Proton and gamma radiation test data in recent COTS and radiation-tolerant optocouplers

ESA-CNES Final Presentation Days

6 June 2013

Contents

Objectives

- Data overview of degradation under irradiation and how different **electrical layout, construction and operational (bias) conditions** impact on the radiation hardness.

- Present
- Result of **separated emitter and receiver irradiation -** to estimate the dominant part in the total degradation.
- **Investigation on screening methodology** for parts selection, based on reverse recovery time of the LEDs was analysed to assess its applicability to the DUTs

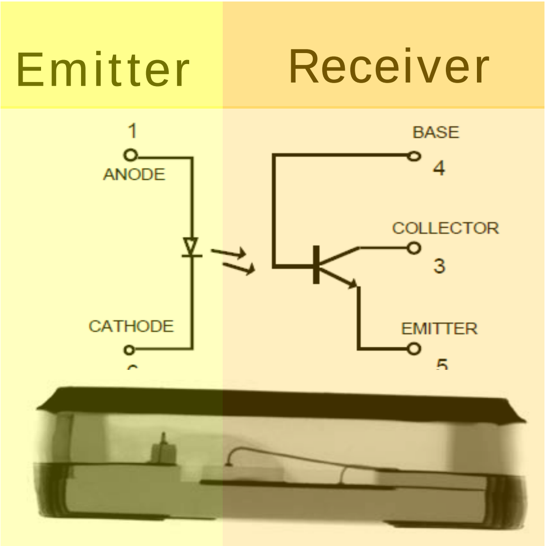
DUT -> Optocouplers

Optocouplers provide electrical isolation between circuit blocks

two dies (Emitter AlGaAs DD - Receiver Si DD&TID)

separated by an optically transparent but electrically isolating medium.

Information is transferred by
the light generated from a light emitting diode (LED)
and
sensed by a photodetector receiver(photodiode or a
phototransistor, or more complex stages).



Example of optocoupler electrical layout and X-ray view (Isolink)

DUTs selection boundaries:

Low bandwidth Analog optocouplers

7 rad tolerand (Isolink, Micropac) +14 COTS

Emitter: 660nm/850nm

Receiver: Phototransistor / Photodiode&Transistor — For radiation tolerant

Receiver:Phototransistor / Photodiode&transistor / Photodiode&darlington — For COTS

Testing: Measurements

Stage	Measurement
Emitter	LED minority carriers reverse recovery time (LED trr) LED reverse current (Ir)
Receiver	Base-collector minority carriers reverse recovery time (BC trr), Dark currents in the collector-emitter and base-collector junctions ($I_{CE\text{-}DARK}$, $I_{BC\text{-}DARK}$), Current gain h_{FE}
Optocoupler	CTR Collector emitter saturation voltage $V_{CE\text{-}SAT}$, Photosensitivity (photocurrent on phototransistor base)

A primary parameter of interest is the **Current Transfer Ratio (CTR).**

CTR is the ratio of the photodetector collector current Ic to the LED forward current If for a fixed collector emitter voltage(Vce):

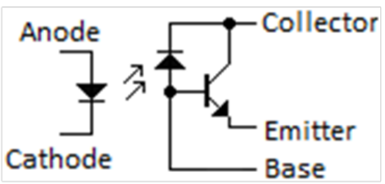
$$CTR = \frac{Ic}{If}$$

The CTR was measured over the LED forward current range, from 0.1 to 20mA.

Rad tolerant part type vs Rad.test overview

CTR was measured at the nominal condition indicated in the manufacturer's datasheet of each part type

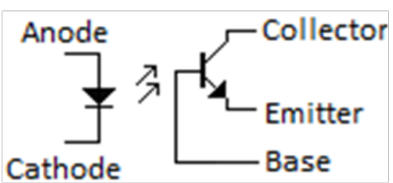
Receiver: Photodiode and transistor



Micropac: 66191-303, 66191-313, 66223-001, 66226-001,

If=10mA, Vce=1V

Receiver: Phototransistor



Micropac: 66266-001
Isolink:OLH249, OLS449

If=1 mA, Vce=5V

Part type, Date code (D/C), Screening level	Co-60 Irradiations		Proton Irradiations	
	Dose rate	Number of DUTs and biasing conditions	Proton Energy	Number of DUTs and biasing conditions
66191-303 D/C 1004 JAN-S	360 rad/h	3 B (If=10mA,Ic=1mA)	-	-
	360 rad/h	3 B (Vce=12V)	-	-
	360 rad/h	4 B (If=10mA)	-	-
66191-313 D/C 1031 JAN-S	-	-	28 MeV	6 GND
	-	-	60 MeV	9 GND
	-	-	184MeV	9 GND
	360 rad/h	3 B (If=10mA,Ic=1mA)	-	-
	360 rad/h	3 B (Vce=12V)	-	-
	360 rad/h	4 B (If=10mA)	-	-
66223-001 D/C 1116 commercial	-	-	60 MeV	4 GND
66226-001 D/C 1112 commercial	-	-	28 MeV	6 GND
	-	-	60 MeV	9 GND
	-	-	184MeV	9 GND
66266 D/C 1117 commercial	-	-	30 MeV	2 GND
	-	-	30 MeV	2 B (If=1mA,Vce=5V)
	-	-	60 MeV	4 GND
	-	-	60 MeV	4 B (If=1mA,Vce=5V)
66266	-	-	60 MeV	Separated parts
OLH249 D/C 0614 commercial	-	-	60 MeV	3 GND
OLS449 D/C 0949 commercial	36 rad/h	4 GND	-	-
	36 rad/h	4 B (If=1mA,Vce=5V)	-	-
	360 rad/h	4 GND	-	-
	360 rad/h	4 B (If=1mA,Vce=5V)	-	-
	-	-	50 MeV	4 GND
	-	-	50 MeV	4 B (If=1mA,Vce=5V)
	-	-	173 MeV	4 GND
	-	-	173 MeV	4 B (If=1mA,Vce=5V)
OLS449 D/C 1118 commercial	-	-	60 MeV	3 GND
	-	-	60 MeV	4 GND
	-	-	184 MeV	3 GND
OLS449	-	-	60 MeV	Separated parts

Testing: Irradiation

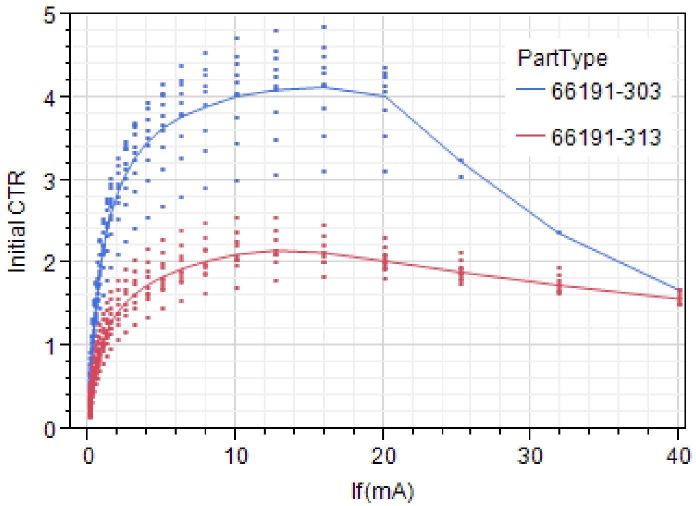
Proton and/or gamma rays were used as radiation sources. Gamma-ray (Co-60) induces total ionizing dose (TID) effects, while protons induce both TID and displacement damage (DD).

