

DEVELOPMENT AND ESCC EVALUATION OF A EUROPEAN RADIATION TOLERANT OPTOCOUPLER

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Abstract — This paper presents a new European optocoupler type. This component has been developed by Optoi in the framework of ESA's European Component Initiative (Phase 2). The most recent results are reported, specifically related to a full ESCC Evaluation Testing.

I. INTRODUCTION

Optoelettronica Italia Srl, better known as Optoi, is an Italian Company dealing with optoelectronics and microelectronics. A new development centred on a radiation tolerant optocoupler started in 2011, among the rapidly growing activities involving the Company's aerospace unit [1, 2]. This activity for ESA was funded by European Component Initiative (Phase 2), and it was focused on the development of a European optocoupler with its European-Space-Component-Coordination (ESCC) evaluation for space applications, keeping the performances of the non-European counterparts as reference [3]. The main motivation for this activity is due to the absence of an ESCC qualified or evaluated European source for this type of components, available for the space sector.

This paper presents the most representative results obtained during this evaluation, which allowed identifying the main device failure modes and performance characteristics in harsh space environment.

Such result elaboration was possible after about 40 months of project work, based on a close collaboration with Optoi's two partners Fondazione Bruno Kessler (FBK, specifically its Micro Nano Facility - MNF) and AdvEOTec.

II. PROJECT BACKGROUND

A. Component description

The optocoupler is manufactured using Optoi's internal facilities; the project consortium includes FBK for the microelectronic front-end and AdvEOTec as optoelectronic test house, for the accomplishment of the evaluation and reliability testing. It is expected that AdvEOTec performs the screening testing activity during the future procurement of the Optoi components.

Optocouplers are devices used in space electronics, in order to provide electrical isolation between microelectronic circuit sectors; they are typically composed of two dices, separated by an optically transparent but electrically isolating medium indicated as light pipe or encapsulation gel. The signal is transferred by the light generated by a Light Emitting Diode (LED) and absorbed by a photodetector receiver; the photodetector used in Optoi's OIER10 optocoupler is a phototransistor manufactured by FBK, in its MNF unit. A photo of the OIER10 component assembled in an LCC6 ceramic package is shown in Figure 1.



Figure 1: Optoi's optocoupler coded OIER10, mounted in a LCC package with 6 pins

B. Device development

The progressive achievements of this development have been presented in public in the past couple of years. Specifically, the device functional characteristics together with a preliminary radiation study and the intended ETP analysis were presented at ICSO in 2012 [4]. The full radiation campaign performed in 2013 was later presented at RADECS [5]. In particular, proton irradiations have been performed at the Kernfysisch Versneller

Instituut (KVI) in Groningen [6] with proton beams at 25 MeV, 60 MeV and 185 MeV and five different fluence steps each (Figure 2).

The TID testing was performed at ESA ESTEC with a Co-60 source [7], at 36 and 360 rad(Si)/h (Figure 3).

In both types of radiation studies, devices biased during irradiation have been compared to unbiased counterparts, as well as to optocouplers currently available on the market.

The resulting radiation report which is now available on the ESCIES website [8] shows how under proton irradiation the detected degradation in the device performance is comparable to other rad-hard optocoupler available outside Europe. The degradation in performance under gamma irradiation is reduced, placing the OIER10 optocoupler in direct competition with existing space grade optocouplers, in terms of radiation hardness and performance.

