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European Space Research and Technology Centre Keplerlaan 1 2201 AZ Noordwijk The NetherlandsO T +31 (0)71 565 6565 F +31 (0)71 565 6040 www.esa.intO

DOCUMENT

RA0585-E Co60 TID Test Results on Part Type 66191 (Micropac)

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APPROVAL

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| Author Alessandra Costantino (TEC-QTC) | Date 03/10/2011 All Com | | | | | | | | |
| Approved by Stephan Hernandez (TEC-QTC) | Date 07/10/2011 | | | | | | | | |
| Authorised by Ali Zadeh (TEC-QEC) | Date 07/10/2011 Ali Zadh | | | | | | | | |

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1 INTRODUCTION

The following report describes irradiation tests performed on the Micropac 66191 optocoupler to characterise radiation sensitivity variations observed in the two versions of the device used on ESA missions. The Micropac optocoupler 66191 is manufactured employing a 660 nm AlGaAs LED coupled to a photodiode and a 2N2222 transistor (Figure 1).



Figure 1: 66191 electrical layout

There are two version of the 66191 employed in ESA projects. The older version, 66191-303, contains a 2N2222 transistor from Microsemi. The newer optocoupler version, 66191-313, employs an in-house (Micropac) 2n2222 and replaces the Microsemi transistor. Micropac state that the in-house transistor was selected following TID radiation evaluation of 2N2222 transistors from different manufacturers. TID evaluation testing was carried out by Micropac at high dose rates. At the time of writing it is not known whether Micropac also performed Displacement Damage testing on the new version of the 66191-313.

The ESA TID tests of the 66191 were initiated due to an unexpected increased TID sensitivity observed following low dose rate (108rad(Si)/h) TID irradiation testing of the 66191-313 by Alter for an ESA projec. The irradiation tests were performed biased and unbiased.

The scope of the irradiation tests described here is to perform low dose rate testing on the two versions of the 66191 and to establish whether the 2N2222 is the source of the observed increased TID sensitivity mentioned above. Additionally, these tests are performed to verify findings by Alter. The tests were performed at various biasing conditions based on information received from ESA projects.

2 **REFERENCES**

REF1 ESA/SCC 22900 "Total Dose Steady-State Irradiation Test Method", issue 3 REF2 ESSB-ST-Q-001, "Space product assurance - Radiation Hardness Assurance" Issue 1



3 TEST DESCRIPTION

3.1 Facility and Dosimetry

The ESTEC Co-60 facility comprises of a Nordion Gammabeam 150C irradiator containing a nominal 74.8 TBq (2000 Ci) Co-60 source at the last reload date in June 2007. The irradiation room is monitored for temperature, relative humidity and pressure.

The dosimetry system is based on Farmer type 2571A 0.6 cc air ionisation chambers linked to Farmer 2670 electrometers. The dosimetry system is compensated against temperature and pressure environmental fluctuation.

All irradiations and measurements were performed at room temperature (22.5 ± 3 °C).

3.2 Devices Under Test

A total of 20 devices were received from Micropac, ten (10) 66191-303 devices and ten (10) 66191-313 devices. The datasheet specification, reported in Annex A, refers to screened devices with reference 66191-300 (S-level screening). The 66191-300 specification is also applicable to part types 66191-303 and 66191-313. No specific datasheet is available for the 66191-303 and 66191-313.

| Parts description: | |
|-----------------------|---|
| Component Designation | 66191-303 |
| Manufacturer | Micropac |
| Family | Opto-electronics |
| Group | Optocoupler |
| Package | 6 pin, hermetically sealed Leadless Ceramic Carrier |
| Lot date code | 1004 |
| Device serial numbers | 180, 187, 188, 189, 190, 195, 199, 201, 205, 206 |

| Component Designation | 66191-313 |
|-----------------------|---|
| Manufacturer | Micropac |
| Family | Opto-electronics |
| Group | Optocoupler |
| Package | 6 pin, hermetically sealed Leadless Ceramic Carrier |
| Lot date code | 1031 |
| Device serial numbers | 211, 217, 220, 221, 223, 224, 225, 228, 237, 238 |



3.3 Biasing conditions

For both device versions the following biasing conditions were applied during irradiation:

A) 3 samples in On mode. Vce = OV (Vce sat), Ic = 1mA, Ib = OA (disconnected), I LED=10mA;

B) 3 samples in Off mode. Vce = 12V, Ic = 0A, Ib = 0A (disconnected), I LED = 0A (grounded);

C) 4 samples biased with ILED=10mA, receiver pins grounded.

To ensure stability and functionality of the measurement system a Micropac 66223 optocoupler was used as reference device and was electrically tested before and after each optocoupler electrical measurement.

| Par type | S/n's | Description | | | | |
|-----------|--------------------|--|--|--|--|--|
| 66191-303 | 180, 187, 188 | Biased during ⁶⁰ Co irradiation, biasing condition A | | | | |
| 66191-303 | 189, 190, 195 | Biased during ⁶⁰ Co irradiation, biasing condition B | | | | |
| 66191-303 | 199, 201, 205, 206 | Biased during ⁶⁰ Co irradiation, biasing condition C | | | | |
| 66191-313 | 211, 217, 220 | Biased during ⁶⁰ Co irradiation, biasing condition A | | | | |
| 66191-313 | 221, 223, 224 | Biased during ⁶⁰ Co irradiation, biasing condition B | | | | |
| 66191-313 | 225, 228, 237, 238 | Biased during 60Co irradiation, biasing condition C | | | | |
| 66223 | 1 | Reference device (not irradiated) - Electrically tested before and | | | | |
| | 1 | after each optocoupler electrical measurement | | | | |

Table 1 Device Under Test biasing conditions



3.4 Radiation Test Plan

Irradiation tests were performed in accordance to REF1. This section provides a summary of the Radiation Test Plan with reference "20105".

The actual radiation test steps are reported in Table 2.

| Step | Total Dose krad(Si) |
|-------------------------|------------------------|
| (Pre irradiation) 0 | 0 |
| Irradiation step # 1 | 6675 |
| Irradiation step # 2 | 14229 |
| Irradiation step # 3 | 20910 |
| Irradiation step # 4 | 44851 |
| Irradiation step # 5 | 63515 |
| Irradiation step # 6 | 80696 |
| Irradiation step # 7 | 105221 |
| Table O. Asteral Same d | 1 - 4 ¹ |

Table 2: Actual irradiation steps

The dose rate chosen was 360 rad (Si)/h, a lower dose rate was not employed because of time limitations.

Pre and post-irradiation electrical measurements and intermediate electrical measurements (following each irradiation step) were carried out as described in Section 3.5

At the end of the final irradiation run, all devices were electrically measured and annealed for 24 hours at room temperature and subsequently underwent accelerated aging at 100°C (for 168 hrs in total), maintaining the same bias conditions applied during the TID test. Table 3 reports the annealing/accelerated ageing sequence detail.

| Step | Temperature | Duration | | |
|-----------------------|------------------|-----------|--|--|
| Anneal | Room temperature | 24 hours | | |
| Accelerated Ageing | 100 °C | 168 hours | | |

Table 3: Annealing information



3.5 Measurement Setup

No in-situ measurements were performed during irradiation. The electrical characterisation was performed after each irradiation, annealing and ageing step as follows:

- 1 OC Performances
 - a. Current Transfer Ratio (CTR) @ Vce=1V If=0.1-40mA
 - b. Saturation Voltage @ If=20mA Ic=10mA
- 2 Phototransistor performances
 - a. Collector emitter dark current @Vce= 20V
 - b. Collector emitter off (BR) @Vce= 40V
 - c. Collector base off (BR) @Veb = 5V
 - d. Emitter collector off (BR) @Vce= 40V
- 3 LED performances
 - a. Current Voltage Characteristic @If=0.1÷40mA
 - b. Reverse Current @V=-3

All above parameters were measured using the following equipment:

Parameter analyzer: Agilent 4156C (s/n JPIOJ00469)

Text Fixture Agilent: 16442A

All measurements were controlled by an automatic test program using Wavevue (Microvue), the acquired data were analyzed with Microsoft Excel.

All measurements have been archived but only CTR measurements have been presented in this report.



4 **TEST RESULTS**

The test results are shown in sections 4.1 to 4.5. Due to the limited number of samples available, the one sided tolerance limit statistical method has been applied to treat the irradiation test results in accordance to REF.2.

One device (Sample 190, 66191-303, biasing condition B) failed during irradiation after 14229 rad(Si) due to an electrical overstress. For this biasing group, with only two samples remaining, statistical analysis was not possible; for this reason the corresponding graphs report only the average of measured data without the 90% probability with 90% confidence limits.



4.1 CTR decrease with radiation Measurements on all tested parts

| | CTR @If=10mA, Vce=1V | | | | | | | | | | | | | |
|-----------|----------------------|-----|------|------|-------|---------|---------|-------|-------|--------|--|-------------|------------|--------------|
| | Riasing | | | | | Dose (r | ad(Si)) | | | | | Last | Annealing | Ageing hours |
| Part type | condition | s/n | | | | 2000 (. | 44(0.)) | | | | | irradiation | hours @ RT | @ 100°C |
| | | | 0 | 6675 | 14229 | 20910 | 44851 | 63515 | 80696 | 105221 | | inaciation | 24 | 168 |
| 66191-313 | Α | 211 | 2.25 | 1.66 | 1.37 | 1.22 | 0.88 | 0.73 | 0.65 | 0.58 | | 0.58 | 0.6 | 1.21 |
| 66191-313 | А | 217 | 2.05 | 1.46 | 1.2 | 1.06 | 0.75 | 0.62 | 0.55 | 0.49 | | 0.49 | 0.5 | 1.08 |
| 66191-313 | А | 220 | 1.71 | 1.26 | 1.04 | 0.92 | 0.68 | 0.58 | 0.53 | 0.47 | | 0.47 | 0.49 | 0.91 |
| 66191-313 | в | 221 | 2.23 | 1.61 | 1.31 | 1.13 | 0.68 | 0.48 | 0.38 | 0.3 | | 0.3 | 0.31 | 1.06 |
| 66191-313 | в | 223 | 2.38 | 1.72 | 1.41 | 1.23 | 0.74 | 0.53 | 0.43 | 0.34 | | 0.34 | 0.34 | 1.16 |
| 66191-313 | В | 224 | 2.56 | 1.86 | 1.52 | 1.34 | 0.87 | 0.66 | 0.54 | 0.43 | | 0.43 | 0.44 | 1.28 |
| 66191-313 | С | 225 | 1.95 | 1.41 | 1.14 | 0.99 | 0.58 | 0.41 | 0.33 | 0.27 | | 0.27 | 0.28 | 1 |
| 66191-313 | С | 228 | 2.09 | 1.42 | 1.09 | 0.92 | 0.52 | 0.38 | 0.31 | 0.26 | | 0.26 | 0.27 | 0.98 |
| 66191-313 | С | 237 | 1.96 | 1.39 | 1.14 | 0.99 | 0.6 | 0.43 | 0.35 | 0.28 | | 0.28 | 0.28 | 0.98 |
| 66191-313 | С | 238 | 2.04 | 1.37 | 1.08 | 0.91 | 0.53 | 0.38 | 0.32 | 0.27 | | 0.27 | 0.27 | 0.98 |
| | | - | | | | | | | | | | - | | |
| | | _ | | | | | | | | | | | | |
| 66191-303 | А | 180 | 4.5 | 3.74 | 3.36 | 3.18 | 2.78 | 2.58 | 2.44 | 2.28 | | 2.28 | 2.29 | 2.79 |
| 66191-303 | А | 187 | 4.72 | 3.88 | 3.5 | 3.35 | 3.01 | 2.83 | 2.71 | 2.55 | | 2.55 | 2.55 | 2.98 |
| 66191-303 | А | 188 | 3.75 | 3.08 | 2.75 | 2.6 | 2.27 | 2.1 | 1.99 | 1.85 | | 1.85 | 1.86 | 2.29 |
| 66191-303 | в | 189 | 4.28 | 3.53 | 3.22 | 3.1 | 2.82 | 2.59 | 2.5 | 2.38 | | 2.38 | 2.39 | 2.73 |
| 66191-303 | в | 190 | 4.03 | 3.29 | 2.97 | | | | | | | | | |
| 66191-303 | в | 195 | 4.07 | 3.27 | 2.928 | 2.77 | 2.4 | 2.21 | 2.08 | 1.91 | | 1.91 | 1.91 | 2.522 |
| 66191-303 | С | 199 | 4.42 | 3.64 | 3.27 | 3.1 | 2.65 | 2.43 | 2.27 | 2.06 | | 2.06 | 2.07 | 0 |
| 66191-303 | С | 201 | 3.44 | 2.81 | 2.5 | 2.35 | 2.02 | 1.87 | 1.76 | 1.64 | | 1.64 | 1.64 | 2.15 |
| 66191-303 | С | 205 | 3 | 2.42 | 2.16 | 2.04 | 1.74 | 1.59 | 1.49 | 1.37 | | 1.37 | 1.38 | 1.84 |
| 66191-303 | С | 206 | 4.18 | 3.46 | 3.13 | 2.94 | 2.56 | 2.37 | 2.24 | 2.07 | | 2.07 | 2.07 | 2.68 |

Table 4: CTR (@Vce=1V, If=10mA) measured at every dose step for each tested sample.



Figure 2 : CTR degradation of each tested part due to TID irradiation.



4.2 Normalised CTR decrease with radiation

Measurements on all tested parts

| | | | | | ! | Normaliz | ed CTR (| @lf=10m | A, Vce= | 1V | | | | |
|-----------|-----------|-----|------|------|-------|----------|----------|---------|---------|--------|---|----------|------------|--------------|
| | Biasing | | | | | Dose (| rad(Si)) | | | | | Last TID | Annealing | Ageing hours |
| Part type | condition | s/n | | | | 2000 (. | uu(e.)) | | | | | step | hours @ RT | @ 100°C |
| | | | 0 | 6675 | 14229 | 20910 | 44851 | 63515 | 80696 | 105221 | | 0 | 24 | 168 |
| 66191-313 | А | 211 | 1.00 | 0.74 | 0.61 | 0.54 | 0.39 | 0.32 | 0.29 | 0.26 | | 0.26 | 0.27 | 0.54 |
| 66191-313 | А | 217 | 1.00 | 0.71 | 0.59 | 0.52 | 0.37 | 0.30 | 0.27 | 0.24 | | 0.24 | 0.24 | 0.53 |
| 66191-313 | А | 220 | 1.00 | 0.74 | 0.61 | 0.54 | 0.40 | 0.34 | 0.31 | 0.27 | | 0.27 | 0.29 | 0.53 |
| 66191-313 | В | 221 | 1.00 | 0.72 | 0.59 | 0.51 | 0.30 | 0.22 | 0.17 | 0.13 | | 0.13 | 0.14 | 0.48 |
| 66191-313 | В | 223 | 1.00 | 0.72 | 0.59 | 0.52 | 0.31 | 0.22 | 0.18 | 0.14 | | 0.14 | 0.14 | 0.49 |
| 66191-313 | В | 224 | 1.00 | 0.73 | 0.59 | 0.52 | 0.34 | 0.26 | 0.21 | 0.17 | | 0.17 | 0.17 | 0.50 |
| 66191-313 | С | 225 | 1.00 | 0.72 | 0.58 | 0.51 | 0.30 | 0.21 | 0.17 | 0.14 | | 0.14 | 0.14 | 0.51 |
| 66191-313 | С | 228 | 1.00 | 0.68 | 0.52 | 0.44 | 0.25 | 0.18 | 0.15 | 0.12 | | 0.12 | 0.13 | 0.47 |
| 66191-313 | С | 237 | 1.00 | 0.71 | 0.58 | 0.51 | 0.31 | 0.22 | 0.18 | 0.14 | | 0.14 | 0.14 | 0.50 |
| 66191-313 | С | 238 | 1.00 | 0.67 | 0.53 | 0.45 | 0.26 | 0.19 | 0.16 | 0.13 | | 0.13 | 0.13 | 0.48 |
| | | | | | | | | | | | - | | | |
| | | | | | | | | | | | | | | |
| 66191-303 | А | 180 | 1.00 | 0.83 | 0.75 | 0.71 | 0.62 | 0.57 | 0.54 | 0.51 | | 0.51 | 0.51 | 0.62 |
| 66191-303 | А | 187 | 1.00 | 0.82 | 0.74 | 0.71 | 0.64 | 0.60 | 0.57 | 0.54 | | 0.54 | 0.54 | 0.63 |
| 66191-303 | А | 188 | 1.00 | 0.82 | 0.73 | 0.69 | 0.61 | 0.56 | 0.53 | 0.49 | | 0.49 | 0.50 | 0.61 |
| 66191-303 | В | 189 | 1.00 | 0.82 | 0.75 | 0.72 | 0.66 | 0.61 | 0.58 | 0.56 | | 0.56 | 0.56 | 0.64 |
| 66191-303 | В | 190 | 1.00 | 0.82 | 0.74 | | | | | | | 1 | | |
| 66191-303 | В | 195 | 1.00 | 0.80 | 0.72 | 0.68 | 0.59 | 0.54 | 0.51 | 0.47 | | 0.47 | 0.47 | 0.62 |
| 66191-303 | С | 199 | 1.00 | 0.82 | 0.74 | 0.70 | 0.60 | 0.55 | 0.51 | 0.47 | | 0.47 | 0.47 | 0.63 |
| 66191-303 | С | 201 | 1.00 | 0.82 | 0.73 | 0.68 | 0.59 | 0.54 | 0.51 | 0.48 | | 0.48 | 0.48 | 0.63 |
| 66191-303 | С | 205 | 1.00 | 0.81 | 0.72 | 0.68 | 0.58 | 0.53 | 0.50 | 0.46 | | 0.46 | 0.46 | 0.61 |
| 66191-303 | С | 206 | 1.00 | 0.83 | 0.75 | 0.70 | 0.61 | 0.57 | 0.54 | 0.50 | | 0.50 | 0.50 | 0.64 |