- **Proton irradiation** with proton beams ranging from 28 MeV to 184 MeV
  - Kernfysisch Versneller Instituut (KVI) in Groningen and
  - Université Catholique de Louvain-la-Neuve (UCL)
- **Gamma ray irradiation** with a Co-60 source at 36 and 360 rad(Si)/h
  - ESA-ESTEC (European Space Agency, European Space Research and Technology Center).

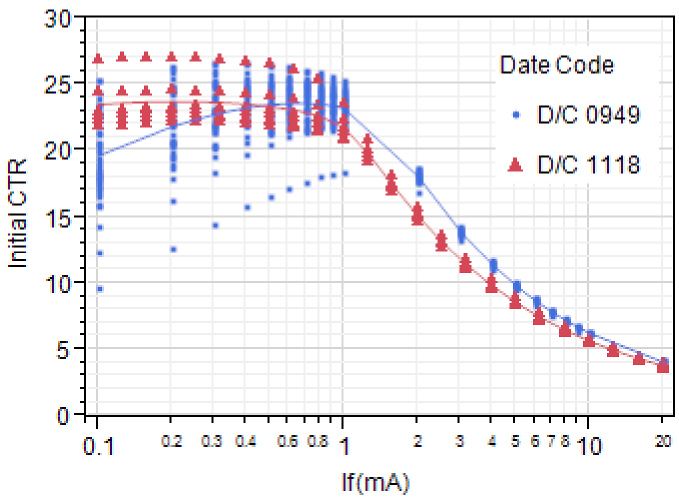
Facility	*Radiation*	*Energy*
Estec	Co-60 γ-rays	1.17, 1.33 MeV; Dose rates: 36, 360 rad/h
KVI	Proton	28, 50, 60, 173, 184 MeV
UCL	Proton	30, 60 MeV

Part-to-part and lot-to-lot variability (before irradiation)

- An important source of part-to-part variations comes from **the precision of hybrid mounting** of the dies **, coupling media deposition, combined variability of emitter and receiver performances**.
- In the graphs below is reported the initial CTR characteristic of each DUT measured with a sweep of forward current applied on the LED (If=0.1 to 40mA), with a fix polarisation between collector and emitter (VCE).



Initial CTR characteristic for two Micropac part types 66191-303 and 66191-313 measured at VCE=1V. Dots are the single DUT measurement, lines are the average for each group.



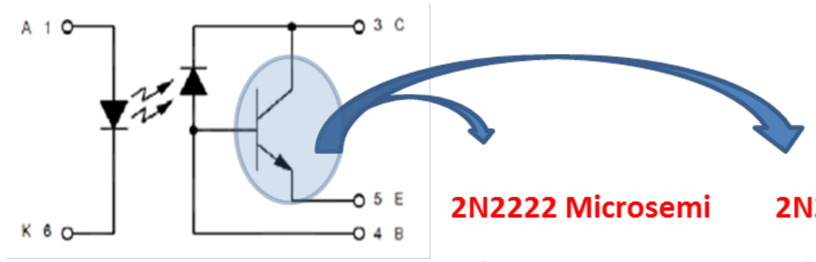
Initial CTR characteristic for Isolink OLS449 measured at VCE=5V. Comparison of two lost with different date code. Dots are the single DUT measurement, lines are the average for each group.

Study Case: process change

The 2N2222 transistor in the receiver stage was changed in MII 66191

Comparison of the older (66191-303) and the newer (66191-313)

Same LED and same photodiodes
 => direct comparison
of TID degradation effects
due to the different transistors



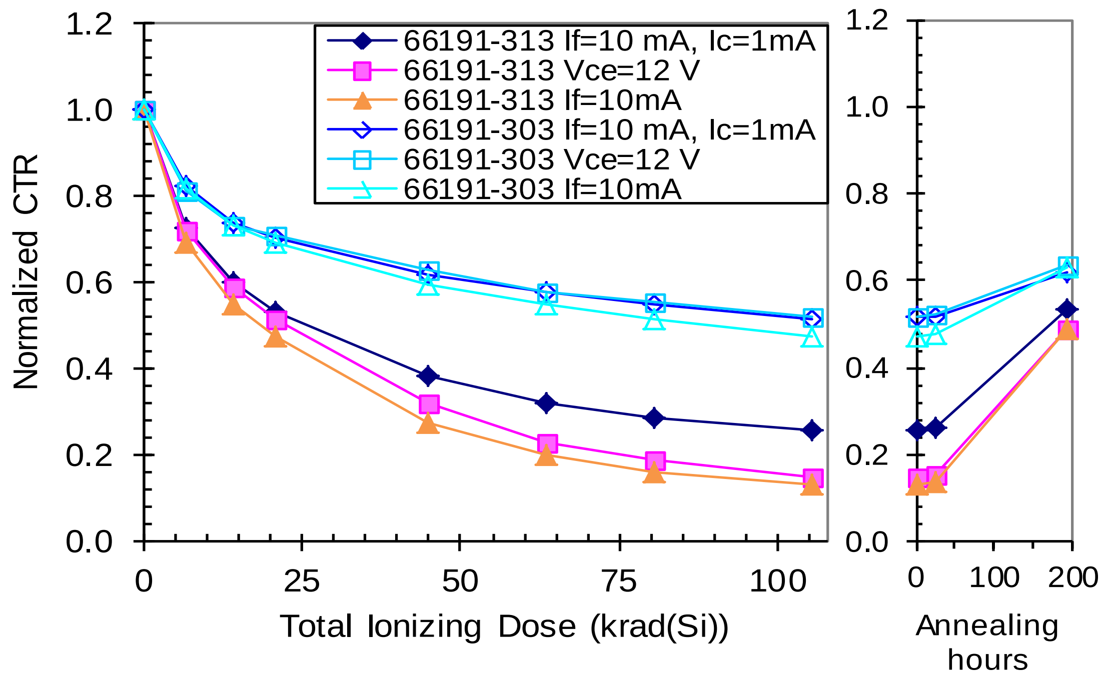
2N2222 Microsemi — Micropac 66191-303

2N2222 Micropac — Micropac 66191-313

– Normalized CTR (If=10mA, Vce=1V) of MII 66191-303 and 66191-313

– Co-60 gamma rays irradiation

– Three different biasing during irradiation and following annealing.