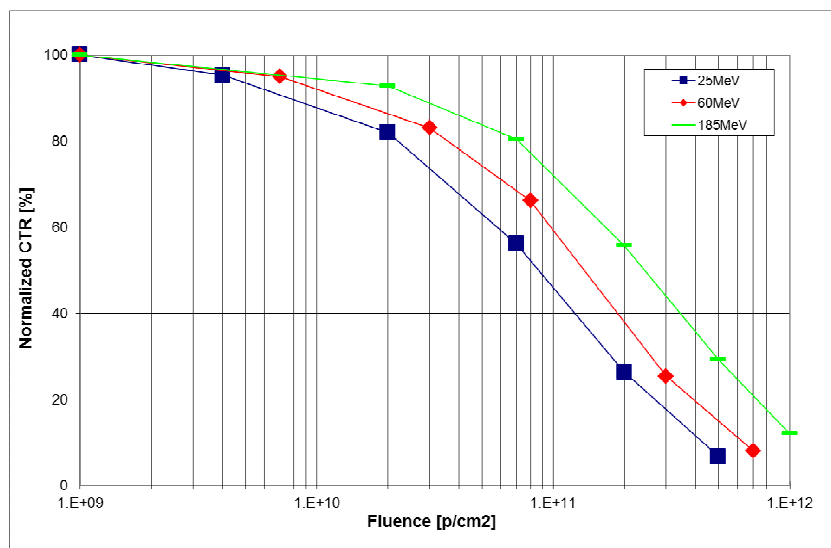


Figure 2: comparison of normalized averaged CTR degradations on unbiased OIER10 devices as a function of fluence at different energies with $I_f=1mA$, $V_{ce}=5V$ [5]

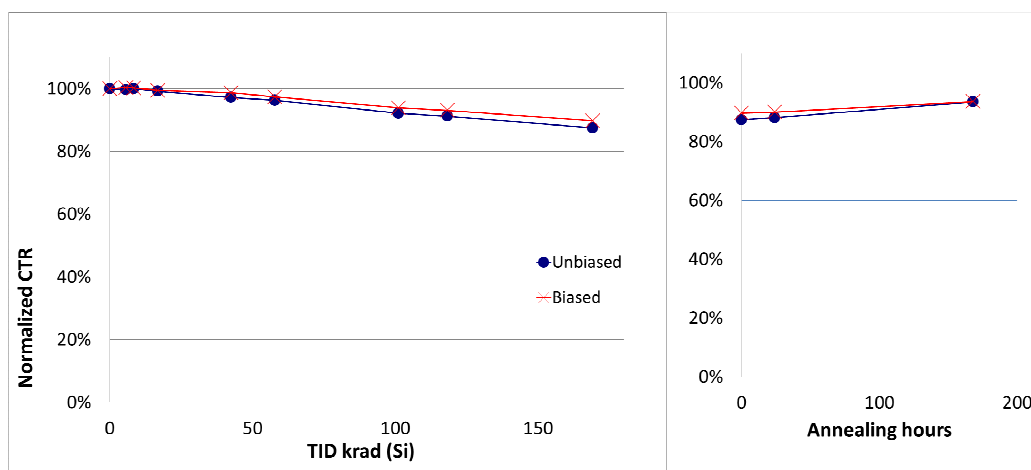


Figure 3: normalized averaged CTR ($I_f=1mA$, $V_{ce}=5V$) of OIER10 optocouplers exposed to Co-60 gamma rays with high dose rate and either biased or unbiased during irradiation, and following annealing [5]

More recently, the most promising device typology resulting from the previous development activity has been submitted to a full ESCC evaluation test campaign, under the supervision of ESA and with the support of AdvEOTec. The ESCC evaluation program has involved optocouplers assembled in three different packages: LCC4, LCC6 and TO-5. In the next section, the details of this activity are reported.

III. ESCC EVALUATION TEST PLAN

A. General considerations

After having collected promising results in line with the competition, an Evaluation Testing was carried out by Optoi's partner AdvEOTec. Such activity was based on a set of tests and stresses, whose design and definition involved the previous project phase. In fact, the calibration of the aggressiveness in the various test conditions of this reliability study had to be identified as a trade-off between the device basic characteristics already determined in the past, and the intention to over-stress the device. Indeed the Evaluation Test Plan followed the ESCC philosophy, in the sense that its purpose was to determine the device operational boundaries, possibly identifying its technological limits and weaknesses for potentially implementing a future subsequent device qualification.