Table 5 CTR (Vce=1V, If=10mA) normalised to the pre-irradiation measurement. The data are reported for every dose step, for each tested sample



Figure 3: CTR after irradiation normalised to initial CTR value for each tested part.

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4.3 Average CTR degradation for each biasing group

| Part type | Biasing Condition | sing Dose (rad(Si)) dition | | | | | | | | | 20.7 | 27.8 |
|-----------|----------------------|-------------------------------|------|-------|-------|-------|-------|-------|--------|------|------|------|
| | | 0 | 6675 | 14229 | 20910 | 44851 | 63515 | 80696 | 105221 | 0 | 24 | 192 |
| 66191-313 | A | 2.00 | 1.46 | 1.20 | 1.07 | 0.77 | 0.64 | 0.58 | 0.51 | 0.51 | 0.53 | 1.07 |
| 66191-313 | В | 2.39 | 1.73 | 1.41 | 1.23 | 0.76 | 0.56 | 0.45 | 0.36 | 0.36 | 0.36 | 1.17 |
| 66191-313 | С | 2.01 | 1.40 | 1.11 | 0.95 | 0.56 | 0.40 | 0.33 | 0.27 | 0.27 | 0.28 | 0.99 |
| 66191-303 | А | 4.32 | 3.57 | 3.20 | 3.04 | 2.69 | 2.50 | 2.38 | 2.23 | 2.23 | 2.23 | 2.69 |
| 66191-303 | В | 4.13 | 3.36 | 3.04 | 2.94 | 2.61 | 2.40 | 2.29 | 2.15 | 2.15 | 2.15 | 2.63 |
| 66191-303 | С | 3.76 | 3.08 | 2.77 | 2.61 | 2.24 | 2.07 | 1.94 | 1.79 | 1.79 | 1.79 | 2.36 |

Table 6 Average CTR (@Vce=1V, If=10mA) within the biasing group, at every dose step.



Figure 4: CTR degradation for each biasing condition applied during TID irradiation (average on all tested samples of the same biasing group). Figure 5 compares the trend of each biasing group and the limits of 90% confidence.



Average CTR degradation of the samples belonging to the same biasing group



Figure 5.I– Biasing group A



Figure 5.II- Biasing group B





Figure 5.III– Biasing group C

Figure 5 Comparison of CTR decrease for each biasing group. The plotted points are the average of CTR measured at each irradiation step on the samples belonging to the same biasing group. There is 90% probability with 90% confidence that the electrical parameters will be within the limits indicated by the dashed lines (one sided tolerance limit statistical treatment of data).



4.4 Normalised average CTR decrease for each biasing group

| Part type | Biasing | Dose (rad(Si)) | | | | | | | | | | |
|-----------|-----------|----------------|------|-------|-------|-------|-------|-------|--------|------|------|------|
| | Condition | 0 | 6675 | 14229 | 20910 | 44851 | 63515 | 80696 | 105221 | 0 | 24 | 168 |
| 66191-313 | А | 2.00 | 1.46 | 1.20 | 1.07 | 0.77 | 0.64 | 0.58 | 0.51 | 0.51 | 0.53 | 1.07 |
| 66191-313 | В | 2.39 | 1.73 | 1.41 | 1.23 | 0.76 | 0.56 | 0.45 | 0.36 | 0.36 | 0.36 | 1.17 |
| 66191-313 | С | 2.01 | 1.40 | 1.11 | 0.95 | 0.56 | 0.40 | 0.33 | 0.27 | 0.27 | 0.28 | 0.99 |
| 66191-303 | А | 4.32 | 3.57 | 3.20 | 3.04 | 2.69 | 2.50 | 2.38 | 2.23 | 2.23 | 2.23 | 2.69 |
| 66191-303 | В | 4.13 | 3.36 | 3.04 | 2.94 | 2.61 | 2.40 | 2.29 | 2.15 | 2.15 | 2.15 | 2.63 |
| 66191-303 | С | 3.76 | 3.08 | 2.77 | 2.61 | 2.24 | 2.07 | 1.94 | 1.79 | 1.79 | 1.79 | 2.36 |

Table 7 CTR (@Vce=1V, If=10mA) normalised to the pre-irradiation measurement, average within the biasing group, at every dose step.



Figure 6: CTR after irradiation normalised to initial CTR value.

The graph reports the trend for all the three biasing condition applied during TID. The plotted points are the average on the samples belonging to the same biasing group. Figure 7 compares the trend of each biasing group and the limits of 90% confidence.



Average of normalised CTR decrease of the samples belonging to the same biasing group



Figure 7. I – Biasing group A



Figure 7. II Biasing group B





Figure 7. III Biasing group C

Figure 7: Comparison of trend of each biasing group. Plots report the average of normalised CTR on the samples belonging to the same biasing group. There is 90% probability with 90% confidence that the electrical parameters will be within the limits indicated by the dashed lines (one sided tolerance limit statistical treatment of data).



4.5 CTR characteristic at each step

Biasing A

| У | | dose | | | | | | | | | | |
|-----------|---------|--------|-------|-------|-------|-------|-------|-------|-------|--------|-----------|-----------|
| | | | | | | | | | | | annealing | annealing |
| PartType | biasing | lf | 0 | 6675 | 14229 | 20910 | 44851 | 63515 | 80696 | 105221 | 24h tamb | 100C 168h |
| 66191-303 | A | 0.1 | 0.307 | 0.218 | 0.181 | 0.162 | 0.112 | 0.088 | 0.072 | 0.056 | 0.058 | 0.116 |
| | | 0.1259 | 0.400 | 0.290 | 0.243 | 0.218 | 0.156 | 0.124 | 0.103 | 0.081 | 0.083 | 0.160 |
| | | 0.1585 | 0.516 | 0.380 | 0.321 | 0.290 | 0.212 | 0.171 | 0.144 | 0.115 | 0.118 | 0.217 |
| | | 0.1996 | 0.655 | 0.489 | 0.416 | 0.378 | 0.281 | 0.231 | 0.197 | 0.159 | 0.163 | 0.286 |
| | | 0.2514 | 0.820 | 0.618 | 0.529 | 0.483 | 0.366 | 0.304 | 0.263 | 0.215 | 0.220 | 0.370 |
| | | 0.3165 | 1.009 | 0.766 | 0.660 | 0.605 | 0.465 | 0.392 | 0.342 | 0.284 | 0.290 | 0.468 |
| | | 0.3985 | 1.221 | 0.934 | 0.808 | 0.743 | 0.580 | 0.494 | 0.436 | 0.367 | 0.374 | 0.579 |
| | | 0.5018 | 1.451 | 1.117 | 0.971 | 0.895 | 0.707 | 0.608 | 0.542 | 0.461 | 0.469 | 0.703 |
| | | 0.6319 | 1.695 | 1.314 | 1.146 | 1.058 | 0.846 | 0.734 | 0.659 | 0.568 | 0.576 | 0.838 |
| | | 0.7956 | 1.951 | 1.520 | 1.330 | 1.231 | 0.995 | 0.871 | 0.788 | 0.686 | 0.694 | 0.982 |
| | | 1.002 | 2.212 | 1.732 | 1.521 | 1.409 | 1.150 | 1.014 | 0.923 | 0.811 | 0.820 | 1.133 |
| | | 1.261 | 2.472 | 1.946 | 1.714 | 1.594 | 1.312 | 1.165 | 1.068 | 0.946 | 0.956 | 1.291 |
| | | 1.588 | 2.732 | 2.160 | 1.908 | 1.780 | 1.478 | 1.321 | 1.217 | 1.087 | 1.096 | 1.453 |
| | | 2 | 2.985 | 2.370 | 2.100 | 1.963 | 1.645 | 1.479 | 1.369 | 1.232 | 1.241 | 1.617 |
| | | 2.518 | 3.229 | 2.575 | 2.288 | 2.144 | 1.811 | 1.638 | 1.523 | 1.379 | 1.388 | 1.782 |
| | | 3.171 | 3.459 | 2.771 | 2.468 | 2.318 | 1.974 | 1.795 | 1.677 | 1.527 | 1.536 | 1.945 |
| | | 3.993 | 3.672 | 2.957 | 2.639 | 2.485 | 2.133 | 1.949 | 1.828 | 1.675 | 1.683 | 2.106 |
| | | 5.027 | 3.866 | 3.130 | 2.800 | 2.642 | 2.286 | 2.099 | 1.976 | 1.820 | 1.828 | 2.263 |
| | | 6.33 | 4.026 | 3.288 | 2.948 | 2.791 | 2.429 | 2.241 | 2.117 | 1.960 | 1.967 | 2.411 |
| | | 7.971 | 4.153 | 3.422 | 3.079 | 2.922 | 2.560 | 2.374 | 2.251 | 2.093 | 2.099 | 2.550 |
| | | 10.04 | 4.309 | 3.549 | 3.193 | 3.031 | 2.676 | 2.493 | 2.372 | 2.217 | 2.222 | 2.675 |
| | | 12.64 | 4.393 | 3.645 | 3.285 | 3.126 | 2.776 | 2.594 | 2.479 | 2.327 | 2.332 | 2.789 |
| | | 15.91 | 4.430 | 3.707 | 3.351 | 3.197 | 2.854 | 2.671 | 2.568 | 2.422 | 2.427 | 2.878 |
| | | 20.04 | 4.177 | 3.701 | 3.362 | 3.233 | 2.896 | 2.685 | 2.632 | 2.493 | 2.497 | 2.929 |
| 66191-313 | A | 0.1 | 0.187 | 0.107 | 0.065 | 0.044 | 0.013 | 0.008 | 0.006 | 0.004 | 0.005 | 0.052 |
| | | 0.1259 | 0.236 | 0.139 | 0.087 | 0.060 | 0.019 | 0.011 | 0.009 | 0.006 | 0.007 | 0.071 |
| | | 0.1585 | 0.295 | 0.177 | 0.114 | 0.081 | 0.028 | 0.017 | 0.012 | 0.009 | 0.010 | 0.095 |
| | | 0.1996 | 0.362 | 0.222 | 0.147 | 0.108 | 0.039 | 0.024 | 0.018 | 0.013 | 0.015 | 0.123 |
| | | 0.2514 | 0.437 | 0.274 | 0.186 | 0.139 | 0.054 | 0.033 | 0.025 | 0.019 | 0.021 | 0.157 |
| | | 0.3165 | 0.521 | 0.331 | 0.231 | 0.175 | 0.073 | 0.046 | 0.035 | 0.026 | 0.029 | 0.196 |
| | | 0.3985 | 0.611 | 0.394 | 0.280 | 0.217 | 0.096 | 0.062 | 0.047 | 0.036 | 0.040 | 0.240 |
| | | 0.5018 | 0.708 | 0.462 | 0.335 | 0.264 | 0.123 | 0.082 | 0.063 | 0.049 | 0.053 | 0.287 |
| | | 0.6319 | 0.808 | 0.534 | 0.393 | 0.315 | 0.155 | 0.105 | 0.082 | 0.064 | 0.070 | 0.338 |
| | | 0.7956 | 0.912 | 0.608 | 0.455 | 0.369 | 0.190 | 0.132 | 0.105 | 0.083 | 0.090 | 0.391 |
| | | 1.002 | 1.018 | 0.685 | 0.519 | 0.426 | 0.230 | 0.163 | 0.131 | 0.105 | 0.114 | 0.446 |
| | | 1.261 | 1.125 | 0.763 | 0.585 | 0.486 | 0.273 | 0.198 | 0.161 | 0.131 | 0.141 | 0.504 |
| | | 1.588 | 1.232 | 0.842 | 0.652 | 0.547 | 0.319 | 0.236 | 0.195 | 0.160 | 0.172 | 0.563 |
| | | 2 | 1.339 | 0.921 | 0.721 | 0.610 | 0.368 | 0.278 | 0.232 | 0.193 | 0.206 | 0.623 |
| | | 2.518 | 1.443 | 1.000 | 0.790 | 0.674 | 0.420 | 0.323 | 0.273 | 0.229 | 0.243 | 0.684 |
| | | 3.171 | 1.545 | 1.078 | 0.859 | 0.739 | 0.474 | 0.371 | 0.317 | 0.269 | 0.284 | 0.745 |
| | | 3.993 | 1.645 | 1.156 | 0.929 | 0.805 | 0.530 | 0.421 | 0.364 | 0.312 | 0.328 | 0.808 |
| | | 5.027 | 1.741 | 1.232 | 0.998 | 0.870 | 0.588 | 0.474 | 0.413 | 0.358 | 0.375 | 0.871 |
| | | 6.33 | 1.832 | 1.308 | 1.066 | 0.936 | 0.647 | 0.529 | 0.465 | 0.407 | 0.424 | 0.935 |
| | | 7.9/1 | 1.919 | 1.381 | 1.134 | 1.001 | 0.707 | 0.585 | 0.519 | 0.458 | 0.476 | 0.999 |
| | | 10.04 | 1.997 | 1.453 | 1.199 | 1.066 | 0.767 | 0.643 | 0.575 | 0.511 | 0.529 | 1.062 |
| | | 12.64 | 2.050 | 1.520 | 1.262 | 1.128 | 0.828 | 0.701 | 0.631 | 0.565 | 0.583 | 1.126 |
| | | 15.91 | 2.039 | 1.5/2 | 1.319 | 1.188 | 0.887 | 0.758 | 0.687 | 0.619 | 0.637 | 1.186 |
| | | 20.04 | 1.958 | 1.576 | 1.344 | 1.236 | 0.941 | 0.813 | 0.741 | 0.671 | 0.689 | 1.235 |

Table 8 Average CTR characteristic (If=1-20mA, Vce=1V) calculated on the samples of biasing group "A" for each irradiation step of both references.