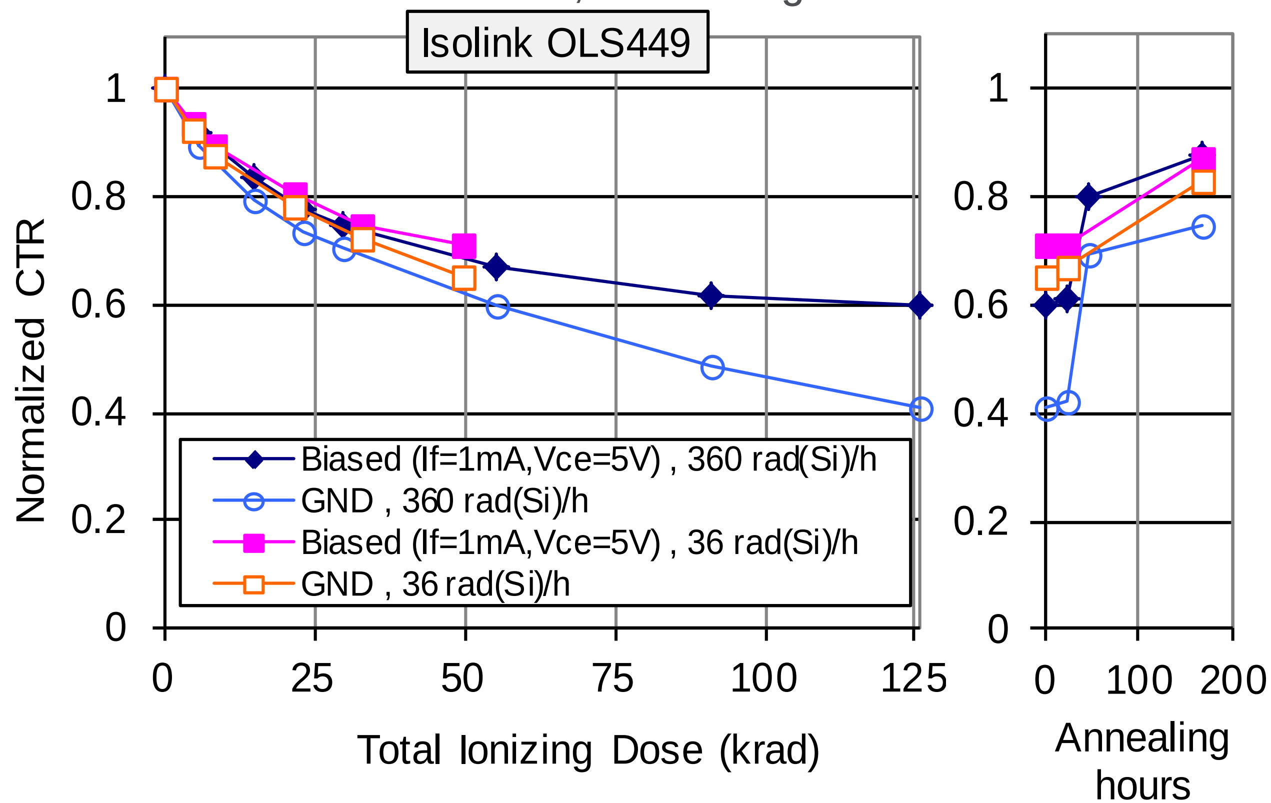
MII 66191-303	MII 66191-313	MII 66223	MII 66226-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

Gamma ray irradiations

- TID tests were performed at 360 rad(Si)/h and 36rad(Si)/h .
- The parts were biased or grounded during irradiation.
- The Co-60 irradiation were followed by a 24-hour anneal at room temperature and 168-hour anneal at 100°C, according to ESCC22900.

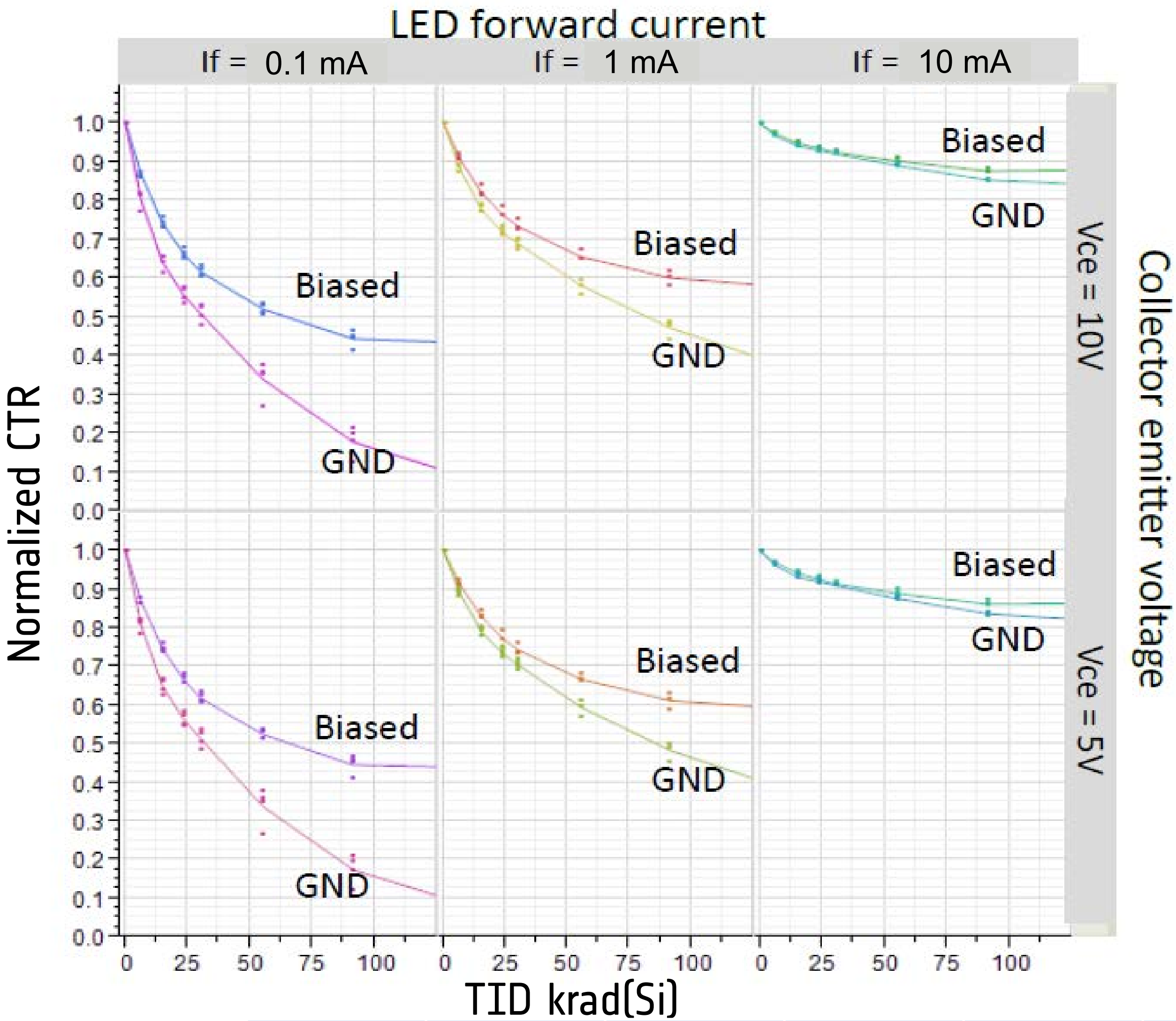
ELDRS not observed

Important effect
of biasing condition
during irradiation
-worst case GND-



MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

Measurement condition comparison



OLS449
Phototransistor

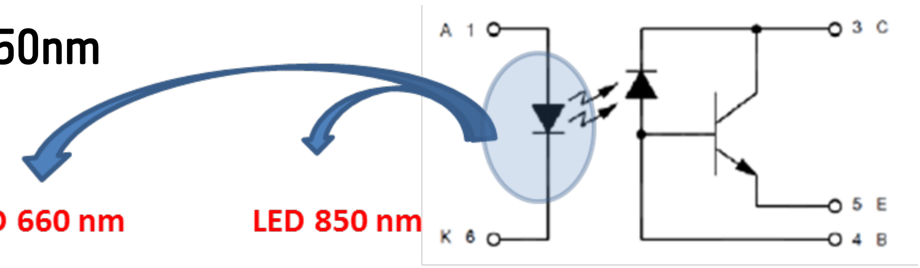
Irradiation:
- Co-60 gamma ray
- Dose rate : 360 rad/h
- Biasing:
  - GND
  - Biased(If=1mA,Vcc=5V)

MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

Study case: Process change

LED replacement MII 66191-313 -> MII 66226-001

Same receiver stage, different LED: 660nm or 850nm



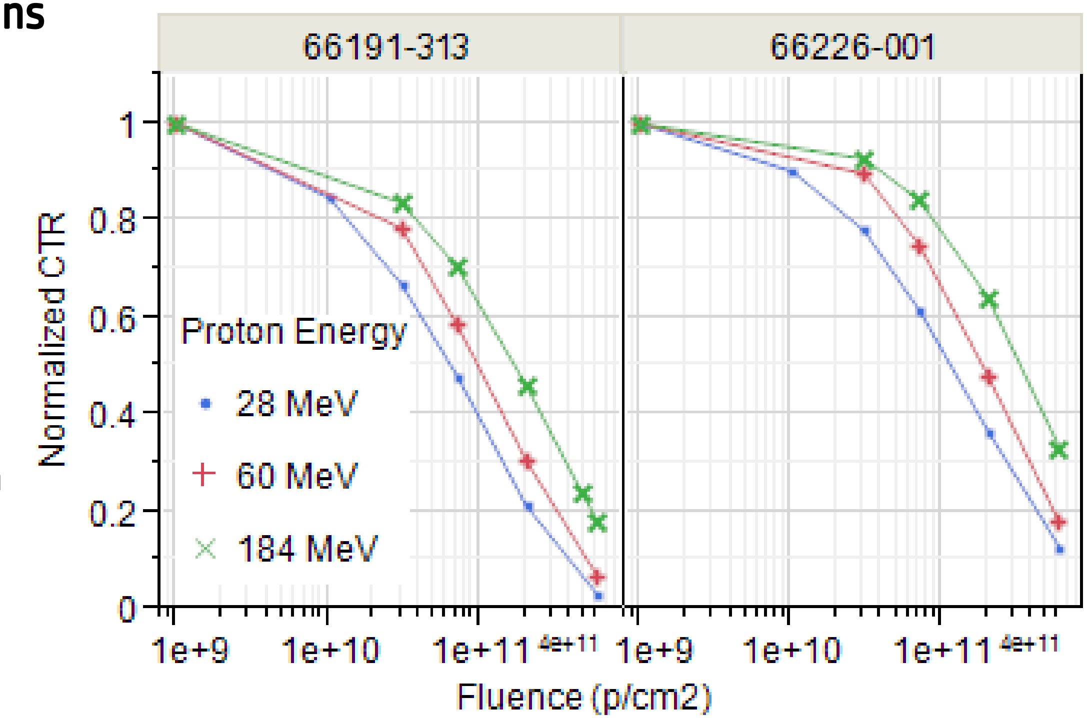
Micropac 66191-313 **Micropac 66226-001**

As DD is almost always the dominant degradation mechanisms for the LED, a comparison of the two part types was performed with **proton beam irradiations** at various energies.

- Normalized CTR (If=10mA, Vce=1V)

-Grounded

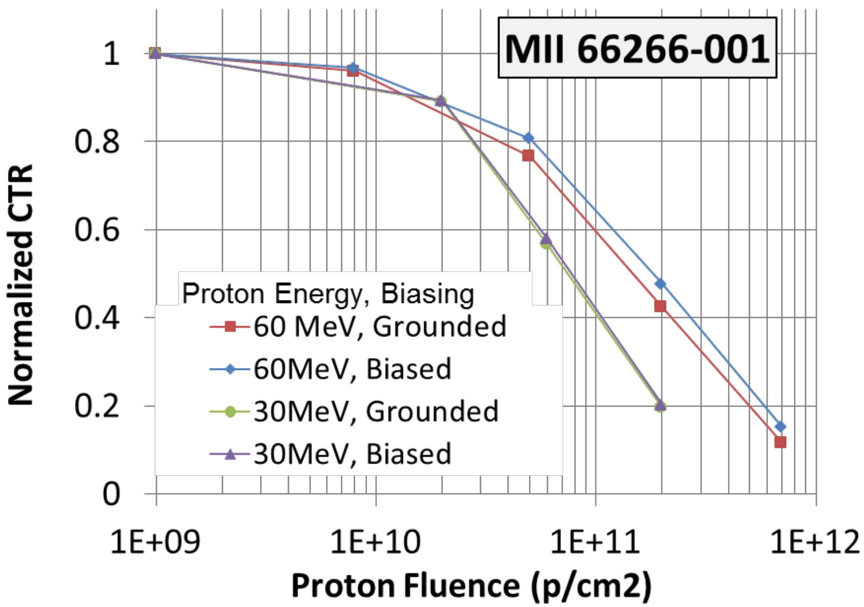
-Irradiation with different proton beam energies (28, 60 and 184MeV)