The work plan defined through this process and approved by ESA is illustrated in Figure 4. It was based on the methodology described in ESCC 2265000, so it incorporates four main groups: destructive tests, endurance tests, control devices and spare parts. Each test sequence is concluded by Destructive Physical Analyses, whose detail was tuned based on the relevance of each test.

The ETP has been carried out on three different package typologies, i.e. LCC6, LCC4 and TO-5, leading to an overall number of involved components in the range of 140 parts. The whole activity lasted from around late August 2013 until February 2014; the subsequent two months were spent elaborating and interpreting the collected findings on one hand, and making further inspections and analyses on the other.

The results reported in the present paper mainly focus on the LCC6 device variant, on which Optoi's focus was centred also during the radiation campaign.

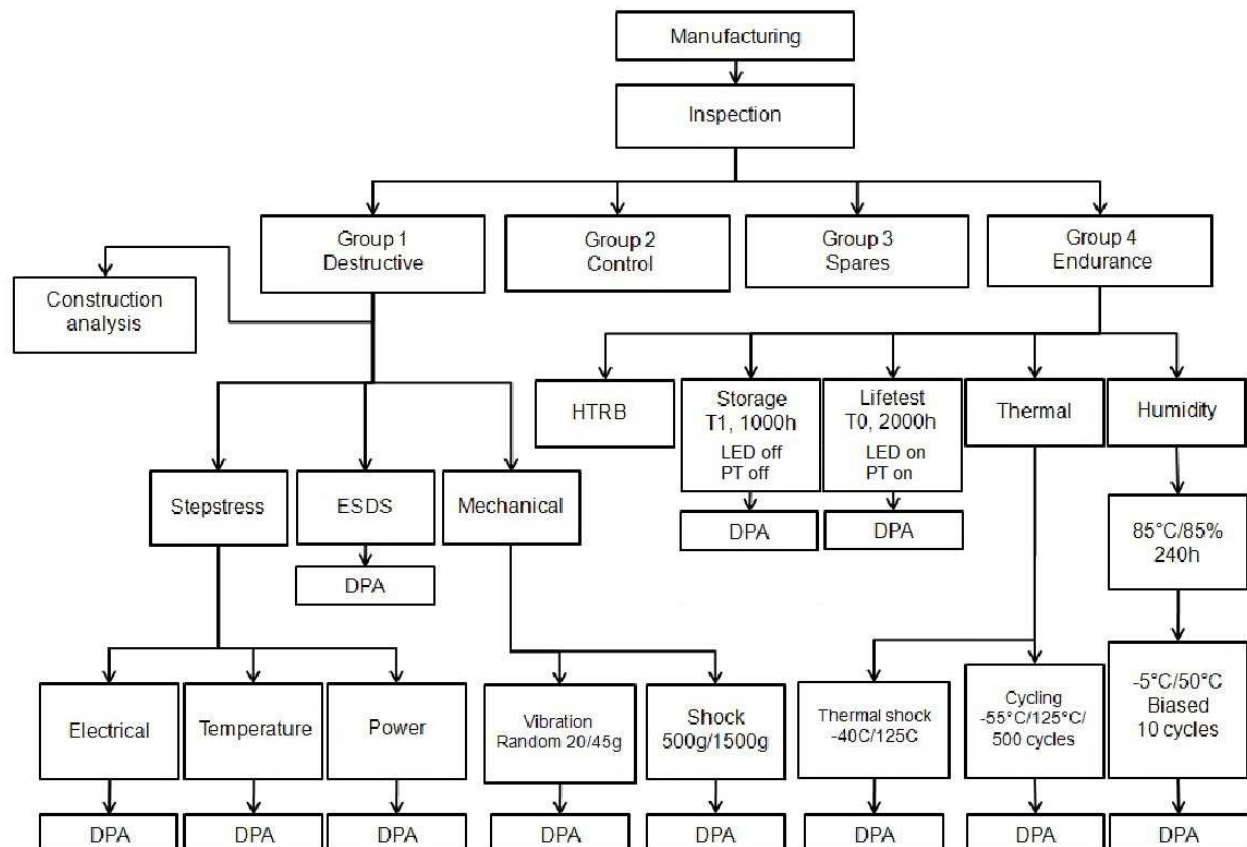


Figure 4: ESCC Evaluation Test Plan

B. Test conditions and overall progress

For each group of tests in Figure 4, initial and final measurements are represented by the optocoupler's Current Transfer Ratio (CTR) and its dynamics, as well as the LED I-V characteristic in order to monitor any intrinsic drift in its electrical behaviour. For intermediate steps, CTR was mainly taken into account.

Specifically, CTR measurements were conducted biasing the phototransistor collector at 0, 5 and 10V while the photocurrent was acquired varying the LED current, from 0 to 10mA. To characterize parameter drifts, CTR values with $I_{led}=1mA$ and $5mA$ were recorded, both at $V_c=5V$ and $10V$. Rise and fall times were measured at room temperature (25degC) biasing the phototransistor at $V_c=5V$ with 100Ohm load resistor at the emitter.

In early September 2013, the optocouplers were submitted to initial characterizations; Safe Operating Area definition, Electro Static Discharge Susceptibility (ESDS) tests and electrical - temperature - power step stresses were conducted. These destructive tests allowed determining the operational limits of the device; the collected results were considered positive and they allowed the definition of the environmental test conditions for the subsequent testing activities, which started in the second half of October 2013.

In early 2014, when the test groups were concluding, some parts were selected for Destructive Physical Analyses and such inspections allowed the activity conclusion in April, through the analysis of the encountered failure modes.

