correctly after $8x10^{11}$ p/s/cm^2.

Therefore, it has been shown that these optocouplers can be used for the intended application, but it is important to properly select the operating conditions because the radiation induced degradation is highly dependent of not only the LED forward conditions but also the operating temperature of the final application.

This paper has shown how complex this custom device behaves from a radiation perspective. It clearly show how important is to have knowledge of the device construction and what it is more important to evaluate the device radiation resistance at the required operating conditions of the final application as non-expected results may be found.

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