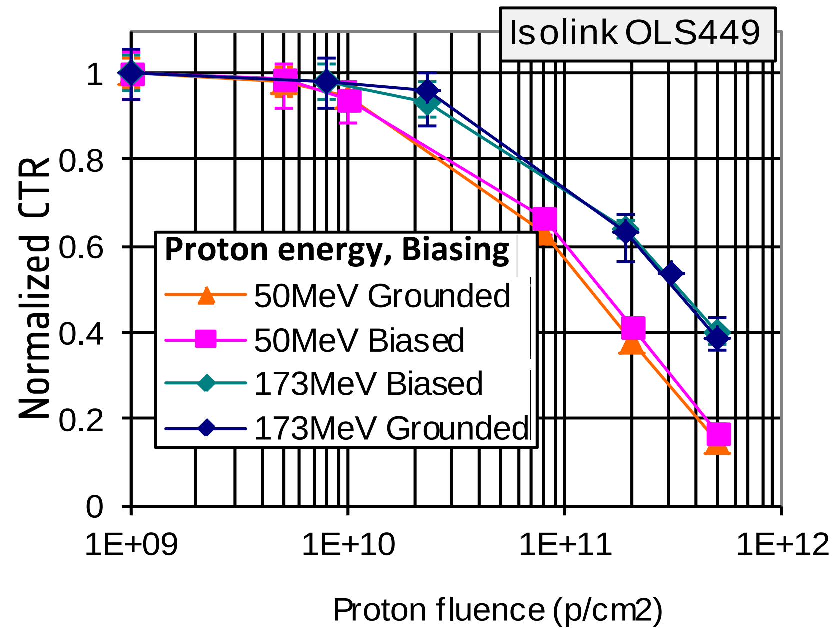


MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

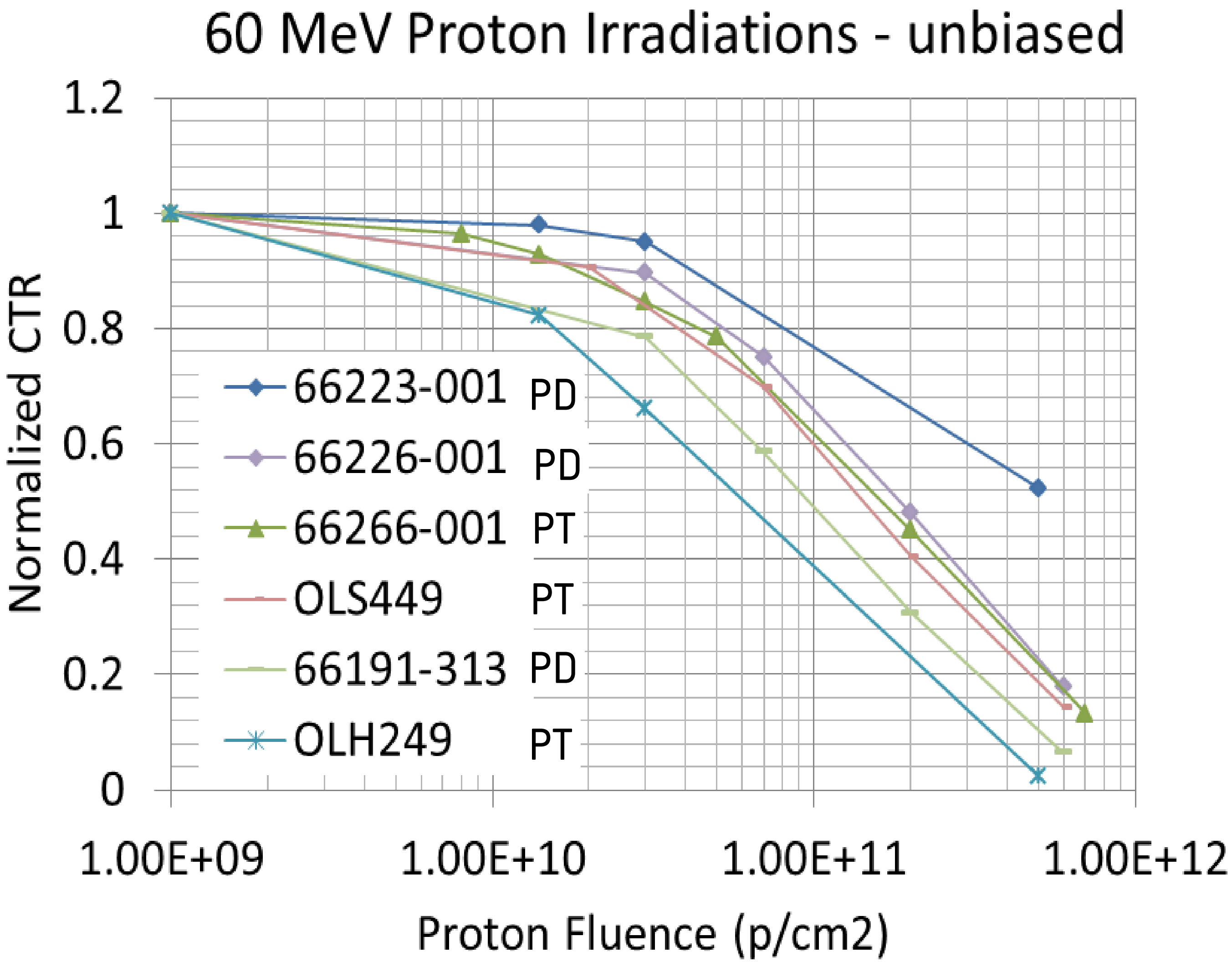
Proton irradiations
Energy &biasing

- Measurements were performed at increasing proton fluences with several proton energies ranging from 28 to 184 MeV.



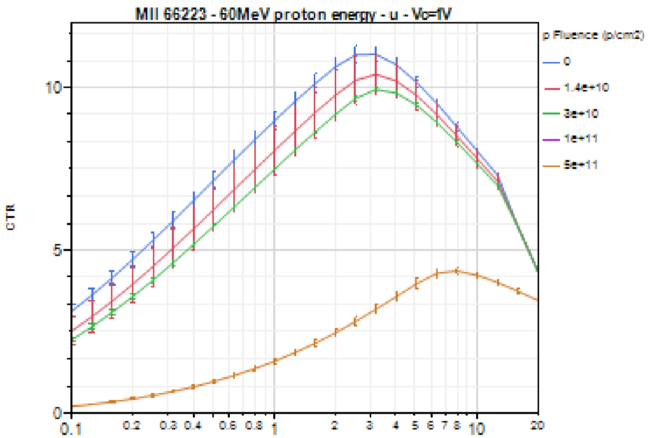


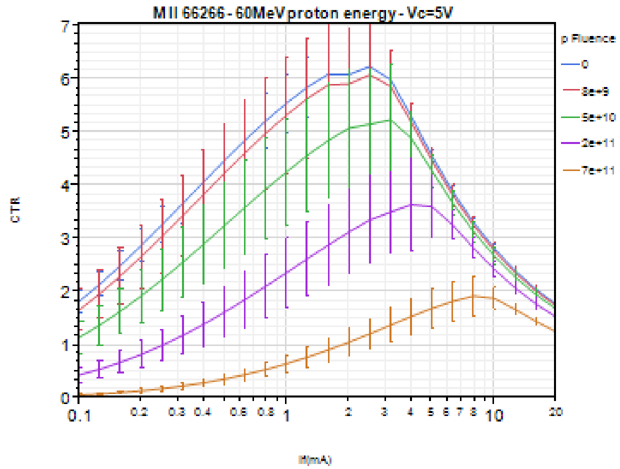
Proton irradiations
Normalized CTR

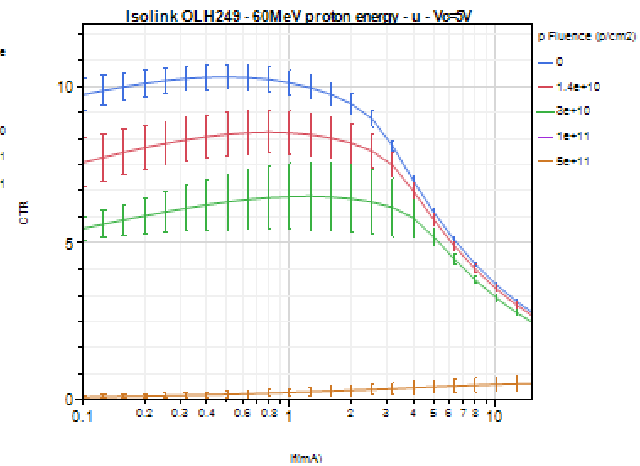


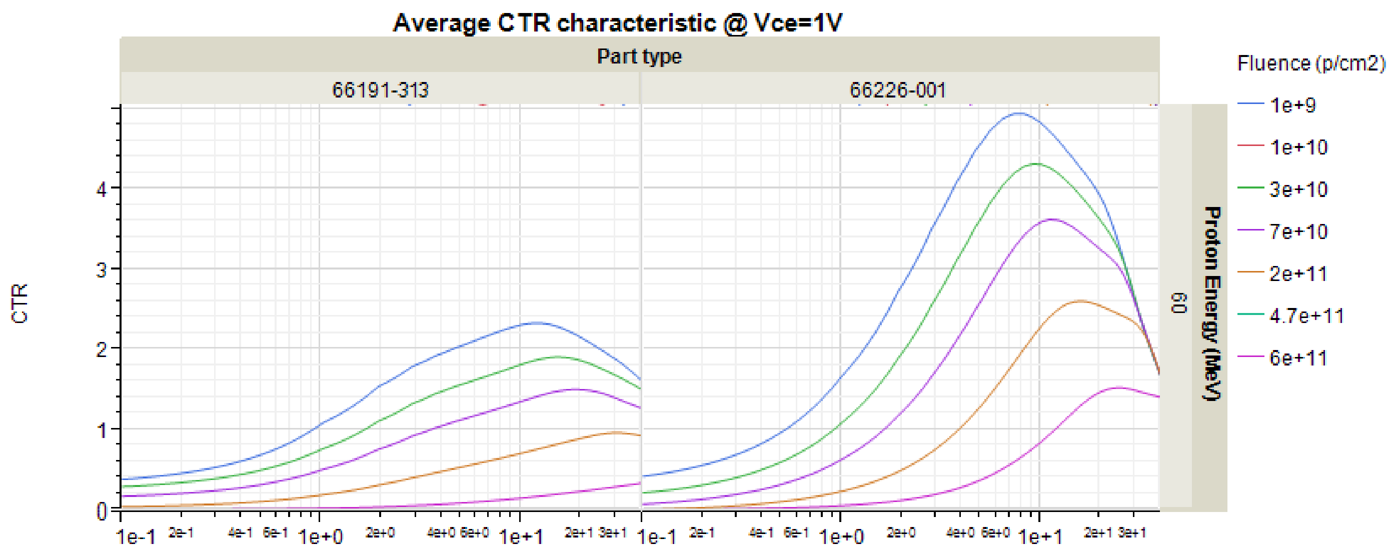
MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