In parallel, Construction Analyses had been performed on all the three device variants, in order to verify the compliance of the manufacture with the ESCC inspection criteria.

IV. EXPERIMENTAL RESULTS

In this section, the most representative results collected within the ESCC ETP are presented, specifically focusing on the LCC6 device variant.

After having determined the device Safe Operating Area through electrical - temperature - power step stresses, ESDS tests were conducted following MIL-STD-883 Method 3015. The Human Body Model was applied with positive and negative pulses for each combination of pins, leading to the identified device robustness up to 4kV discharge. Subsequent internal visual inspections allowed localizing the spatial degradation origin within the component.

Mechanical tests consisted of two typologies: random vibration and shock test, the former at 28.4 and 44.8g rms (following MIL-STD-883 Method 2026 conditions H and J respectively), and the latter up to 1500g/0.5ms (following MIL-STD-2002 condition B). Test results confirmed the device robustness, after having verified the drifts in the CTR and the dynamics as well as the LED electrical characteristic.

Following the conclusion of the destructive tests, the test conditions for the endurance tests were extrapolated and applied.

The developed protocol for High Temperature Reverse Bias features the progressive increase of the phototransistor bias, up to 40V with intermediate measures after each session of 125degC/48h. This analysis allowed identifying the device robustness as a function of the package type and specifically its power dissipation properties.

In the high temperature storage test, the parts have been heated at 150degC for 1000 hours and no relevant performance degradation was noticed as shown in Table 1, confirming previous results of temperature step stress carried out on a separate session.

N° DUT	Initial		After 1000h storage			
	CTR (1mA/5V)	CTR (5mA/5V)	CTR (1mA/5V)	CTR (5mA/5V)	CTR drift (1mA/5V)	CTR drift (5mA/5V)
AB68	5.3	6.2	5.3	6.0	-1%	-3%
AB70	4.2	5.3	4.1	5.2	-2%	-3%
AB71	4.7	5.5	4.9	5.4	3%	-1%
AC31	4.1	5.2	4.3	5.2	5%	0%
AC35	3.7	4.8	3.9	4.8	5%	0%
AC36	4.0	4.9	4.0	4.8	0%	-2%
AC40	4.0	5.1	4.1	5.0	3%	-1%

Table 1: CTR values and drifts before and after high temperature storage

Based on technical discussions and ESA supervision, the lifetests were conducted applying 100degC during the first 1000 hours and 125degC in the second 1000 hours, on the same devices which were constantly kept monitored; the in-situ device monitoring proved good stability of the optocouplers during high temperature operation, as illustrated in Figure 5.