Figure 8: 66191-303 CTR characteristic degradation with TID irradiation (average on samples tested with biasing condition A).



Figure 9: 66191-313 CTR characteristic degradation with TID irradiation (average on samples tested with biasing condition A).

esa



Biasing B

| Partype biasing # 0 6675 14229 20010 44851 63751 600860 10221 1002 | | | | | | | | | | | | annealing 24h | annealing |
|---|-----------|---------|---------|-------|-------|-------|-------|-------|-------|-------|--------|---------------|-----------|
| 66191-303 P 0.11 0.366 0.224 0.116 0.155 0.074 0.047 0.039 0.039 0.039 9 0.125 0.047 0.299 0.211 0.106 0.060 0.077 0.058 0.059 0.127 0.1595 0.047 0.299 0.214 0.0153 0.114 0.122 0.041 0.373 0.216 0.102 0.046 0.172 0.2165 0.112 0.030 0.218 0.141 0.029 0.221 0.224 0.226 0.228 0.322 0.556 0.510 1.132 0.949 0.877 0.497 0.447 0.384 0.388 0.558 0.558 0.558 0.558 0.558 0.558 0.558 0.558 0.558 0.521 0.771 0.577 0.442 0.447 0.789 0.557 0.442 0.447 0.783 0.558 0.581 1.250 1.022 2.558 1.732 1.1281 1.134 0.592 < | PartType | biasing | lf | 0 | 6675 | 14229 | 20910 | 44851 | 63515 | 80696 | 105221 | tamb | 100C 168h |
| 0.1259 0.471 0.229 0.221 0.0100 0.080 0.070 0.088 0.069 0.172 0.1555 0.599 0.392 0.306 0.284 0.155 0.116 0.102 0.084 0.086 0.172 0.214 0.120 0.122 0.241 0.2164 0.820 0.837 0.643 0.336 0.322 0.288 0.226 0.229 0.436 0.3165 1.112 0.787 0.643 0.486 0.332 0.380 0.228 0.229 0.436 0.332 0.380 0.392 0.381 0.392 0.382 0.392 0.487 0.487 0.487 0.487 0.487 0.487 0.487 0.487 0.487 0.481 0.498 0.480 0.481 0.393 0.392 0.392 0.392 0.392 0.392 0.392 0.392 0.392 0.392 0.481 0.481 0.481 0.481 0.481 0.481 0.481 0.481 0.481 0.481 0.481< | 66191-303 | В | 0.1 | 0.366 | 0.224 | 0.168 | 0.153 | 0.074 | 0.054 | 0.047 | 0.039 | 0.039 | 0.089 |
| 0.1585 0.0596 0.392 0.306 0.284 0.155 0.1163 0.102 0.086 0.172 0.1986 0.749 0.555 0.041 0.373 0.216 0.163 0.149 0.120 0.022 0.224 0.2516 1.112 0.787 0.643 0.640 0.386 0.300 0.286 0.229 0.415 0.3665 1.132 0.944 0.790 0.621 0.497 0.447 0.384 0.386 0.655 0.6319 1.1776 1.1324 1.120 1.661 0.759 0.447 0.447 0.384 0.386 0.655 0.6319 1.1776 1.1204 1.496 1.706 1.497 1.941 0.951 0.755 0.442 0.487 0.751 1.126 1.413 0.949 0.891 1.257 1.126 1.413 0.941 0.951 1.452 1.261 1.491 1.633 1.918 1.636 1.589 1.257 1.125 1.425 | | | 0.1259 | 0.471 | 0.299 | 0.229 | 0.211 | 0.108 | 0.080 | 0.070 | 0.058 | 0.059 | 0.127 |
| 61996 0.749 0.505 0.401 0.373 0.216 0.144 0.120 0.122 0.241 0.2514 0.920 0.637 0.514 0.481 0.225 0.199 0.167 0.170 0.336 0.3165 1.122 0.787 0.643 0.604 0.336 0.226 0.226 0.229 0.415 0.3165 1.322 0.954 0.780 0.745 0.446 0.332 0.336 0.226 0.226 0.427 0.388 0.651 0.611 1.759 1.482 1.408 1.066 0.769 0.474 0.384 0.881 0.891 0.779 0.745 0.484 0.881 0.891 0.789 0.789 0.789 0.789 0.789 0.891 1.475 1.191 1.136 1.432 1.441 1.529 1.411 1.275 1.413 1.275 1.413 1.275 1.720 1.414 1.429 1.436 1.932 1.557 1.293 1.357 1.226 | | | 0.1585 | 0.599 | 0.392 | 0.306 | 0.284 | 0.155 | 0.116 | 0.102 | 0.084 | 0.086 | 0.177 |
| 66191-313 0.2514 0.920 0.637 0.541 0.2431 0.223 0.293 0.167 0.170 0.302 0.3165 1.132 0.664 0.360 0.300 0.268 0.229 0.302 0.552 0.518 1.545 0.790 0.745 0.496 0.397 0.621 0.482 0.482 0.482 0.482 0.482 0.487 0.795 0.071 0.557 0.482 0.487 0.795 0.775 0.577 0.482 0.487 0.783 0.779 0.567 0.482 0.487 0.783 0.779 0.567 0.482 0.487 0.773 0.7719 1.094 1.026 1.575 0.442 0.481 0.766 1.176 1.128 1.258 1.257 1.129 1.126 1.653 0.583 0.598 0.553 0.565 0.633 0.586 1.257 1.272 1.780 1.285 1.256 1.413 1.278 1.285 1.256 1.413 1.272 1.780 <td< td=""><td></td><td></td><td>0.1996</td><td>0.749</td><td>0.505</td><td>0.401</td><td>0.373</td><td>0.216</td><td>0.163</td><td>0.144</td><td>0.120</td><td>0.122</td><td>0.241</td></td<> | | | 0.1996 | 0.749 | 0.505 | 0.401 | 0.373 | 0.216 | 0.163 | 0.144 | 0.120 | 0.122 | 0.241 |
| 61112 0.787 0.643 0.604 0.386 0.326 0.226 0.229 0.415 0.5956 1.322 0.954 0.790 0.745 0.446 0.382 0.552 0.5018 1.545 1.134 0.949 0.827 0.621 0.447 0.384 0.388 0.651 0.7956 2.077 1.820 1.298 1.233 0.909 0.749 0.860 0.593 0.598 0.938 1.002 2.2854 1.230 1.482 1.406 1.066 0.890 0.845 0.845 0.851 1.259 1.281 2.495 1.918 1.665 1.588 1.232 1.041 0.954 0.845 0.851 1.259 1.680 1.577 1.129 1.136 0.257 1.221 1.403 1.275 1.583 1.575 1.221 1.431 1.278 1.285 1.560 3.993 3.557 2.627 2.571 2.211 1.989 1.377 | | | 0.2514 | 0.920 | 0.637 | 0.514 | 0.481 | 0.293 | 0.225 | 0.199 | 0.167 | 0.170 | 0.320 |
| 66191-313 8 0.3985 1.322 0.954 0.745 0.496 0.322 0.350 0.299 0.302 0.526 0.6319 1.178 1.324 1.120 1.061 0.759 0.617 0.557 0.482 0.487 0.788 0.789 0.796 2.017 1.520 1.482 1.406 1.066 0.590 0.612 0.713 0.719 1.084 1.002 2.285 1.720 1.482 1.406 1.040 0.812 0.713 0.719 1.084 1.886 2.728 2.115 1.1665 1.588 1.257 1.129 1.136 0.884 0.991 1.425 2.518 3.169 2.436 2.202 2.110 1.737 1.520 1.1473 1.786 1.587 1.757 1.436 1.787 1.380 1.577 2.018 2.577 2.216 1.992 1.387 1.377 1.428 1.436 1.923 3.3965 3.147 2.807 | | | 0.3165 | 1.112 | 0.787 | 0.643 | 0.604 | 0.386 | 0.300 | 0.268 | 0.226 | 0.229 | 0.415 |
| 66191-313 0.5018 1.545 1.134 0.9497 0.621 0.447 0.384 0.388 0.6651 0.0391 1.778 1.324 1.120 1.061 0.759 0.617 0.557 0.442 0.447 0.789 0.7966 2.017 1.520 1.482 1.406 1.066 0.690 0.612 0.713 0.719 1.944 1.261 2.495 1.720 1.1482 1.666 1.690 1.498 1.257 1.129 1.136 1.585 2.294 2.306 2.202 2.110 1.776 1.400 1.493 1.425 1.413 1.229 1.436 1.925 2.518 3.169 2.267 2.262 2.272 1.902 1.680 1.570 1.429 1.436 1.925 3.933 3.557 2.827 2.5271 2.212 1.998 1.876 1.729 1.737 2.814 5.03 3.3665 3.114 2.802 2.353 2.2161 | | | 0.3985 | 1.322 | 0.954 | 0.790 | 0.745 | 0.496 | 0.392 | 0.350 | 0.299 | 0.302 | 0.526 |
| 66339 1.778 1.324 1.120 1.061 0.759 0.617 0.557 0.482 0.487 0.789 9.0756 2.017 1.520 1.288 1.233 0.909 0.749 0.680 0.557 0.482 0.713 0.719 1.084 1.002 2.258 1.720 1.482 1.408 1.066 0.890 0.812 0.713 0.719 1.084 1.588 2.2954 2.306 2.028 1.941 1.569 1.358 1.257 1.129 1.136 1.583 2.516 3.168 2.4964 2.202 2.110 1.777 1.520 1.1413 1.776 1.428 1.496 1.923 3.393 3.557 2.872 2.524 2.242 2.100 1.876 1.729 1.737 2.231 6.33 3.865 3.114 2.804 2.494 2.206 2.137 2.408 2.352 2.361 2.777 6.191 3.979 3.226 2 | | | 0.5018 | 1.545 | 1.134 | 0.949 | 0.897 | 0.621 | 0.497 | 0.447 | 0.384 | 0.388 | 0.651 |
| 68191-313 0.7956 2.017 1.520 1.232 0.909 0.749 0.680 0.533 0.598 0.938 1.261 2.495 1.700 1.482 1.406 1.066 0.890 0.812 0.713 0.719 1.094 1.281 2.495 1.918 1.666 1.588 1.722 1.113 1.123 0.944 0.944 0.991 1.425 2.2954 2.306 2.028 1.941 1.569 1.358 1.257 1.129 1.136 1.583 2.518 3.169 2.449 2.202 2.110 1.737 1.620 1.413 1.276 1.737 1.285 1.720 1.737 1.291 1.336 1.923 1.933 3.557 2.827 2.524 2.462 2.060 1.870 1.725 1.587 2.281 2.444 2.268 2.157 2.018 2.500 1.004 4.108 3.447 3.025 2.292 2.598 2.390 2.252 2.261 2.706 <td></td> <td></td> <td>0.6319</td> <td>1.778</td> <td>1.324</td> <td>1.120</td> <td>1.061</td> <td>0.759</td> <td>0.617</td> <td>0.557</td> <td>0.482</td> <td>0.487</td> <td>0.789</td> | | | 0.6319 | 1.778 | 1.324 | 1.120 | 1.061 | 0.759 | 0.617 | 0.557 | 0.482 | 0.487 | 0.789 |
| 1.002 2.258 1.720 1.482 1.406 1.069 0.954 0.845 0.851 1.259 1.588 2.294 2.2115 1.448 1.760 1.401 1.981 1.103 0.984 0.984 0.994 1.413 1.27 1.281 1.271 1.307 2.663 2.667 2.212 1.999 1.670 1.413 1.279 1.386 1.993 3.557 2.297 2.426 2.4260 1.891 1.172 1.737 1.737 3.733 2.021 1.899 1.872 1.881 2.371 2.268 2.497 2.493 2.2232 2.268 | | | 0.7956 | 2.017 | 1.520 | 1.298 | 1.233 | 0.909 | 0.749 | 0.680 | 0.593 | 0.598 | 0.938 |
| 66191-313 B 1.261 1.264 1.275 1.241 0.4954 0.845 0.845 1.425 2 2.954 2.306 2.028 1.941 1.569 1.128 1.129 1.138 1.227 1.129 1.136 1.529 2.518 3.169 2.489 2.022 2.110 1.737 1.520 1.413 1.228 1.436 1.923 3.171 3.370 2.663 2.367 2.272 1.902 1.680 1.570 1.429 1.436 1.923 5.027 3.757 2.697 2.670 2.571 2.212 1.989 1.876 1.729 1.877 2.201 1.880 1.729 1.872 1.881 2.371 7.971 3.397 3.262 2.922 2.818 2.266 2.492 2.263 2.262 2.263 2.262 2.261 2.777 2.044 4.115 3.622 3.166 3.076 2.775 2.568 2.428 2.437 2.8 | | | 1.002 | 2.258 | 1.720 | 1.482 | 1.408 | 1.066 | 0.890 | 0.812 | 0.713 | 0.719 | 1.094 |
| 66191-313 B 0.158 2.2729 2.215 1.848 1.766 1.400 1.198 1.103 0.944 0.991 1.425 2.518 3.169 2.489 2.202 2.110 1.737 1.520 1.413 1.278 1.429 1.436 1.923 3.993 3.557 2.627 2.524 2.426 2.060 1.837 1.725 1.580 1.477 1.579 1.429 1.436 1.923 6.33 3.865 3.114 2.804 2.702 2.353 2.137 2.099 2.018 2.464 2.268 2.157 2.009 2.018 2.501 10.04 4.108 3.347 3.106 3.009 2.262 2.137 2.146 2.612 2.708 11.501 4.211 3.497 3.166 3.076 2.775 2.566 2.488 2.352 2.261 2.767 2.044 4.155 3.527 3.166 3.076 2.775 2.566 2.488 <td< td=""><td></td><td></td><td>1.261</td><td>2.495</td><td>1.918</td><td>1.665</td><td>1.588</td><td>1.232</td><td>1.041</td><td>0.954</td><td>0.845</td><td>0.851</td><td>1.259</td></td<> | | | 1.261 | 2.495 | 1.918 | 1.665 | 1.588 | 1.232 | 1.041 | 0.954 | 0.845 | 0.851 | 1.259 |
| 66191-313 B 0.125 0.206 1.941 1.569 1.257 1.129 1.136 1.563 3.171 3.370 2.663 2.267 2.272 1.902 1.680 1.570 1.429 1.436 1.923 3.993 3.557 2.827 2.524 2.246 2.060 1.837 1.725 1.737 2.201 6.33 3.865 3.114 2.804 2.702 2.353 2.133 2.021 1.872 1.881 2.371 7.971 3.979 3.226 2.922 2.818 2.484 2.268 2.157 2.009 2.018 2.500 10.04 4.108 3.347 3.025 2.923 2.598 2.390 2.262 2.261 2.708 11.591 4.211 3.497 3.166 3.070 2.678 2.488 2.352 2.361 2.776 20.04 4.155 3.522 3.195 3.114 2.827 2.649 2.558 2.428 2.43 | | | 1.588 | 2.729 | 2.115 | 1.848 | 1.766 | 1.400 | 1.198 | 1.103 | 0.984 | 0.991 | 1.425 |
| 66191-313 B 0.1 0.257 0.125 0.1413 0.1278 0.1278 0.1285 66191-313 B 0.01 0.703 0.025 0.013 0.006 0.007 0.008 0.007 0.008 0.007 0.008 0.007 0.008 0.007 0.008 0.007 0.008 0. | | | 2 | 2.954 | 2.306 | 2.028 | 1.941 | 1.569 | 1.358 | 1.257 | 1.129 | 1.136 | 1.593 |
| 66191-313 B 0.1 0.570 1.429 1.436 1.929 66191-313 0.1 0.502 7.3725 2.587 2.2524 2.426 2.060 1.837 1.725 1.580 1.587 2.281 6.33 3.865 3.114 2.804 2.702 2.353 2.103 2.021 1.872 1.818 2.231 10.04 4.108 3.347 3.025 2.922 2.818 2.484 2.268 2.157 2.009 2.018 2.500 110.04 4.109 3.434 3.005 2.923 2.598 2.390 2.282 2.137 2.146 2.610 2.706 15.91 4.211 3.497 3.166 3.076 2.775 2.586 2.488 2.352 2.361 2.787 20.04 4.155 3.522 3.114 2.827 2.649 2.558 2.428 2.437 2.812 66191-313 0.1 0.252 0.130 0.067 0.038 | | | 2.518 | 3.169 | 2.489 | 2.202 | 2.110 | 1.737 | 1.520 | 1.413 | 1.278 | 1.285 | 1.760 |
| 66191-313 B 0.1 0.257 2.267 2.2624 2.2426 2.060 1.837 1.725 1.580 1.587 2.021 6.33 3.865 3.114 2.804 2.702 2.353 2.133 2.021 1.872 1.881 2.371 7.971 3.979 3.226 2.922 2.818 2.444 2.268 2.157 2.009 2.018 2.501 10.04 4.108 3.347 3.025 2.923 2.598 2.390 2.2281 2.146 2.612 12.64 4.179 3.434 3.106 3.009 2.696 2.497 2.393 2.253 2.261 2.768 12.91 4.155 3.122 3.145 3.114 2.827 2.649 2.588 2.428 2.437 2.812 66191-313 B 0.1 0.252 0.130 0.067 0.038 0.004 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0. | | | 3.171 | 3.370 | 2.663 | 2.367 | 2.272 | 1.902 | 1.680 | 1.570 | 1.429 | 1.436 | 1.923 |
| 6191-313 B 0.1 0.257 0.257 0.257 0.257 0.257 0.212 1.989 1.876 1.729 1.737 0.2235 6.33 3.866 3.114 0.204 2.702 2.353 2.021 1.872 1.881 2.371 7.971 3.979 3.226 2.922 2.818 2.484 2.282 2.137 2.146 2.612 12.64 4.179 3.434 3.108 3.009 2.696 2.497 2.333 2.253 2.261 2.708 15.91 4.211 3.434 3.108 3.007 2.775 2.566 2.488 2.352 2.361 2.776 20.04 4.155 3.522 3.195 3.114 2.807 2.649 2.558 2.428 2.437 2.812 66191-313 B 0.1 0.252 0.130 0.067 0.038 0.004 0.005 0.000 0.005 0.000 0.005 0.000 0.005 0.0006 0.00 | | | 3.993 | 3.557 | 2.827 | 2.524 | 2.426 | 2.060 | 1.837 | 1.725 | 1.580 | 1.587 | 2.081 |
| 66131 33 3.866 3.114 2.204 2.702 2.253 2.133 2.001 1.872 1.881 2.250 7.971 3.979 3.226 2.292 2.818 2.484 2.268 2.157 2.009 2.018 2.641 10.04 4.108 3.347 3.025 2.923 2.588 2.390 2.282 2.137 2.146 2.612 12.64 4.179 3.434 3.108 3.009 2.696 2.497 2.393 2.253 2.261 2.787 20.04 4.155 3.522 3.195 3.114 2.827 2.649 2.558 2.428 2.437 2.812 66191-313 0.1 0.252 0.130 0.067 0.038 0.004 0.003 0.000 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.005 0.000 0.007 0.008 0.006 0.007 0.008 0.006 0.007 0.008 < | | | 5.027 | 3.725 | 2.979 | 2.670 | 2.571 | 2.212 | 1.989 | 1.876 | 1.729 | 1.737 | 2.231 |