Proton irradiations
CTR characteristic (If=0.1 – If=20 mA)





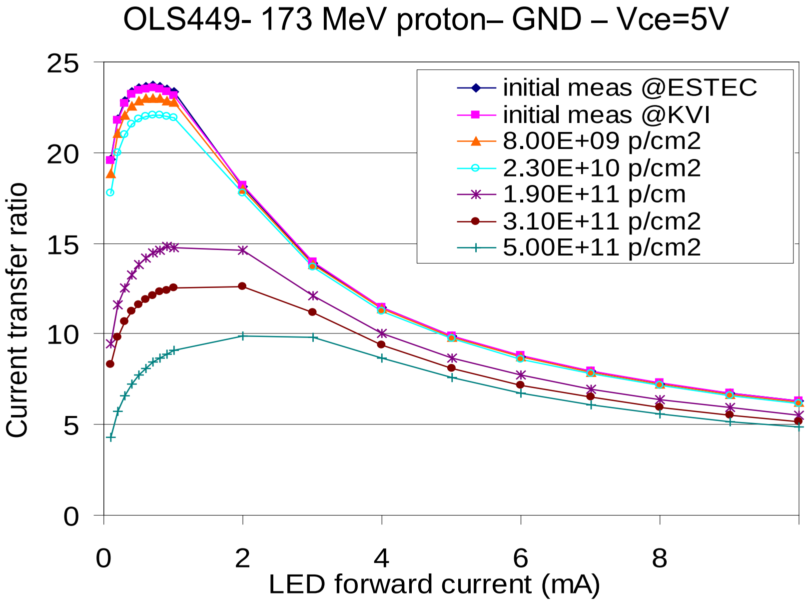


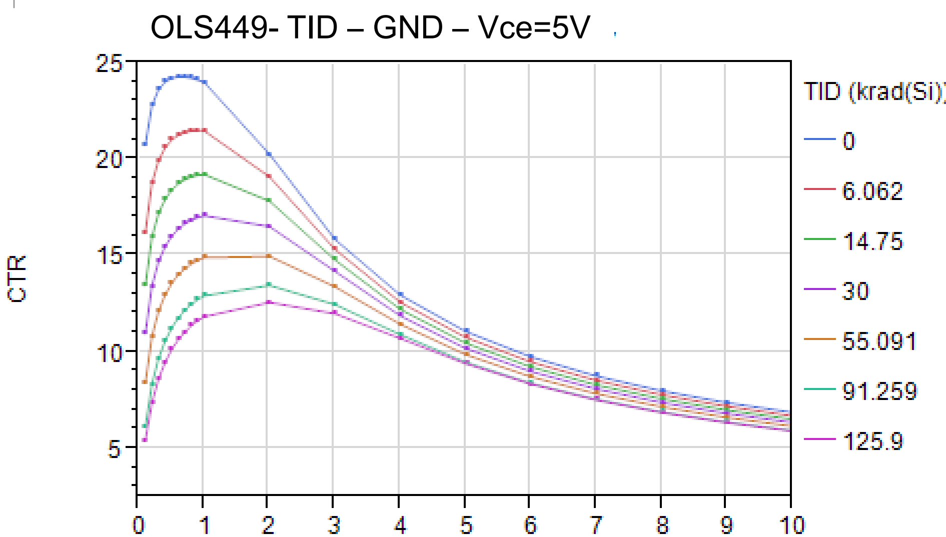


MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

Space Agency

Proton irradiations & Co-60 gamma rays CTR characteristic (If=0.1 – If=20 mA)





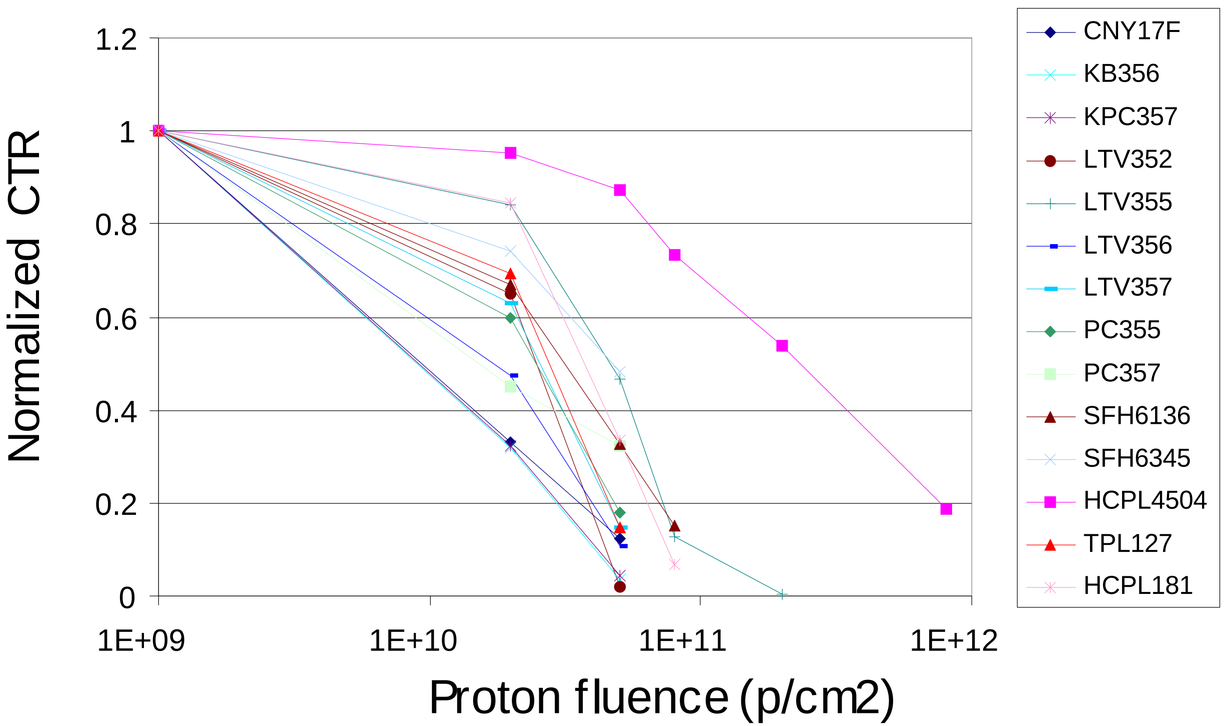
MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

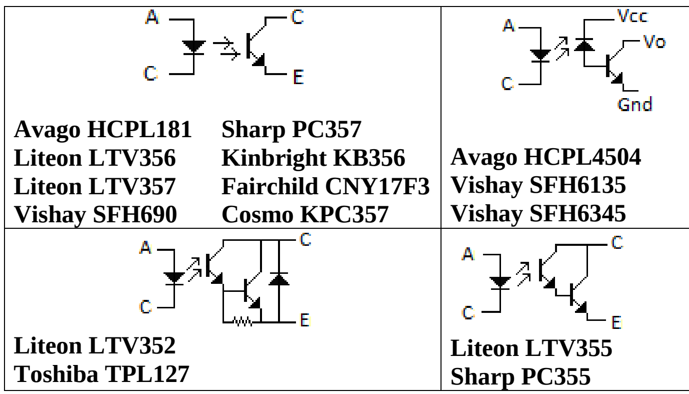
Agency

Commercial optocouplers

Comparison of normalized CTR of 14 part types of COTS optocouplers irradiated in unbiased conditions by ***60MeV proton****.*

The CTR value is averaged on 3 samples.