Thermal endurance tests consisted of temperature shock and cycling. In the thermal shock tests, five abrupt transitions between -65degC to +125degC were applied, with 1 minute transfer time and 30 minute dwell time (following MIL-STD-202 Method 107G test condition B of Table 107-I). The recorded effect on the device characteristics is very limited, as shown in Table 2.

The thermal cycles have been conducted between -55 and 125degC, with a slope of 5degC/minute and dwell time of 10 minutes, following MIL-STD-883 Method 1010 B. Intermediate measures were carried out after 100, 200 and 300 cycles. As shown in Table 3, no relevant drift was observed after 500 cycles neither on the CTR nor in the other parameters under analysis.

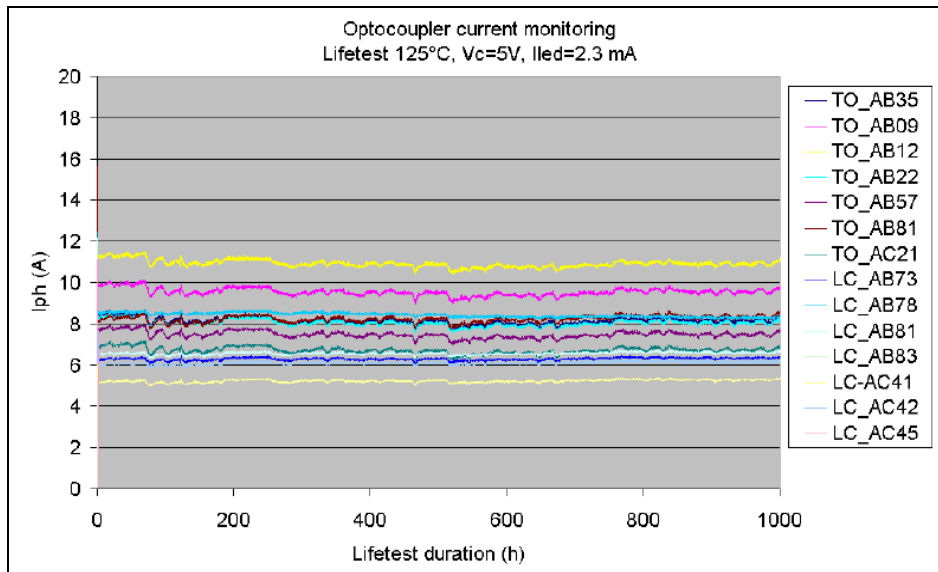


Figure 5: photocurrent in-situ monitoring during lifetest (1000h at 125degC following a previous step of 1000h at 100degC on the same devices)

N° DUT	Initial		After Thermal shock			
	CTR (1mA/5V)	CTR (5ma/5V)	CTR (1mA/5V)	CTR (5ma/5V)	CTR drift (1mA/5V)	CTR drift (5ma/5V)
AB96	4,9	5,7	4,9	5,7	1%	-1%
AC04	4,9	5,9	5,4	6,0	11%	2%
AB97	5,2	5,7	5,2	5,8	1%	2%

Table 2: CTR values and drifts before and after thermal shock

N° DUT	Initial		After 500 cyc			
	CTR (1mA/5V)	CTR (5ma/5V)	CTR (1mA/5V)	CTR (5ma/5V)	CTR drift (1mA/5V)	CTR drift (5ma/5V)
AB34	5.5	6.2	5.9	6.2	7%	0%
AC46	4.1	5.2	4.5	5.3	12%	3%
AB85	5.0	5.7	5.4	5.7	9%	0%

Table 3: CTR values after 500 thermal cycles

The humidity test consisted of two steps, i.e. the application of 85degC / 85%RH of damp heat for 240 hours on non-biased devices, followed by temperature cycling between -5 and +50degC under humidity on biased devices ($I_{led}=2mA$ and $V_{ce}=5V$).