| 66191-313 B 0.10 4.108 3.347 3.025 2.923 2.988 2.390 2.283 2.263 2.263 2.263 2.263 2.263 2.263 2.263 2.263 2.263 2.263 2.263 2.261 2.708 15.91 4.211 3.497 3.166 3.076 2.775 2.568 2.488 2.352 2.361 2.787 20.04 4.155 3.522 3.195 3.114 2.827 2.649 2.558 2.488 2.352 2.361 2.787 20.04 4.155 3.522 3.195 3.114 2.827 2.649 2.558 2.488 2.352 2.361 2.787 20.04 4.155 0.392 0.214 0.121 0.074 0.016 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.006 0.007 0.988 0.365 0.213 0.061 0.011 0.008 0.006 0.007 0.986 0.619 0.031 | | | 6.33 | 3.865 | 3.114 | 2.804 | 2.702 | 2.353 | 2.133 | 2.021 | 1.872 | 1.881 | 2.371 |
| 10.04 4.108 3.347 3.025 2.998 2.390 2.282 2.137 2.146 2.619 12.64 4.179 3.434 3.008 2.068 2.497 2.332 2.261 2.708 15.91 4.211 3.497 3.166 3.007 2.775 2.586 2.488 2.352 2.261 2.708 20.04 4.155 3.522 3.195 3.114 2.827 2.649 2.588 2.428 2.437 2.812 66191-313 0.1 0.252 0.130 0.067 0.038 0.008 0.004 0.003 0.003 0.039 0.1259 0.317 0.168 0.091 0.054 0.011 0.006 0.005 0.004 0.004 0.058 0.155 0.392 0.214 0.157 0.100 0.022 0.011 0.008 0.006 0.007 0.988 0.196 0.478 0.267 0.193 0.058 0.029 0.020 0.014 0 | | | 7.971 | 3.979 | 3.226 | 2.922 | 2.818 | 2.484 | 2.268 | 2.157 | 2.009 | 2.018 | 2.500 |
| 12.64 4.179 3.434 3.008 3.009 2.696 2.497 2.393 2.253 2.251 2.261 2.708 15.91 4.211 3.497 3.166 3.076 2.775 2.586 2.488 2.352 2.313 2.812 66191-313 0 0.1 0.252 0.130 0.067 0.038 0.004 0.003 0.004 0.054 0.014 0.155 0.372 0.158 0.174 0.013 0.014 0.006 0.005 0.007 0.098 0.026 0.011 0.011 0.011 0.016 0.011 0.011 0.016 0.011 0.011 <td></td> <td></td> <td>10.04</td> <td>4.108</td> <td>3.347</td> <td>3.025</td> <td>2.923</td> <td>2.598</td> <td>2.390</td> <td>2.282</td> <td>2.137</td> <td>2.146</td> <td>2.612</td> | | | 10.04 | 4.108 | 3.347 | 3.025 | 2.923 | 2.598 | 2.390 | 2.282 | 2.137 | 2.146 | 2.612 |
| 15.91 4.211 3.497 3.166 3.076 2.775 2.586 2.488 2.352 2.361 2.781 66191-313 B 0.1 0.252 0.130 0.067 0.038 0.008 0.004 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.005 0.004 0.004 0.005 | | | 12.64 | 4.179 | 3.434 | 3.108 | 3.009 | 2.696 | 2.497 | 2.393 | 2.253 | 2.261 | 2.708 |
| 66191-313 B 0.1 0.252 0.130 0.067 0.038 0.006 0.004 0.003 0.004 0.004 0.004 0.004 0.005 0.004 0.004 0.005 0 | | | 15.91 | 4.211 | 3.497 | 3.166 | 3.076 | 2.775 | 2.586 | 2.488 | 2.352 | 2.361 | 2.787 |
| 66191-313 B 0.1 0.252 0.130 0.067 0.038 0.008 0.004 0.003 0.004 0.004 0.054 0.1585 0.392 0.214 0.121 0.074 0.016 0.006 0.006 0.007 0.988 0.2514 0.574 0.328 0.200 0.131 0.016 0.011 0.008 0.009 0.127 0.3165 0.678 0.395 0.249 0.169 0.022 0.011 0.011 0.162 0.3985 0.791 0.469 0.305 0.213 0.058 0.029 0.020 0.014 0.015 0.202 0.5018 0.909 0.548 0.366 0.263 0.077 0.393 0.025 0.026 0.303 0.021 | | - | 20.04 | 4.155 | 3.522 | 3.195 | 3.114 | 2.827 | 2.649 | 2.558 | 2.428 | 2.437 | 2.812 |
| 0.1259 0.317 0.168 0.091 0.054 0.011 0.006 0.004 0.004 0.004 0.1585 0.332 0.214 0.127 0.074 0.016 0.008 0.006 0.005 0.005 0.074 0.1996 0.478 0.267 0.157 0.100 0.022 0.011 0.008 0.006 0.007 0.098 0.2514 0.574 0.328 0.200 0.131 0.031 0.016 0.011 0.008 0.009 0.127 0.3165 0.678 0.395 0.249 0.169 0.043 0.021 0.011 0.011 0.011 0.162 0.5018 0.909 0.548 0.366 0.263 0.077 0.039 0.027 0.019 0.020 0.248 0.6319 1.031 0.632 0.433 0.318 0.100 0.055 0.035 0.025 0.026 0.302 0.7956 1.156 0.719 0.503 0.379 0.128 | 66191-313 | в | 0.1 | 0.252 | 0.130 | 0.067 | 0.038 | 0.008 | 0.004 | 0.003 | 0.003 | 0.003 | 0.039 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 0.1259 | 0.317 | 0.168 | 0.091 | 0.054 | 0.011 | 0.006 | 0.005 | 0.004 | 0.004 | 0.054 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 0.1585 | 0.392 | 0.214 | 0.121 | 0.074 | 0.016 | 0.008 | 0.006 | 0.005 | 0.005 | 0.074 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 0.1996 | 0.478 | 0.267 | 0.157 | 0.100 | 0.022 | 0.011 | 0.008 | 0.006 | 0.007 | 0.098 |
| 0.3165 0.678 0.395 0.249 0.169 0.043 0.021 0.015 0.011 0.011 0.161 0.161 0.3985 0.791 0.469 0.305 0.213 0.058 0.029 0.020 0.014 0.015 0.202 0.5018 0.909 0.548 0.366 0.263 0.077 0.039 0.027 0.019 0.020 0.248 0.6319 1.031 0.632 0.433 0.318 0.100 0.052 0.035 0.025 0.026 0.300 0.7956 1.156 0.719 0.503 0.379 0.128 0.068 0.046 0.032 0.034 0.356 1.002 1.283 0.810 0.578 0.443 0.160 0.087 0.060 0.042 0.044 0.416 1.261 1.409 0.901 0.655 0.513 0.198 0.110 0.077 0.054 0.056 0.431 1.58 1.534 0.994 0.735 | | | 0.2514 | 0.574 | 0.328 | 0.200 | 0.131 | 0.031 | 0.016 | 0.011 | 0.008 | 0.009 | 0.127 |
| 0.3985 0.791 0.409 0.306 0.213 0.058 0.029 0.020 0.014 0.015 0.204 0.5018 0.909 0.548 0.366 0.263 0.077 0.039 0.027 0.019 0.020 0.248 0.6319 1.031 0.632 0.433 0.318 0.100 0.052 0.025 0.026 0.300 0.7956 1.156 0.719 0.503 0.379 0.128 0.068 0.046 0.032 0.034 0.356 1.002 1.283 0.810 0.578 0.443 0.160 0.087 0.060 0.042 0.044 0.416 1.261 1.409 0.901 0.655 0.513 0.198 0.110 0.077 0.054 0.056 0.481 1.58 1.534 0.994 0.735 0.585 0.241 0.138 0.069 0.072 0.549 2.518 1.776 1.180 0.900 0.738 0.343 0.205 0 | | | 0.3165 | 0.678 | 0.395 | 0.249 | 0.169 | 0.043 | 0.021 | 0.015 | 0.011 | 0.011 | 0.162 |
| 0.5018 0.309 0.548 0.366 0.265 0.077 0.039 0.027 0.019 0.020 0.243 0.6319 1.031 0.632 0.433 0.318 0.100 0.052 0.035 0.025 0.026 0.300 0.7956 1.156 0.719 0.503 0.379 0.128 0.068 0.046 0.032 0.034 0.356 1.002 1.283 0.810 0.578 0.443 0.160 0.087 0.060 0.042 0.044 0.416 1.261 1.409 0.901 0.655 0.513 0.198 0.110 0.077 0.054 0.056 0.481 1.588 1.534 0.994 0.735 0.585 0.241 0.138 0.069 0.072 0.549 2 1.656 1.087 0.817 0.661 0.290 0.153 0.110 0.114 0.692 2.518 1.776 1.180 0.900 0.738 0.343 0.202 0.187 | | | 0.3985 | 0.791 | 0.469 | 0.305 | 0.213 | 0.058 | 0.029 | 0.020 | 0.014 | 0.015 | 0.202 |
| 0.6319 1.031 0.632 0.433 0.316 0.100 0.052 0.035 0.025 0.026 0.026 0.030 0.7956 1.156 0.719 0.503 0.379 0.128 0.068 0.046 0.032 0.034 0.356 1.002 1.283 0.810 0.578 0.443 0.160 0.087 0.060 0.042 0.044 0.416 1.261 1.409 0.901 0.655 0.513 0.198 0.110 0.077 0.054 0.056 0.481 1.588 1.534 0.994 0.735 0.585 0.241 0.138 0.098 0.069 0.072 0.549 2 1.656 1.087 0.817 0.661 0.290 0.171 0.123 0.087 0.091 0.620 2.518 1.776 1.180 0.900 0.738 0.343 0.209 0.153 0.110 0.114 0.692 3.171 1.892 1.273 0.984 0.481< | | | 0.5018 | 0.909 | 0.548 | 0.366 | 0.263 | 0.077 | 0.039 | 0.027 | 0.019 | 0.020 | 0.248 |
| 1.07936 1.135 0.719 0.0379 0.128 0.066 0.046 0.052 0.034 0.034 1.002 1.283 0.810 0.578 0.443 0.160 0.087 0.060 0.042 0.044 0.146 1.261 1.409 0.901 0.655 0.513 0.198 0.110 0.077 0.054 0.056 0.481 1.588 1.534 0.994 0.735 0.585 0.241 0.138 0.098 0.069 0.072 0.549 2 1.656 1.087 0.817 0.661 0.290 0.171 0.123 0.087 0.091 0.620 2.518 1.776 1.180 0.900 0.738 0.343 0.209 0.153 0.110 0.114 0.692 3.171 1.892 1.273 0.984 0.818 0.402 0.225 0.187 0.137 0.142 0.767 3.993 2.003 1.365 1.069 0.899 0.466 0.301 | | | 0.6319 | 1.031 | 0.632 | 0.433 | 0.318 | 0.100 | 0.052 | 0.035 | 0.025 | 0.026 | 0.300 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 0.7956 | 1.100 | 0.719 | 0.503 | 0.379 | 0.120 | 0.000 | 0.046 | 0.032 | 0.034 | 0.336 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 1.002 | 1.203 | 0.810 | 0.576 | 0.443 | 0.100 | 0.007 | 0.060 | 0.042 | 0.044 | 0.416 |
| 1.368 1.334 0.334 0.335 0.361 0.136 0.036 0.009 0.072 0.342 2 1.656 1.087 0.817 0.661 0.290 0.171 0.123 0.087 0.091 0.620 2.518 1.776 1.180 0.900 0.738 0.343 0.209 0.153 0.110 0.114 0.692 3.171 1.892 1.273 0.984 0.818 0.402 0.252 0.187 0.137 0.142 0.767 3.993 2.003 1.365 1.069 0.899 0.466 0.301 0.227 0.168 0.175 0.844 5.027 2.109 1.457 1.154 0.981 0.534 0.356 0.227 0.168 0.175 0.844 5.027 2.109 1.457 1.154 0.981 0.534 0.356 0.227 0.168 0.175 0.844 6.33 2.210 1.547 1.239 1.064 0.666 0.417 <td></td> <td></td> <td>1.201</td> <td>1.409</td> <td>0.901</td> <td>0.000</td> <td>0.513</td> <td>0.190</td> <td>0.110</td> <td>0.077</td> <td>0.054</td> <td>0.030</td> <td>0.461</td> | | | 1.201 | 1.409 | 0.901 | 0.000 | 0.513 | 0.190 | 0.110 | 0.077 | 0.054 | 0.030 | 0.461 |
| 2 1.007 0.017 0.038 0.123 0.171 0.123 0.007 0.031 0.029 2.518 1.776 1.180 0.900 0.738 0.343 0.209 0.153 0.107 0.142 0.691 0.0291 3.171 1.892 1.273 0.984 0.818 0.402 0.252 0.187 0.137 0.142 0.767 3.993 2.003 1.365 1.069 0.899 0.466 0.301 0.227 0.168 0.175 0.844 5.027 2.109 1.457 1.154 0.981 0.534 0.356 0.273 0.206 0.213 0.922 6.33 2.210 1.547 1.239 1.064 0.606 0.417 0.326 0.249 0.257 1.001 7.971 2.303 1.636 1.323 1.147 0.683 0.384 0.298 0.307 1.080 10.04 2.381 1.721 1.405 1.230 0.762 0.555 <td></td> <td></td> <td>1.566</td> <td>1.004</td> <td>1.097</td> <td>0.735</td> <td>0.565</td> <td>0.241</td> <td>0.130</td> <td>0.098</td> <td>0.009</td> <td>0.072</td> <td>0.549</td> | | | 1.566 | 1.004 | 1.097 | 0.735 | 0.565 | 0.241 | 0.130 | 0.098 | 0.009 | 0.072 | 0.549 |
| $\begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 2 5 1 9 | 1.000 | 1.007 | 0.017 | 0.001 | 0.290 | 0.171 | 0.123 | 0.087 | 0.091 | 0.020 |
| 3.171 1.592 1.273 0.304 0.516 0.402 0.227 0.167 0.142 0.707 3.993 2.003 1.365 1.069 0.899 0.466 0.301 0.227 0.168 0.175 0.844 5.027 2.109 1.457 1.154 0.981 0.534 0.356 0.273 0.206 0.213 0.922 6.33 2.210 1.547 1.239 1.064 0.606 0.417 0.326 0.249 0.257 1.001 7.971 2.303 1.636 1.323 1.147 0.683 0.483 0.384 0.298 0.307 1.080 10.04 2.381 1.721 1.405 1.230 0.762 0.555 0.448 0.354 0.364 1.159 12.64 2.400 1.799 1.486 1.311 0.843 0.630 0.518 0.415 0.426 1.237 15.91 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 2004 2.194 | | | 2.516 | 1.770 | 1.180 | 0.900 | 0.738 | 0.343 | 0.209 | 0.155 | 0.110 | 0.114 | 0.092 |
| 5.353 2.003 1.003 0.035 0.400 0.037 0.103 0.113 0.034 5.027 2.109 1.457 1.154 0.981 0.534 0.356 0.273 0.206 0.213 0.922 6.33 2.210 1.547 1.239 1.064 0.606 0.417 0.326 0.249 0.257 1.001 7.971 2.303 1.636 1.323 1.147 0.683 0.483 0.384 0.298 0.307 1.080 10.04 2.381 1.721 1.405 1.230 0.762 0.555 0.448 0.354 0.364 1.159 12.64 2.400 1.799 1.486 1.311 0.843 0.630 0.518 0.415 0.426 1.237 15.91 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 204 2.194 1.785 1.579 1.440 1.003 0.788 0.660 </td <td></td> <td></td> <td>3.003</td> <td>2 003</td> <td>1.273</td> <td>1.060</td> <td>0.818</td> <td>0.402</td> <td>0.252</td> <td>0.187</td> <td>0.137</td> <td>0.142</td> <td>0.707</td> | | | 3.003 | 2 003 | 1.273 | 1.060 | 0.818 | 0.402 | 0.252 | 0.187 | 0.137 | 0.142 | 0.707 |
| 3.027 2.103 1.137 0.331 0.334 0.330 0.213 0.0213 0.332 6.33 2.210 1.547 1.239 1.064 0.606 0.417 0.326 0.249 0.257 1.001 7.971 2.303 1.636 1.323 1.147 0.683 0.483 0.384 0.298 0.307 1.080 10.04 2.381 1.721 1.405 1.230 0.762 0.555 0.448 0.354 0.364 1.159 12.64 2.400 1.799 1.486 1.311 0.843 0.630 0.518 0.415 0.426 1.237 15.91 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 2004 2.194 1.785 1.579 1.440 1.003 0.788 0.660 0.552 0.564 1.358 | | | 5.027 | 2.003 | 1.303 | 1.003 | 0.099 | 0.400 | 0.301 | 0.227 | 0.100 | 0.173 | 0.044 |
| 0.00 2.210 1.034 1.233 1.147 0.683 0.483 0.284 0.295 1.080 7.971 2.303 1.636 1.323 1.147 0.683 0.384 0.298 0.307 1.080 10.04 2.381 1.721 1.405 1.230 0.762 0.555 0.448 0.354 0.364 1.159 12.64 2.400 1.799 1.486 1.311 0.843 0.630 0.518 0.415 0.426 1.237 15.91 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 20 0.4 2.94 1.785 1.577 1.440 1.003 0.788 0.660 0.552 0.564 1.358 | | | 6.33 | 2.103 | 1.437 | 1 230 | 1.064 | 0.504 | 0.330 | 0.275 | 0.200 | 0.213 | 1 001 |
| 1.01 2.303 1.023 1.147 0.003 0.304 0.236 0.307 1.089 10.04 2.381 1.721 1.405 1.230 0.762 0.555 0.448 0.354 0.364 1.159 12.64 2.400 1.799 1.486 1.311 0.843 0.630 0.518 0.415 0.426 1.237 15.91 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 20 04 2.194 1.785 1.579 1.440 1.003 0.788 0.660 0.555 0.564 1.358 | | | 7 071 | 2.210 | 1.636 | 1 323 | 1 1/7 | 0.000 | 0.417 | 0.320 | 0.249 | 0.207 | 1 080 |
| 10.04 2.301 1.721 1.403 1.230 0.402 0.330 0.443 0.334 0.304 1.139 12.64 2.400 1.799 1.486 1.311 0.843 0.630 0.518 0.415 0.426 1.237 15.91 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 20 04 2.194 1.785 1.579 1.440 1.003 0.788 0.660 0.552 0.564 1.358 | | | 10.04 | 2.303 | 1 721 | 1.020 | 1.147 | 0.003 | 0.403 | 0.304 | 0.290 | 0.307 | 1 150 |
| 12.01 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 15.91 2.327 1.829 1.557 1.389 0.925 0.709 0.593 0.482 0.494 1.310 20.04 2.194 1.785 1.577 1.389 0.925 0.709 0.593 0.482 0.494 1.310 | | | 12 64 | 2.301 | 1 700 | 1 486 | 1 311 | 0.702 | 0.000 | 0.440 | 0.334 | 0.304 | 1 237 |
| 2007 2007 1005 1007 1005 0.005 0.005 0.000 0.002 0.004 1.310 2007 2017 1005 1007 1007 0.005 0.005 0.000 0.005 0.00 | | | 15 01 | 2 327 | 1 820 | 1 557 | 1 380 | 0.045 | 0.000 | 0.510 | 0.482 | 0.420 | 1 310 |
| | | | 20.04 | 2 194 | 1 785 | 1.579 | 1 440 | 1 003 | 0 788 | 0.669 | 0.552 | 0 564 | 1.358 |