Radiation tests ongoing on ECI-2 activity
Development of an European Radiation tolerant Optocoupler (OIER 10)

European Radiation Tolerant Optocoupler OIER 10

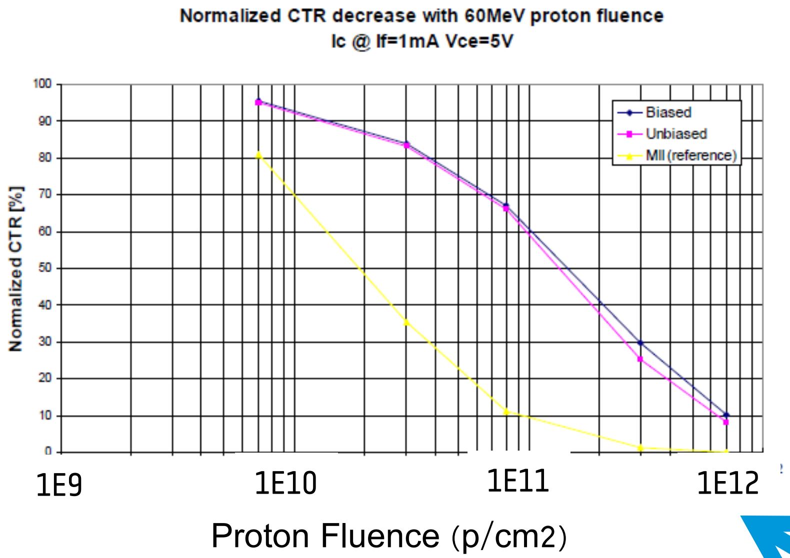
Project funded by the European Space Agency,
coordinated by TEC-QTC,
in the frame of the European Component Initiative (Phase 2)

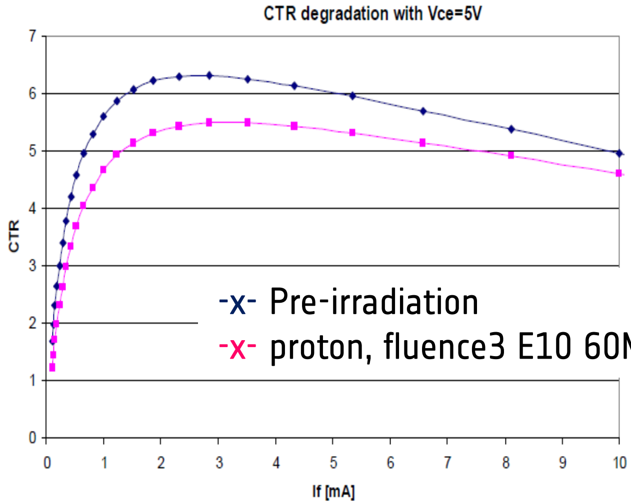
Project consortium:
Optoi (coordination and manufacturing)
FBK (front-end)
AdvEOTec (testing)

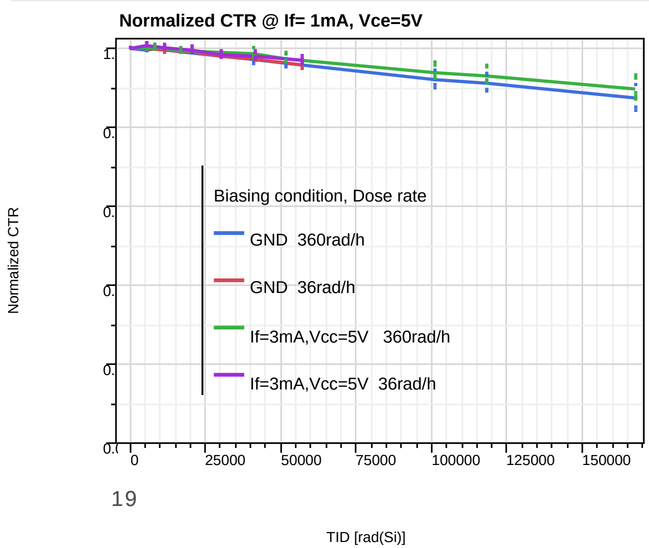
Ongoing radiation testing:
Proton irradiation, beam energy (KVI): 25 MeV, 60MeV and 185 MeV
Gamma ray irradiation (ESA-ESTEC Co-60): 36 rad(Si)/h and 360 rad(Si)/h

Next step of the activity ESCC evaluation testing (planned for Jun-Dec 2013)

Test results



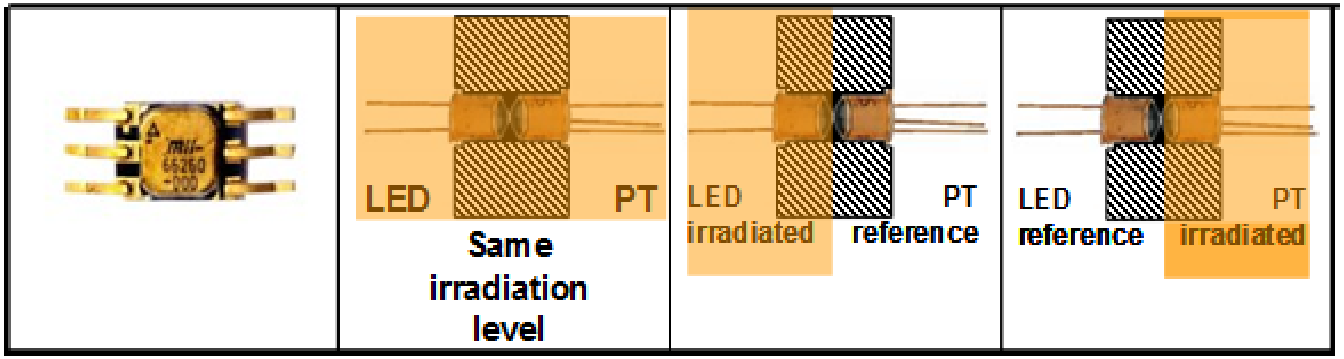




Proton irradiation
biased/unbiased

Co-60 gamma-ray irradiation
biased/unbiased
36/360 rad/h

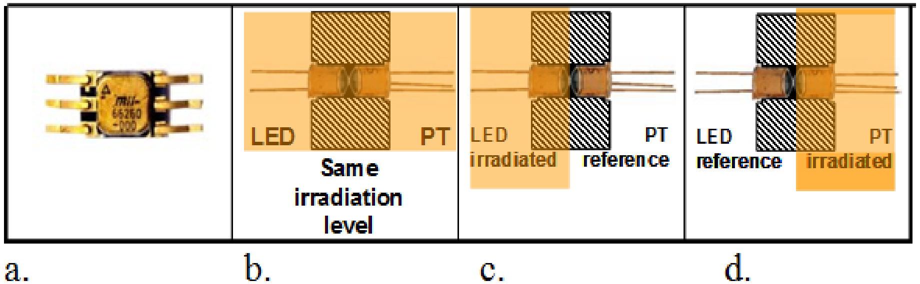
Separate irradiations of the LED and Phototransistor