After five weeks of room temperature storage some parts have been characterized again for comparative measurements. Globally, the optocouplers resisted well to this stress and the measured variations in the CTR characteristic are shown in Table 4.

N° DUT	Initial		After humidity test			
	CTR (1mA/5V)	CTR (5ma/5V)	CTR (1mA/5V)	CTR (5ma/5V)	CTR drift (1mA/5V)	CTR drift (5ma/5V)
AC47	3.9	4.9	4.2	5.1	10%	3%
AB93	5.4	6.1	5.6	6.1	4%	1%
AB92	6.3	6.9	6.6	7.0	5%	2%

Table 4: CTR values after humidity tests

V. PHYSICAL INSPECTION AND QUALITY ASSESSMENT

During the course of the ETP, Construction Analyses were carried out successfully, in order to verify the compliance of the device structure and assembly with the reference requirements, in particular ESCC Basic Specification No. 2045000 and 2049000. Optoi's OIER10 component was validated according to the following analyses: external and internal visual inspections (MIL-STD-883 Methods 2009.10 and 2017.9, ESCC 20400, ESCC 2045000), physical dimension (MIL-STD-883 Method 2016), radiographic inspection (ESCC 2099000 and MIL-STD-883 Method 2012.8), die shear test (MIL-STD-883 Methods 2019.8 and 2019.9), wire bond pull (MIL-STD-883 Method 2011.7), Residual Gas Analyses (Internal Water Vapor Analyses), scanning electron microscope inspection, focused ion beam analysis, metallographic cross sectioning and material analysis. Subsequently, separate destructive physical analyses verified the construction quality after each of the ETP legs of Figure 4. The typologies of verifications were similar to the ones specified above and in this case also terminal strength test was performed (MIL-STD-750 Method 2036 Condition A and MIL-STD-202G Method 211A). Besides, fine and gross leak tests were carried out following MIL-STD-883 Method 1014.

CONCLUSION

The accomplishment of the ESCC ETP allowed the identification of the OIER10 optocoupler's operational boundaries as well as the verification of the device's functionality preservation under aggressive test conditions following ESCC 2265000, making this device a European candidate source for space projects.

Based on the ETP result analyses, no major anomaly or limitation was found on the two LCC device variants, making them the first two proposals for inclusion into ESA's European Preferred Part List (EPPL), by the end of this year. Despite the functionality of the TO-5 type proved as much reliable and robust as for the two LCC counterparts, this device variant is currently undergoing further investigations and it might be proposed for EPPL inclusion at a later stage, depending on strategy.

The outcomes of the ETP are currently allowing the definition of the device Detailed Specifications, besides the screening criteria and procurement-related procedures for any upcoming demand of the developed component are being drawn, following ESCC 5000 as well as various methodologies and internal procedures in the framework of the preparations for the formal ESCC audit, to be held in September and involving all the three entities within the consortium, i.e. Optoi, FBK and AdvEOTec.

In case the end-users' interest is confirmed, an ESCC qualification of this component will be carried out, for its subsequent inclusion into ESA's Qualified Part List (QPL).

ACKNOWLEDGMENTS

The reported activities have been conducted within a development for ESA, funded by the European Component Initiative (Phase 2).

The entire work was coordinated by Optoi which mostly focused on component design, selection and procurement of raw materials and device assembly; the photodetector receiver has been manufactured by FBK's MNF staff; the reported tests relating the ESCC ETP have been mainly conducted by AdvEOTec upon supervision of Optoi and ESA. AdvEOTec also formulated the ESCC ETP before its actual accomplishment, upon supervision of Optoi and ESA.

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