Table 9 Average CTR characteristic (If=1-20mA, Vce=1V) calculated calculated on the samples of biasing group "B" for each irradiation step of both references.





Figure 10: 66191-303 CTR characteristic degradation with TID irradiation (average on samples tested with biasing condition B).



Figure 11: 66191-313 CTR characteristic degradation with TID irradiation (average on samples tested with biasing condition B).

Biasing C

| PartType bissing x 0 6675 1422 20910 44851 60961 10521 24h tamb 100C (f8h) 66191-303 C 0.12 0.228 0.203 0.145 0.114 0.055 0.029 0.021 0.022 0.104 0.0566 0.044 0.032 0.012 0.022 0.116 0.083 0.056 0.044 0.042 0.022 0.017 0.022 0.017 0.022 0.017 0.022 0.017 0.025 0.017 0.022 0.017 0.0135 0.010 0.027 0.038 0.021 0.0249 0.143 0.144 0.148 0.385 0.261 0.449 0.335 0.010 0.273 0.285 0.460 0.791 0.774 0.725 1.887 <t< th=""><th>у</th><th></th><th></th><th>dose</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<> | у | | | dose | | | | | | | | | |
|---|-----------|---------|--------|-------|-------|-------|-------|-------|-------|-------|--------|-----------|-----------|
| PartType biasing x 0 6675 14229 20910 44851 63515 80086 105221 241 hamb 1002 1861 66191-303 C 0.125 0.424 0.273 0.200 0.166 0.032 0.021 0.072 0.021 0.072 0.1565 0.541 0.860 0.270 0.2200 0.166 0.046 0.042 0.021 0.072 0.2203 0.2514 0.839 0.588 0.460 0.397 0.226 0.167 0.135 0.142 0.144 0.144 0.386 0.2251 0.251 0.216 0.444 0.388 0.2251 0.255 0.167 0.128 0 | | | | | | | | | | | | annealing | annealing |
| 66191-303 C 0.11 0.228 0.224 0.220 0.144 0.052 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.062 0.065 0.044 0.032 0.052 0.064 0.049 0.104 0.1596 0.680 0.465 0.357 0.228 0.167 0.135 0.102 0.103 0.273 0.3165 1.017 0.726 0.579 0.494 0.393 0.227 0.166 0.144 0.136 0.3165 1.017 0.726 0.681 0.751 0.498 0.427 0.749 0.143 0.432 0.326 0.651 0.453 0.531 0.413 0.432 0.257 0.260 0.571 0.651 0.447 0.744 0.626 0.628 1.141 0.626 0.628 1.141 0.455 0.530 0.586 0.531 1.417 0.628 1.641 1.427 1.2 | PartType | biasing | x | 0 | 6675 | 14229 | 20910 | 44851 | 63515 | 80696 | 105221 | 24h tamb | 100C 168h |
| 0.1259 0.424 0.273 0.200 0.160 0.082 0.032 0.032 0.032 0.1585 0.541 0.360 0.270 0.220 0.118 0.085 0.0461 0.047 0.022 0.2514 0.839 0.588 0.460 0.387 0.228 0.167 0.135 0.102 0.103 0.273 0.3165 1.017 0.728 0.579 0.484 0.030 0.227 0.135 0.102 0.194 0.194 0.444 0.388 0.3995 1.212 0.841 0.714 0.616 0.393 0.301 0.249 0.194 0.146 0.458 0.6319 1.635 1.221 1.047 1.0466 0.357 0.322 0.335 0.659 1.002 2.076 1.594 1.348 1.207 0.871 0.741 0.745 1.227 2.161 2.292 2.044 1.846 1.455 1.654 1.441 0.995 0.999 1.559 | 66191-303 | С | 0.1 | 0.328 | 0.203 | 0.145 | 0.114 | 0.055 | 0.037 | 0.029 | 0.021 | 0.021 | 0.072 |
| 0.1585 0.541 0.360 0.270 0.220 0.118 0.083 0.048 0.049 0.049 0.049 0.049 0.049 0.049 0.049 0.023 0.221 0.095 0.071 0.072 0.167 0.132 0.102 0.103 0.223 0.3165 1.017 0.728 0.579 0.494 0.033 0.227 0.126 0.113 0.141 0.133 0.141 0.333 0.301 0.249 0.194 0.196 0.458 0.5018 1.419 1.051 0.861 0.751 0.496 0.337 0.223 0.516 0.520 0.663 0.663 1.419 0.422 0.889 1.113 0.442 0.422 0.881 1.419 1.422 1.765 1.581 1.441 1.650 1.307 1.422 0.636 0.489 1.417 1.581 2.502 2.298 2.004 1.486 1.412 0.986 0.468 1.412 1.957 1.581 2.512 | | | 0.1259 | 0.424 | 0.273 | 0.200 | 0.160 | 0.082 | 0.056 | 0.044 | 0.032 | 0.032 | 0.104 |
| 0.1996 0.680 0.367 0.295 0.167 0.120 0.095 0.071 0.072 0.203 0.3165 1.017 0.728 0.579 0.484 0.303 0.227 0.186 0.143 0.144 0.338 0.3165 1.212 0.884 0.714 0.616 0.393 0.325 0.257 0.260 0.577 0.6319 1.635 1.222 1.017 0.886 0.611 0.487 0.418 0.332 0.335 0.684 0.7966 1.855 1.410 1.181 1.050 0.711 0.714 0.646 0.487 1.002 2.075 1.594 1.348 1.207 0.831 0.419 0.422 0.828 1.022 2.075 1.594 1.341 1.042 0.487 0.744 0.745 1.267 1.022 2.075 1.597 1.633 1.331 1.199 0.833 0.511 0.741 0.745 1.267 2.518 2.9 | | | 0.1585 | 0.541 | 0.360 | 0.270 | 0.220 | 0.118 | 0.083 | 0.065 | 0.048 | 0.049 | 0.147 |
| 0.2514 0.839 0.588 0.460 0.387 0.228 0.167 0.135 0.102 0.103 0.273 0.3965 1.212 0.884 0.714 0.616 0.333 0.301 0.228 0.143 0.144 0.356 0.5116 1.419 1.051 0.861 0.751 0.496 0.387 0.325 0.250 0.260 0.570 0.6319 1.635 1.228 1.017 0.886 0.611 0.447 0.413 0.332 0.335 0.689 1.261 2.292 1.776 1.516 1.369 1.031 0.447 0.744 0.745 1.267 1.261 2.2902 2.176 1.516 1.307 1.122 1.005 0.865 0.689 1.419 2.518 2.902 2.741 2.448 1.486 1.486 1.526 1.142 0.171 1.781 2.351 3.513 2.864 2.549 2.391 2.009 1.818 1.806 <td< td=""><td></td><td></td><td>0.1996</td><td>0.680</td><td>0.465</td><td>0.357</td><td>0.295</td><td>0.167</td><td>0.120</td><td>0.095</td><td>0.071</td><td>0.072</td><td>0.203</td></td<> | | | 0.1996 | 0.680 | 0.465 | 0.357 | 0.295 | 0.167 | 0.120 | 0.095 | 0.071 | 0.072 | 0.203 |
| 0.3165 1.017 0.728 0.579 0.494 0.303 0.227 0.148 0.143 0.144 0.386 0.5018 1.419 1.051 0.861 0.751 0.496 0.337 0.325 0.257 0.260 0.570 0.6319 1.635 1.228 1.017 0.866 0.611 0.447 0.418 0.332 0.332 0.332 0.634 0.706 1.853 1.228 1.017 0.866 0.611 0.447 0.741 0.625 0.628 1.117 1.628 2.2075 1.534 1.531 1.159 0.983 0.871 0.741 0.741 0.745 1.287 1.2 2.706 2.131 1.846 1.690 1.307 1.422 1.005 0.865 0.869 1.419 2.518 2.902 2.296 2.161 1.307 1.421 1.122 1.102 1.767 1.863 3.171 3.042 2.266 2.560 1.743 1. | | | 0.2514 | 0.839 | 0.588 | 0.460 | 0.387 | 0.228 | 0.167 | 0.135 | 0.102 | 0.103 | 0.273 |
| 0.3985 1.212 0.884 0.714 0.616 0.393 0.301 0.249 0.194 0.194 0.496 0.458 0.6319 1.635 1.222 1.017 0.861 0.751 0.449 0.413 0.332 0.335 0.664 0.795 1.855 1.410 1.181 1.050 0.781 0.717 0.623 0.518 0.419 0.422 0.829 1.002 2.075 1.594 1.348 1.207 0.871 0.741 0.745 1.257 1.261 2.292 2.776 1.516 1.683 1.531 1.585 0.487 0.741 0.745 1.257 2.516 2.906 2.298 2.040 1.846 1.455 1.495 0.863 0.866 0.869 1.419 2.512 2.768 2.802 2.186 1.465 1.611 1.407 1.281 1.122 1.032 1.771 3.933 3.250 2.603 2.296 2.136 1. | | | 0.3165 | 1.017 | 0.728 | 0.579 | 0.494 | 0.303 | 0.227 | 0.186 | 0.143 | 0.144 | 0.358 |
| 0.5018 1.419 1.051 0.861 0.751 0.496 0.325 0.225 0.260 0.532 0.6319 1.635 1.228 1.070 0.896 0.611 0.487 0.413 0.332 0.332 0.335 0.694 1.002 2.075 1.584 1.348 1.207 0.871 0.717 0.623 0.516 0.520 0.969 1.261 2.292 1.776 1.516 1.369 0.847 0.744 0.625 0.628 1.117 1.588 2.504 1.957 1.683 1.531 1.159 0.847 0.741 0.745 0.262 1.491 2.518 2.902 2.298 2.064 1.846 1.465 1.426 1.142 0.995 0.999 1.569 3.171 3.084 2.456 2.155 1.995 1.541 1.412 1.932 1.767 1.881 1.426 1.481 3.013 2.846 2.549 2.328 2.055 1. | | | 0.3985 | 1.212 | 0.884 | 0.714 | 0.616 | 0.393 | 0.301 | 0.249 | 0.194 | 0.196 | 0.458 |
| 0.6319 1.635 1.228 1.017 0.896 0.611 0.443 0.332 0.335 0.684 0.7956 1.855 1.410 1.181 1.050 0.738 0.513 0.413 0.322 0.335 0.682 1.002 2.075 1.594 1.348 1.207 0.871 0.717 0.623 0.516 0.520 0.989 1.261 2.202 1.776 1.683 1.531 1.159 0.993 0.871 0.714 0.628 0.422 0.826 0.448 1.455 1.265 1.420 0.995 0.599 1.569 2.518 2.902 2.282 2.004 1.846 1.455 1.427 1.422 1.422 1.422 1.421 1.422 1.422 1.422 1.422 1.428 1.428 1.424 1.428 1.424 1.422 1.424 1.441 1.686 1.661 2.249 1.331 1.442 1.424 1.441 1.686 1.661 2.249 1.932 | | | 0.5018 | 1.419 | 1.051 | 0.861 | 0.751 | 0.496 | 0.387 | 0.325 | 0.257 | 0.260 | 0.570 |
| 0.7956 1.855 1.410 1.181 1.0050 0.738 0.513 0.419 0.422 0.829 1.261 2.292 1.776 1.584 1.207 0.871 0.717 0.625 0.625 0.628 1.117 1.588 2.504 1.957 1.683 1.531 1.159 0.983 0.871 0.741 0.745 1.267 2 2.708 2.311 1.846 1.460 1.307 1.122 1.005 0.865 0.869 1.419 2.518 2.902 2.298 2.004 1.846 1.455 1.265 1.142 0.995 0.999 1.539 3.171 3.084 2.456 2.155 1.995 1.601 1.407 1.281 1.262 1.267 1.860 5.027 3.402 2.968 2.505 2.188 1.586 1.397 1.402 1.988 1.043 3.446 3.297 2.467 2.302 2.155 1.932 1.776 1.731< | | | 0.6319 | 1.635 | 1.228 | 1.017 | 0.896 | 0.611 | 0.487 | 0.413 | 0.332 | 0.335 | 0.694 |
| 1.002 2.075 1.594 1.207 0.871 0.717 0.623 0.516 0.520 0.989 1.261 2.292 1.776 1.563 1.531 1.159 0.983 0.871 0.741 0.745 1.267 2 2.708 2.131 1.846 1.459 1.307 1.122 1.005 0.865 0.899 1.419 2.518 2.902 2.298 2.004 1.446 1.456 1.1419 1.282 1.132 1.717 3.993 3.250 2.603 2.296 1.860 1.666 1.556 1.397 1.402 1.998 6.33 3.531 2.864 2.569 2.000 1.818 1.629 1.534 2.189 7.971 3.642 2.968 2.565 2.002 2.191 1.814 1.656 1.691 3.291 2.455 1.591 3.806 3.231 2.916 2.779 2.457 2.307 1.895 2.899 2.044 | | | 0.7956 | 1.855 | 1.410 | 1.181 | 1.050 | 0.738 | 0.598 | 0.513 | 0.419 | 0.422 | 0.829 |
| 1.261 2.292 1.776 1.568 1.639 1.013 0.847 0.744 0.625 0.628 1.117 1.588 2.504 1.957 1.683 1.551 1.159 0.983 0.871 0.741 0.745 1.267 2 2.708 2.131 1.846 1.690 1.307 1.122 1.005 0.865 0.869 1.419 2.518 2.902 2.298 2.004 1.846 1.442 1.995 0.999 1.563 3.027 3.402 2.741 2.428 2.269 1.880 1.566 1.397 1.402 1.998 6.33 3.531 2.664 2.509 2.235 2.055 1.332 1.776 1.781 2.356 7.971 3.642 2.396 2.656 2.500 2.127 1.941 1.846 1.861 1.861 2.245 12.64 3.813 3.149 2.627 2.236 2.055 1.382 1.768 1.284 | | | 1.002 | 2.075 | 1.594 | 1.348 | 1.207 | 0.871 | 0.717 | 0.623 | 0.516 | 0.520 | 0.969 |