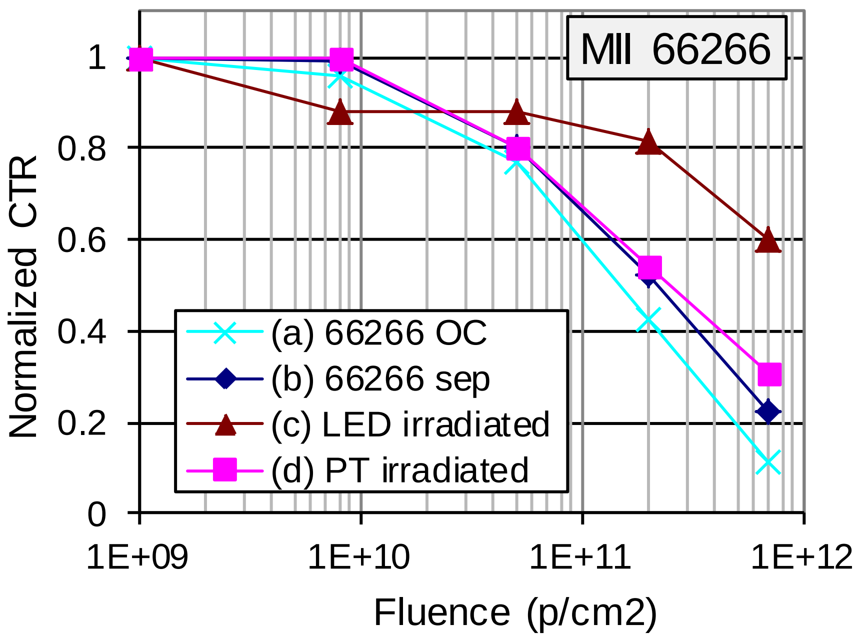


a.	b.	c.	d.
whole optocoupler irradiation	both parts irradiated separately	LED irradiated	phototransistor irradiated

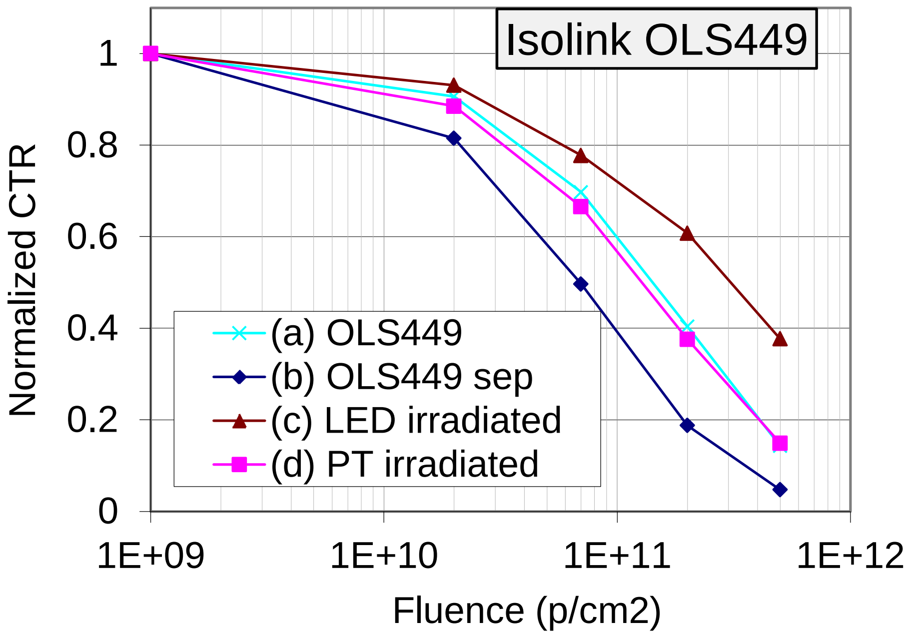
MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

Separate irradiations of the LED and Phototransistor





Comparison of CTR (If=1mA,Vce=5V) degradation of four assemblies of 66266.

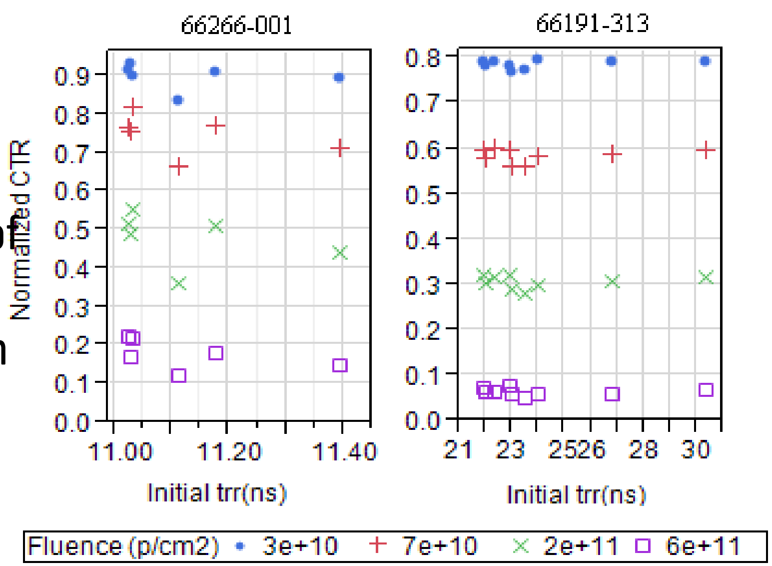


Comparison of CTR (If=1mA,Vce=5V) degradation of four assemblies of OLS449.

CTR correlation with initial reverse recovery time

- **LED minority carriers can be correlated with the LED power degradation caused by displacement damage** [8]. Peyre et al. [9] analyzed the correlation between CTR degradation with proton fluence and the pre-rad value of the LED reverse recovery time (trr), suggesting that this method could be used to select the most promising devices.

During this work, the measurement of the LED trr and base collector junction trr was performed. The graph on the right shows that the measured reverse recovery times of the MII 66266-001 and 66191-313 are is in the range of 10-30ns, typical of heterojunction LEDs. Despite the decrease with proton fluence of the reverse recovery time on both the LED and the base-collector junction, no significant correlation was found on tested parts between the pre-rad value of trr and CTR degradation.



MII 66191-303	MII 66191-313	MII 66223	MII 66226`-001	MII 66266-001	ISOLINK OLS249	ISOLINK OLS449

References

- Compendium of Recent Proton and Co60 Radiation Test Data in Radiation Tolerant Optocouplers and COTS **(Data workshop RADECS 2012)**
  – A. Costantino, S. Hernandez, V. Ferlet-Cavrois, M. Muschitiello, L. Marchand, A. Mohammadzadeh
- Optimized radiation testing methodoloty to predict optocouplers degradation for space applications **(Isros 2012)**
  – A. Costantino, S. Hernandez, G.Quadri, O.Gilard, L.Marchand
- **Escies radiation database**
  – (RA0589) Proton irradiation test results on Micropac Part types 66191-313 and 66226-001
  – (RA0585-E) Co60 TID Test Results on Part Type 66191 (Micropac)

Thank you for your attention!!!

?Q&A?