| 1.588 2.504 1.957 1.683 1.531 1.159 0.983 0.871 0.741 0.745 1.267 2 2.708 2.131 1.846 1.455 1.265 1.142 0.995 0.999 1.569 3.171 3.084 2.456 2.155 1.995 1.601 1.407 1.281 1.122 1.132 1.777 3.993 3.250 2.603 2.236 2.1741 3.486 1.686 1.556 1.397 1.402 1.998 6.33 3.531 2.864 2.569 2.205 1.932 1.776 1.781 2.356 7.971 3.642 2.868 2.500 2.127 1.941 1.866 1.661 2.249 10.04 3.746 3.071 2.750 2.597 2.235 2.055 1.932 1.776 1.781 2.356 15.91 3.850 3.200 2.885 2.247 2.307 2.199 2.060 2.065 2.594 | | | 1.261 | 2.292 | 1.776 | 1.516 | 1.369 | 1.013 | 0.847 | 0.744 | 0.625 | 0.628 | 1.117 |
| 2 2.708 2.131 1.846 1.860 1.307 1.122 1.005 0.865 0.869 1.419 2.518 2.902 2.904 1.846 1.455 1.225 1.102 0.995 0.999 1.569 3.171 3.084 2.456 2.156 1.995 1.601 1.407 1.281 1.122 1.126 1.132 1.717 3.993 3.250 2.603 2.296 1.808 1.686 1.525 1.534 2.128 6.33 3.531 2.864 2.549 2.391 2.009 1.818 1.689 1.529 1.534 2.128 7.971 3.642 2.968 2.656 2.307 2.193 1.865 1.891 2.455 15.91 3.806 3.206 2.885 2.741 2.404 2.243 2.199 1.982 1.988 2.536 20.04 3.806 3.206 2.885 2.779 2.467 2.307 2.199 2.066 2.645 <td></td> <td></td> <td>1.588</td> <td>2.504</td> <td>1.957</td> <td>1.683</td> <td>1.531</td> <td>1.159</td> <td>0.983</td> <td>0.871</td> <td>0.741</td> <td>0.745</td> <td>1.267</td> | | | 1.588 | 2.504 | 1.957 | 1.683 | 1.531 | 1.159 | 0.983 | 0.871 | 0.741 | 0.745 | 1.267 |
| 66191-313 C 2.218 2.204 1.486 1.455 1.285 1.142 0.995 0.999 1.680 3.993 3.250 2.603 2.296 2.136 1.743 1.548 1.142 1.128 1.142 1.1402 1.261 1.860 5.027 3.402 2.741 2.428 2.299 1.880 1.686 1.556 1.397 1.402 1.989 6.33 3.51 2.864 2.549 2.391 2.009 1.816 1.686 1.656 1.661 2.249 10.04 3.746 3.071 2.750 2.597 2.232 2.055 1.932 1.776 1.781 2.245 15.91 3.850 3.206 2.885 2.741 2.404 2.243 2.129 1.982 1.988 2.536 20.04 3.806 3.221 2.916 2.777 2.457 2.007 1.932 1.776 0.330 0.033 0.003 0.002 0.022 0.022 0 | | | 2 | 2.708 | 2.131 | 1.846 | 1.690 | 1.307 | 1.122 | 1.005 | 0.865 | 0.869 | 1.419 |
| 66191-313 C 0.11 0.033 0.047 0.026 0.004 0.003 | | | 2.518 | 2.902 | 2.298 | 2.004 | 1.846 | 1.455 | 1.265 | 1.142 | 0.995 | 0.999 | 1.569 |
| 8.993 3.250 2.603 2.296 2.136 1.743 1.548 1.419 1.262 1.267 1.402 6.33 3.531 2.864 2.549 2.391 2.009 1.818 1.686 1.556 1.397 1.402 1.998 6.33 3.531 2.864 2.549 2.397 2.235 2.055 1.932 1.776 1.781 2.2356 10.04 3.746 3.071 2.750 2.235 2.055 1.932 1.776 1.781 2.356 12.64 3.813 3.149 2.827 2.678 2.328 2.156 2.037 1.885 1.891 2.455 15.91 3.806 3.206 2.885 2.741 2.404 2.437 2.199 2.060 2.066 2.002 0.10 0.155 0.071 0.033 0.018 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0. | | | 3.171 | 3.084 | 2.456 | 2.155 | 1.995 | 1.601 | 1.407 | 1.281 | 1.128 | 1.132 | 1.717 |
| $ \left \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 3.993 | 3.250 | 2.603 | 2.296 | 2.136 | 1.743 | 1.548 | 1.419 | 1.262 | 1.267 | 1.860 |
| 6.33 3.531 2.864 2.549 2.391 2.009 1.818 1.689 1.529 1.534 2.128 7.971 3.642 2.968 2.656 2.500 2.127 1.941 1.814 1.656 1.661 2.249 10.04 3.746 3.071 2.750 2.597 2.232 2.055 1.932 1.776 1.781 2.556 12.64 3.813 3.149 2.827 2.678 2.328 2.156 2.037 1.885 1.891 2.455 15.91 3.850 3.206 2.847 2.407 2.307 2.199 2.060 2.062 2.554 20.04 3.806 3.201 2.916 2.779 2.457 2.303 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.003 0.003 0.003 0.003 0.003 0.004 0.004 0.004 0.004 0.004 0.004 0.004 < | | | 5.027 | 3.402 | 2.741 | 2.428 | 2.269 | 1.880 | 1.686 | 1.556 | 1.397 | 1.402 | 1.998 |
| 10.04 3.742 2.968 2.656 2.500 2.127 1.941 1.814 1.666 1.661 2.249 10.04 3.746 3.071 2.750 2.597 2.235 2.055 1.932 1.776 1.781 2.356 15.91 3.850 3.206 2.885 2.741 2.404 2.243 2.129 1.982 1.988 2.536 20.04 3.806 3.231 2.916 2.779 2.307 2.199 2.000 2.005 2.594 66191-313 0.115 0.071 0.033 0.018 0.004 0.003 | | | 6.33 | 3.531 | 2.864 | 2.549 | 2.391 | 2.009 | 1.818 | 1.689 | 1.529 | 1.534 | 2.128 |
| 10.04 3.746 3.071 2.750 2.257 2.258 2.055 1.932 1.776 1.781 2.356 12.64 3.813 3.149 2.827 2.678 2.328 2.156 2.037 1.885 1.891 2.455 20.04 3.806 3.231 2.916 2.779 2.457 2.307 2.199 2.060 2.065 2.594 66191-313 C 0.1 0.155 0.071 0.033 0.018 0.004 0.003 0.002 0.002 0.022 0.1259 0.203 0.097 0.047 0.026 0.004 0.003 0.003 0.003 0.032 0.1585 0.259 0.128 0.064 0.037 0.009 0.005 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.006 0.006 0.006 0.006 0.006 0.006 0.006 0.006 0.006 0.006 0.006 | | | 7.971 | 3.642 | 2.968 | 2.656 | 2.500 | 2.127 | 1.941 | 1.814 | 1.656 | 1.661 | 2.249 |
| 12.64 3.813 3.149 2.827 2.678 2.328 2.156 2.037 1.885 1.891 2.453 15.91 3.800 3.206 2.885 2.741 2.404 2.243 2.129 1.982 1.988 2.536 66191-313 C 0.1 0.155 0.071 0.033 0.018 0.004 0.003 0.002 0.002 0.022 0.1259 0.203 0.097 0.047 0.026 0.006 0.004 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.006 0.008 0.008 0.008 0.019 0.051 0.037 0.006 0.006 0.004 0.004 0.0010 0.141 0.505 | | | 10.04 | 3.746 | 3.071 | 2.750 | 2.597 | 2.235 | 2.055 | 1.932 | 1.776 | 1.781 | 2.356 |
| 15.91 3.850 3.206 2.885 2.741 2.404 2.243 2.129 1.982 1.988 2.536 66191-313 0.1 0.155 0.071 0.033 0.018 0.004 0.003 0.003 0.002 0.002 0.002 0.1585 0.259 0.128 0.047 0.026 0.006 0.004 0.003 0.003 0.003 0.002 0.002 0.1585 0.259 0.128 0.064 0.037 0.009 0.005 0.006 0.004 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.002 0.005 0.006 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.005 0.006 0.005 0.006 0.005 0.006 0.005 0.006 0.005 0.006 0.005 0.006 0.006 0.006 0.005 0.006 0.006 0.006 0.006 0.006 0.006 0.0101 0.116< | | | 12.64 | 3.813 | 3.149 | 2.827 | 2.678 | 2.328 | 2.156 | 2.037 | 1.885 | 1.891 | 2.455 |
| 20.04 3.806 3.231 2.976 2.779 2.457 2.307 2.199 2.060 2.065 2.594 66191-313 0.1 0.155 0.071 0.033 0.004 0.003 0.003 0.002 0.002 0.022 0.1555 0.259 0.203 0.097 0.047 0.026 0.006 0.004 0.003 0.002 0.002 0.022 0.1585 0.259 0.128 0.064 0.037 0.009 0.005 0.004 0.005 0.006 0.005 0.006 0.006 </td <td></td> <td></td> <td>15.91</td> <td>3.850</td> <td>3.206</td> <td>2.885</td> <td>2.741</td> <td>2.404</td> <td>2.243</td> <td>2.129</td> <td>1.982</td> <td>1.988</td> <td>2.536</td> | | | 15.91 | 3.850 | 3.206 | 2.885 | 2.741 | 2.404 | 2.243 | 2.129 | 1.982 | 1.988 | 2.536 |
| 66191-313 C 0.1 0.155 0.071 0.033 0.018 0.003 0.003 0.002 0.002 0.022 0.1259 0.203 0.097 0.047 0.026 0.004 0.003 0.005 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.005 0.004 0.003 0.005 0.004 0.003 0.005 <t< td=""><td></td><td>-</td><td>20.04</td><td>3.806</td><td>3.231</td><td>2.916</td><td>2.779</td><td>2.457</td><td>2.307</td><td>2.199</td><td>2.060</td><td>2.065</td><td>2.594</td></t<> | | - | 20.04 | 3.806 | 3.231 | 2.916 | 2.779 | 2.457 | 2.307 | 2.199 | 2.060 | 2.065 | 2.594 |
| 0.1259 0.203 0.097 0.047 0.026 0.006 0.004 0.003 0.003 0.003 0.003 0.1585 0.259 0.128 0.064 0.037 0.009 0.005 0.004 0.005 0.005 0.006 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.007 0.006 0.008 0.008 0.008 0.019 0.035 0.013 0.017 0.013 0.010 0.1141 0.501 0.037 0.013 0.017 0.013 0.017 0.013 0.017 0.013 0.017 0.017 0.016 0.017 | 66191-313 | С | 0.1 | 0.155 | 0.071 | 0.033 | 0.018 | 0.004 | 0.003 | 0.003 | 0.002 | 0.002 | 0.022 |
| 0.1585 0.259 0.128 0.064 0.037 0.009 0.004 0.004 0.004 0.004 0.1996 0.326 0.166 0.087 0.052 0.012 0.007 0.006 0.005 0.006 0.005 0.006 0.2514 0.401 0.210 0.115 0.070 0.017 0.010 0.007 0.006 0.008 0.008 0.3985 0.575 0.318 0.187 0.121 0.031 0.017 0.013 0.010 0.014 0.014 0.014 0.010 0.141 0.5018 0.672 0.380 0.231 0.154 0.042 0.023 0.017 0.013 0.013 0.017 0.218 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.022 0.023 0.021 0.023 0.224 0.023 0.024 0.023 0.024 0.023 0.224 0.233 0.226 0.022 0.023 0.226 0.226 | | | 0.1259 | 0.203 | 0.097 | 0.047 | 0.026 | 0.006 | 0.004 | 0.003 | 0.003 | 0.003 | 0.032 |
| 0.1996 0.326 0.166 0.087 0.052 0.012 0.007 0.006 0.005 0.005 0.006 0.2514 0.401 0.210 0.115 0.070 0.017 0.010 0.007 0.006 0.006 0.008 0.3165 0.484 0.261 0.118 0.093 0.023 0.013 0.010 0.008 0.008 0.008 0.3985 0.575 0.318 0.187 0.121 0.031 0.017 0.013 0.010 0.014 0.5018 0.672 0.380 0.231 0.154 0.042 0.023 0.017 0.013 0.013 0.177 0.6319 0.773 0.446 0.280 0.191 0.055 0.030 0.022 0.017 0.017 0.218 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.022 0.023 0.264 1.002 0.986 0.591 0.392 0.281 0.091 0.055 0.037 0.028 0.029 0.314 1.261 1.095 <td></td> <td></td> <td>0.1585</td> <td>0.259</td> <td>0.128</td> <td>0.064</td> <td>0.037</td> <td>0.009</td> <td>0.005</td> <td>0.004</td> <td>0.004</td> <td>0.004</td> <td>0.045</td> | | | 0.1585 | 0.259 | 0.128 | 0.064 | 0.037 | 0.009 | 0.005 | 0.004 | 0.004 | 0.004 | 0.045 |
| 0.2514 0.401 0.210 0.115 0.070 0.017 0.010 0.007 0.006 0.006 0.083 0.3165 0.484 0.261 0.148 0.093 0.023 0.013 0.010 0.008 0.008 0.109 0.3985 0.575 0.318 0.187 0.121 0.031 0.017 0.013 0.010 0.011 0.114 0.5018 0.672 0.380 0.231 0.154 0.042 0.023 0.017 0.013 0.017 0.017 0.017 0.017 0.013 0.017 0.017 0.218 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.022 0.017 0.017 0.218 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.029 0.314 1.002 0.986 0.591 0.332 0.141 0.065 0.047 0.036 0.038 0.682 <t< td=""><td></td><td></td><td>0.1996</td><td>0.326</td><td>0.166</td><td>0.087</td><td>0.052</td><td>0.012</td><td>0.007</td><td>0.006</td><td>0.005</td><td>0.005</td><td>0.062</td></t<> | | | 0.1996 | 0.326 | 0.166 | 0.087 | 0.052 | 0.012 | 0.007 | 0.006 | 0.005 | 0.005 | 0.062 |
| 0.3165 0.484 0.261 0.148 0.093 0.023 0.013 0.010 0.008 0.008 0.109 0.3985 0.575 0.318 0.187 0.121 0.031 0.017 0.013 0.010 0.010 0.1141 0.5018 0.672 0.380 0.231 0.154 0.042 0.023 0.017 0.013 0.010 0.013 0.117 0.6319 0.773 0.446 0.280 0.191 0.055 0.030 0.022 0.017 0.017 0.117 0.118 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.022 0.023 0.264 1.002 0.986 0.591 0.392 0.281 0.091 0.051 0.037 0.028 0.029 0.314 1.261 1.095 0.666 0.454 0.333 0.115 0.065 0.047 0.036 0.426 2 1.313 0.825 0.587 0. | | | 0.2514 | 0.401 | 0.210 | 0.115 | 0.070 | 0.017 | 0.010 | 0.007 | 0.006 | 0.006 | 0.083 |
| 0.3985 0.575 0.318 0.187 0.121 0.031 0.017 0.013 0.010 0.010 0.141 0.5018 0.672 0.380 0.231 0.154 0.042 0.023 0.017 0.013 0.013 0.177 0.6319 0.773 0.446 0.280 0.191 0.055 0.030 0.022 0.017 0.017 0.218 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.022 0.023 0.264 1.002 0.986 0.591 0.392 0.281 0.091 0.055 0.037 0.028 0.029 0.314 1.261 1.095 0.666 0.454 0.333 0.115 0.065 0.047 0.036 0.038 0.388 1.261 1.095 0.667 0.512 0.214 0.104 0.077 0.060 0.061 0.487 2.518 1.420 0.905 0.657 0.512 0.214 0.130 0.097 0.076 0.078 0.551 3.171 1.526 | | | 0.3165 | 0.484 | 0.261 | 0.148 | 0.093 | 0.023 | 0.013 | 0.010 | 0.008 | 0.008 | 0.109 |
| 0.5018 0.672 0.380 0.231 0.154 0.042 0.023 0.017 0.013 0.013 0.177 0.6319 0.773 0.446 0.280 0.191 0.055 0.030 0.022 0.017 0.017 0.218 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.022 0.023 0.264 1.002 0.986 0.591 0.329 0.281 0.091 0.051 0.037 0.028 0.029 0.314 1.261 1.095 0.666 0.454 0.333 0.115 0.065 0.047 0.036 0.038 0.388 1.588 1.204 0.745 0.519 0.389 0.144 0.083 0.067 0.048 0.426 2 1.313 0.825 0.587 0.449 0.176 0.104 0.077 0.060 0.061 0.487 2.518 1.420 0.905 0.657 0.512 0.214 0.130 | | | 0.3985 | 0.575 | 0.318 | 0.187 | 0.121 | 0.031 | 0.017 | 0.013 | 0.010 | 0.010 | 0.141 |
| 0.6319 0.773 0.446 0.280 0.191 0.055 0.030 0.022 0.017 0.017 0.218 0.7956 0.879 0.517 0.334 0.234 0.072 0.039 0.028 0.022 0.023 0.264 1.002 0.986 0.591 0.392 0.281 0.091 0.051 0.037 0.028 0.029 0.314 1.261 1.095 0.666 0.454 0.333 0.115 0.065 0.047 0.048 0.389 1.588 1.204 0.745 0.519 0.389 0.144 0.083 0.061 0.047 0.048 0.426 2 1.313 0.825 0.587 0.449 0.176 0.104 0.077 0.060 0.061 0.487 2.518 1.420 0.905 0.657 0.512 0.214 0.130 0.097 0.076 0.078 0.551 3.171 1.526 0.986 0.729 0.579 0.258 0.160< | | | 0.5018 | 0.672 | 0.380 | 0.231 | 0.154 | 0.042 | 0.023 | 0.017 | 0.013 | 0.013 | 0.177 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 0.6319 | 0.773 | 0.446 | 0.280 | 0.191 | 0.055 | 0.030 | 0.022 | 0.017 | 0.017 | 0.218 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 0.7956 | 0.879 | 0.517 | 0.334 | 0.234 | 0.072 | 0.039 | 0.028 | 0.022 | 0.023 | 0.264 |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$ | | | 1.002 | 0.986 | 0.591 | 0.392 | 0.281 | 0.091 | 0.051 | 0.037 | 0.028 | 0.029 | 0.314 |
| 1.588 1.204 0.745 0.519 0.389 0.144 0.083 0.061 0.047 0.048 0.426 2 1.313 0.825 0.587 0.449 0.176 0.104 0.077 0.060 0.061 0.487 2.518 1.420 0.905 0.657 0.512 0.214 0.130 0.097 0.076 0.078 0.551 3.171 1.526 0.986 0.729 0.579 0.258 0.160 0.121 0.095 0.098 0.617 3.993 1.629 1.068 0.803 0.649 0.306 0.196 0.150 0.119 0.122 0.686 5.027 1.729 1.150 0.879 0.721 0.361 0.238 0.185 0.148 0.152 0.757 6.33 1.825 1.231 0.955 0.795 0.421 0.286 0.226 0.182 0.187 0.831 7.971 1.917 1.312 1.032 0.871 0.486 <td></td> <td></td> <td>1.261</td> <td>1.095</td> <td>0.666</td> <td>0.454</td> <td>0.333</td> <td>0.115</td> <td>0.065</td> <td>0.047</td> <td>0.036</td> <td>0.038</td> <td>0.368</td> | | | 1.261 | 1.095 | 0.666 | 0.454 | 0.333 | 0.115 | 0.065 | 0.047 | 0.036 | 0.038 | 0.368 |
| 2 1.313 0.825 0.587 0.449 0.176 0.104 0.077 0.060 0.061 0.487 2.518 1.420 0.905 0.657 0.512 0.214 0.130 0.097 0.076 0.078 0.551 3.171 1.526 0.986 0.729 0.579 0.258 0.160 0.121 0.095 0.098 0.617 3.993 1.629 1.068 0.803 0.649 0.306 0.196 0.150 0.119 0.122 0.686 5.027 1.729 1.150 0.879 0.721 0.361 0.238 0.185 0.148 0.152 0.757 6.33 1.825 1.231 0.955 0.795 0.421 0.286 0.226 0.182 0.187 0.831 7.971 1.917 1.312 1.032 0.871 0.486 0.341 0.273 0.222 0.228 0.905 10.04 2.002 1.391 1.108 0.948 0.556 <td></td> <td></td> <td>1.588</td> <td>1.204</td> <td>0.745</td> <td>0.519</td> <td>0.389</td> <td>0.144</td> <td>0.083</td> <td>0.061</td> <td>0.047</td> <td>0.048</td> <td>0.426</td> | | | 1.588 | 1.204 | 0.745 | 0.519 | 0.389 | 0.144 | 0.083 | 0.061 | 0.047 | 0.048 | 0.426 |
| 2.518 1.420 0.905 0.657 0.512 0.214 0.130 0.097 0.076 0.078 0.551 3.171 1.526 0.986 0.729 0.579 0.258 0.160 0.121 0.095 0.098 0.617 3.993 1.629 1.068 0.803 0.649 0.306 0.196 0.150 0.119 0.122 0.686 5.027 1.729 1.150 0.879 0.721 0.361 0.238 0.185 0.148 0.152 0.757 6.33 1.825 1.231 0.955 0.795 0.421 0.286 0.226 0.182 0.187 0.831 7.971 1.917 1.312 1.032 0.871 0.486 0.341 0.273 0.222 0.228 0.905 10.04 2.002 1.391 1.108 0.948 0.556 0.402 0.327 0.269 0.276 0.981 12.64 2.067 1.468 1.184 1.025 0.630 | | | 2 | 1.313 | 0.825 | 0.587 | 0.449 | 0.176 | 0.104 | 0.077 | 0.060 | 0.061 | 0.487 |
| 3.171 1.526 0.986 0.729 0.579 0.258 0.160 0.121 0.095 0.088 0.617 3.993 1.629 1.068 0.803 0.649 0.306 0.196 0.150 0.119 0.122 0.686 5.027 1.729 1.150 0.879 0.721 0.361 0.238 0.185 0.148 0.152 0.757 6.33 1.825 1.231 0.955 0.795 0.421 0.286 0.226 0.182 0.187 0.831 7.971 1.917 1.312 1.032 0.871 0.486 0.341 0.273 0.222 0.228 0.905 10.04 2.002 1.391 1.108 0.948 0.556 0.402 0.327 0.269 0.276 0.981 12.64 2.067 1.468 1.184 1.025 0.630 0.468 0.387 0.322 0.329 1.058 15.91 2.059 1.526 1.209 1.160 0.766 | | | 2.518 | 1.420 | 0.905 | 0.657 | 0.512 | 0.214 | 0.130 | 0.097 | 0.076 | 0.078 | 0.551 |
| 3.993 1.629 1.068 0.803 0.649 0.306 0.196 0.150 0.119 0.122 0.686 5.027 1.729 1.150 0.879 0.721 0.361 0.238 0.185 0.148 0.152 0.757 6.33 1.825 1.231 0.955 0.795 0.421 0.286 0.226 0.182 0.187 0.831 7.971 1.917 1.312 1.032 0.871 0.486 0.341 0.273 0.222 0.228 0.905 10.04 2.002 1.391 1.108 0.948 0.556 0.402 0.327 0.269 0.276 0.981 12.64 2.067 1.468 1.184 1.025 0.630 0.468 0.387 0.322 0.329 1.058 15.91 2.059 1.526 1.205 1.011 0.706 0.544 0.381 0.362 0.322 0.329 1.058 15.91 2.059 1.526 1.209 1.160 | | | 3.171 | 1.526 | 0.986 | 0.729 | 0.579 | 0.258 | 0.160 | 0.121 | 0.095 | 0.098 | 0.617 |
| 5.027 1.729 1.150 0.879 0.721 0.361 0.238 0.185 0.148 0.152 0.757 6.33 1.825 1.231 0.955 0.795 0.421 0.286 0.226 0.182 0.187 0.831 7.971 1.917 1.312 1.032 0.871 0.486 0.341 0.273 0.222 0.228 0.905 10.04 2.002 1.391 1.108 0.948 0.556 0.402 0.327 0.269 0.276 0.981 12.64 2.067 1.468 1.184 1.025 0.630 0.468 0.387 0.322 0.329 1.058 15.91 2.059 1.526 1.200 1.161 0.706 0.540 0.453 0.389 1.058 15.91 2.059 1.526 1.200 1.460 0.782 0.614 0.381 0.362 1.103 20.04 4.072 1.543 1.200 1.460 0.782 0.614 0.384 | | | 3.993 | 1.629 | 1.008 | 0.803 | 0.649 | 0.306 | 0.196 | 0.150 | 0.119 | 0.122 | 0.086 |
| 0.03 1.023 1.231 0.955 0.795 0.421 0.266 0.226 0.182 0.187 0.831 7.971 1.917 1.312 1.032 0.871 0.486 0.341 0.273 0.222 0.228 0.905 10.04 2.002 1.391 1.108 0.948 0.556 0.402 0.327 0.269 0.276 0.981 12.64 2.067 1.468 1.184 1.025 0.630 0.468 0.387 0.322 0.329 1.058 15.91 2.059 1.526 1.251 1.101 0.706 0.544 0.381 0.389 1.138 20.04 4.072 4.542 1.290 1.161 0.706 0.544 0.381 0.362 1.193 | | | 5.027 | 1.729 | 1.150 | 0.879 | 0.721 | 0.301 | 0.238 | 0.185 | 0.148 | 0.152 | 0.757 |
| 1.971 1.312 1.032 0.871 0.486 0.341 0.273 0.222 0.228 0.905 10.04 2.002 1.391 1.108 0.948 0.556 0.402 0.327 0.269 0.276 0.981 12.64 2.067 1.468 1.184 1.025 0.630 0.468 0.387 0.322 0.329 1.058 15.91 2.059 1.526 1.255 1.101 0.706 0.540 0.454 0.381 0.369 1.058 15.91 2.059 1.526 1.255 1.101 0.706 0.540 0.454 0.381 0.362 1.058 15.91 2.059 1.526 1.209 1.469 0.782 0.614 0.381 0.362 1.103 | | | 0.33 | 1.825 | 1.231 | 0.955 | 0.795 | 0.421 | 0.200 | 0.220 | 0.182 | 0.187 | 0.831 |
| 10.04 2.002 1.391 1.100 0.948 0.356 0.402 0.327 0.209 0.276 0.981 12.64 2.067 1.468 1.184 1.025 0.630 0.468 0.387 0.322 0.329 1.058 15.91 2.059 1.526 1.255 1.101 0.706 0.540 0.454 0.381 0.389 1.058 20.04 1.079 1.526 1.209 1.160 0.782 0.614 0.572 0.444 0.452 1.109 | | | 1.9/1 | 1.917 | 1.312 | 1.032 | 0.040 | 0.486 | 0.341 | 0.273 | 0.222 | 0.228 | 0.905 |
| 12.04 2.007 1.400 1.104 1.025 0.030 0.400 0.327 0.322 0.329 1.056 15.91 2.059 1.526 1.255 1.101 0.706 0.540 0.454 0.381 0.389 1.056 20.04 4.072 1.526 1.202 1.460 0.452 0.444 0.452 1.400 | | | 10.04 | 2.002 | 1.391 | 1.108 | 1.025 | 0.550 | 0.402 | 0.327 | 0.269 | 0.276 | 0.981 |
| 13.31 Z.039 1.320 1.233 1.101 0.700 0.340 0.434 0.361 0.369 1.133 20.04 4.072 4.542 1.200 1.460 0.722 0.644 0.572 0.444 0.452 1.130 | | | 12.04 | 2.007 | 1.408 | 1.104 | 1.020 | 0.030 | 0.400 | 0.307 | 0.322 | 0.329 | 1.008 |
| | | | 20.04 | 1 973 | 1.520 | 1 200 | 1 160 | 0.700 | 0.540 | 0.434 | 0.301 | 0.369 | 1 100 |

Table 10 Average CTR characteristic (If=1-20mA, Vce=1V) calculated on the samples of biasing group "C" for each irradiation step of both references.







Figure 12: 66191-303 CTR characteristic degradation with TID irradiation (average on samples tested with biasing condition C).



Figure 13: 66191-313 CTR characteristic degradation with TID irradiation (average on samples tested with biasing condition C).

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5 **DISCUSSION**

Due to low sample sizes, the test data was statistically treated employing the one sided tolerance limit method. Parameters employed were 90% probability with 90% confidence. The large part-to-part non-uniformity of the 66191-303 devices significantly impacts the statistical results. The part-to-part non-uniformity of the 66191-313 was less prominent.

Three (3) biasing conditions were employed dictated by ESA mission requirements. The biasing conditions were broadly selected to:

- A) Bias the LED and output section of the optocoupler,
- B) Bias only the output section of the optocoupler
- C) Bias only the optocoupler LED

Due to large part-to-part variation of the 66191-303 it is not clear whether biasing condition A, B or C is worst case. However, the 66191-313 normalised average CTR results, figure 8, weakly indicates that biasing condition C exhibits the highest radiation sensitivity. This conclusion is less clear when taking into account the statistical envelope limits.

Although the average normalised CTR values illustrated in figure 8 show a significant radiation sensitivity increase for the 66191-313 compared to the 66191-303 devices, the difference becomes less significant when accounting for the envelope set by the statistical limits.

Electrical measurements presented in Figure 2 indicate that the pre-irradiation CTR values for the 66191-313 are in average lower than those of the 66191-303 devices. Figure 2 also indicates that the 66191-313 CTR parameters go out of specification with increasing TID exposure. Thus, these measurements support the Alter results and illustrate that the 66191-313 devices are more sensitive to low dose rate TID irradiation than 66191-303 devices.

When considering the CTR values based on statistical limits (figure 7), for bias condition A, the pre-irradiation CTR level is already below manufacturer specification. For bias condition B the CTR value drops below manufacturer specification at about 14krad(Si). For bias condition C the CTR value drops below manufacturer specification between 14 and 20 krad(Si).

The above results are for electrical measurements performed for IF =10mA and Vce =1V. CTR results for other IF values are presented in tables 8 to 10 and figures 8 to 13.



6 CONCLUSIONS

Low dose rate TID irradiation tests were performed to identify the source of the radiation sensitivity discrepancy observed between 66191-303 (old version) and 66191-313 (new version) devices. According to Micropac the only difference between these devices is the output transistor (from two different manufacturers). Ten (10) parts of each device version were irradiated. These parts were provided to ESA by Micropac. The two device versions were irradiated under the same biasing conditions. Three different biasing conditions based on ESA project requirements were applied.

The irradiation test result illustrate that the 66191-313 (new version) devices are more sensitive to TID radiation than the 66191-303 devices. The part-to-part radiation sensitivity non-uniformity is larger for the 66191-303 devices than those of the 66191-313 devices.

For the worst biasing condition (condition C) the average CTR degradation is worst for the 66191-313, compared to the 66191-303, by approximately 18% at 14krad(Si) and approximately 34% at 100krad(Si). Bias conditions A and B follow a similar trend.

The above results support the need to perform Radiation verification Tests on every optocoupler Flight Model lot planned flown on ESA space missions.



APPENDIX A DATASHEET SPECIFICATIONS

| 66191 | 6 PIN LCC RADIATION TOLERAN | OPTOELECTRONIC PRODUCTS DIVISION | |
|--|---|---|---------------------------------------|
| 04/21/2009 | | | |
| Features: Current tra Base lead biasing Low power High radiat 1000 Vdc i | nsfer ratio: 150% typical provided for conventional transistor consumption ion immunity solation test voltage | Applications: Military and Space High Reliability Syste Voltage Level Shiftin Isolated Receiver Ing Communication System | ems g puts iems |
| DESCRIPTION The 66191 Opto | coupler consists of a 660 nm GaAlAs LE | D optically coupled to a pho | otodiode detector driving a radiation |

The 66191 Optocoupler consists of a 660 nm GaAlAs LED optically coupled to a photodiode detector driving a radiation tolerant transistor. This configuration has proven to be highly tolerant to both proton and total dose radiation. Radiation tests performed on the 66099 optocoupler have shown that the electrical performance of the device after irradiation is an order of magnitude better than the 4N49 optocouplers. The 66191 has the same components and layout in a 6 pin, hermetically sealed leadless chip carrier package. Available as commercial or screened levels.

ABSOLUTE MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

| * Input Diode | |
|---|----------------|
| Peak Forward Input Current | |
| Reverse Input Voltage | 7 V |
| Input Power Dissipation (Note 2). | |
| *Output Photodetector | |
| Continuous Collector Current | |
| Collector-Emitter Voltage | |
| Emitter-Collector Voltage | |
| Collector-Base Voltage | |
| Power Dissipation. (Note 3) | |
| Input to output Isolation Voltage (Note 1) | +1 kVdc |
| Storage Temperature | 55°C to +150°C |
| Operating Temperature | 55°C to +100°C |
| Lead Solder Temperature (10 seconds, 1/16" from case) | |
| Notor | |

1. Measured with input diode leads shorted together and output leads shorted together

2. Derate linearly 1.0 mW/°C above 25°C.

3. Derate linearly 2.3mW/°C above 25°C.



ALL DIMENSIONS ARE IN INCHES [MILLIMETERS]

MICROPAC INDUSTRIES, INC. OPTOELECTRONIC PRODUCTS DIVISION • 725 E. Walnut St., Garland, TX 75040 • (972)272-3571 • Fax (972)487-6918 www.micropac.com E-MAIL: OPTOSALES @ MICROPAC.COM



6 PIN LCC RADIATION TOLERANT OPTOCOUPLER

66191 04/21/2009ELECTRICAL CHARACTERISTICS INPUT DIODE $T_A = 25^{\circ}C$ unless otherwise specified.

| PARAMETER | SYMBOL | MIN | TYP | MAX | UNITS | TEST CONDITIONS | NOTE |
|------------------------------------|----------------|-----|-----|-----|-------|-----------------------|------|
| Input Diode Static Reverse Current | I _R | | | 10 | μA | V _R = 3V | |
| Input Diode Static Forward Voltage | VF | .8 | 1.8 | 2 | V | I _F = 10mA | |

| TA 20 0 unioco outor moc opecinica. | | | | | | | |
|-------------------------------------|----------|-----|-----|-----|-------|---|------|
| PARAMETER | SYMBOL | MIN | TYP | MAX | UNITS | TEST CONDITIONS | NOTE |
| Collector-Base Breakdown Voltage | V(BR)CBO | 40 | | | V | I _C = 100 μA, I _F = 0 | |
| Collector-Emitter Breakdown Voltage | V(BR)CEO | 40 | | | V | I _C = 1 mA, I _B = 0, I _F = 0 | |
| Emitter-Collector Breakdown Voltage | V(BR)ECO | 5 | | | V | I _E = 100 μA, I _F = 0 | |
| Collector-Emitter Dark Current | ICEO | | | 100 | nA | 2014 | |
| +100°C | | | | 20 | μA | VCE = 20V | |

COUPLED CHARACTERISTICS

 $T_A = 25^{\circ}C$ unless otherwise specified.

| PARAMETER | SYMBOL | MIN | TYP | MAX | UNITS | TEST CONDITIONS | NOTE |
|--------------------------------------|------------------|-----|-----|------|-------|--|------|
| Current Transfer Ratio | CTR | 100 | | | % | V _{CE} = 1 V, I _F = 10 mA | |
| Collector-Emitter Saturation Voltage | VCE(SAT) | | | 0.3 | V | I _F = 20 mA, I _C =10 mA | |
| Input -Output Isolation Voltage | ∨ _{I-O} | | | 1000 | V | I _{I-O} = 100 nA | 1 |
| Input to Output Capacitance | CI-O | | 2.5 | 5 | pF | f = 1MHz, V _{I-O} = 1kV | 1 |
| Rise Time | tr | | | 5 | μs | $V_{CC} = 5 V$, I _F = 2 mA, R _L = 100 Ω | |
| Fall Time | tf | | | 7 | μs | V_{CC} = 5 V, I _F = 2 mA, R _L = 100 Ω | |

NOTES:

1) These parameters are measured between all phototransistor leads shorted together and with both input diode leads shorted together.

RECOMMENDED OPERATING CONDITIONS:

| PARAMETER | SYMBOL | MIN | MAX | UNITS | | | | | | |
|---------------------------|-----------------|----------------|------|-------|--|--|--|--|--|--|
| Input Current, Low Level | I _{FL} | 0 | 100 | μA | | | | | | |
| Input Current, High Level | IFH | 10 | 20 | mA | | | | | | |
| Supply Voltage | V _{CE} | 5 | 20 | V | | | | | | |
| Operating Temperature | TA | -55 | +100 | °C | | | | | | |
| SELECTION GUIDE | | | | | | | | | | |
| PART NUMBER | PA | RT DESCRIPTION | | | | | | | | |

| PART NUMBER | PART DESCRIPTION |
|-------------|--------------------------|
| 66191-001 | Commercial |
| 66191-101 | Screened to JAN level |
| 66191-103 | Screened to JANTX level |
| 66191-105 | Screened to JANTXV level |
| 66191-300 | Screened to Space level |

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APPENDIX B RADIATION SUMMARY



ESTEC ⁶⁰Co Facility

Keplerlaan, 1 2200AG Noordwijk ZH (NL)



RADIATION TEST SUMMARY

| Irradiation Test Report Number : | 20105 | Date : | 28 July 2011 |
|---|--|--------|--------------|
| Test Requester : Name | ESA | | |
| Address Personnel present : Project/Cost Code : Devices/Components irradiated : Device/Component details : (conditions and identification) | TEC-QTC A Costantino TRP Opto-Couplers Micropac 66191 (types 303 & 313) | | |
| Dosimetry Chain used : Dosimeter : Gas lonisation Chamber : Measured Dosimetry : Dosimetry Procedure : | C Farmer model 2680 – s/n 491 NE Type 2571 – s/n 3573 Total Ionising Dose in [Gy] (water) ESCC 22900 section 4.1.1 TEC-QEC/PR001 - Appendix D | | |

(With the exception of the above specified dosimetry equipment, ESTEC ⁶⁰Co Facility does not assume any liability for the calibration status of any other equipment lent to the requester)

Irradiation Test Campaign Details

| Sc | Source Activity : 43.3TBq | | | on date : 06/07/2011 | | | | |
|-------------------|---------------------------|-------|--------|------------------------------|--|--|----|-----|
| | units | Min. | Max. | Time- weighted Average | | Dosimeter position relative to ⁶⁰ Co source | | |
| Temperature | °C | 24.2 | 24.7 | 24.50 | | Х | cm | -1 |
| Pressure | mbar | 992.8 | 1019.6 | 1009.72 | | Y | cm | 186 |
| Relative Humidity | % | 37.4 | 43.7 | 41.30 | | Z | cm | 10 |

| Run | Start Date & Time (CET) | End Date & Time (CET) | Total lonising Dose [Gy] (water) | Dose Rate [Gy/h] (water) |
|-----|----------------------------|--------------------------|-------------------------------------|-----------------------------|
| 1 | 05 Jul 2011 18:09:35 | 06 Jul 2011 12:39:27 | 75.00 | 4.06 |
| 2 | 06 Jul 2011 13:25:53 | 07 Jul 2011 13:11:17 | 88.29 | 3.95 |
| 3 | 07 Jul 2011 13:15:30 | 08 Jul 2011 08:38:10 | 76.41 | 3.94 |
| 4 | 08 Jul 2011 11:36:00 | 11 Jul 2011 09:10:00 | 277.00 | 3.98 |
| 5 | 11 Jul 2011 10:36:06 | 13 Jul 2011 15:59:55 | 209.71 | 3.9 3 |
| 6 | 13 Jul 2011 16:44:34 | 15 Jul 2011 15:26:36 | 180.68 | 3.93 |
| 7 | 15 Jul 2011 16:46:44 | 18 Jul 2011 13:40:01 | 275.56 | 4.00 |

Note: The uncertainty budget associated with the absorbed dose to water measurements is 4.2 % (k=2) according to TEC-QEC/PR001 paragraph 12

Notes: TID and dose rate figures, expressed in krad and rad/h, are reported, as in *Table 1*, for customer convenience only.

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ESTEC ⁶⁰Co Facility

Keplerlaan, 1 2200AG Noordwijk ZH (NL)

Table 1 radiation summary data expressed in rad and rad/h

| Run | Start Date & Time (CET) | End Date & Time (CET) | Total lonising Dose [krad] (water) | Dose Rate [rad/h] (water) |
|-----|----------------------------|--------------------------|---------------------------------------|------------------------------|
| 1 | 05 Jul 2011 18:09:35 | 06 Jul 2011 12:39:27 | 7.500 | 406 |
| 2 | 06 Jul 2011 13:25:53 | 07 Jul 2011 13:11:17 | 8.829 | 395 |
| 3 | 07 Jul 2011 13:15:30 | 08 Jul 2011 08:38:10 | 7.641 | 394 |
| 4 | 08 Jul 2011 11:36:00 | 11 Jul 2011 09:10:00 | 27.700 | 398 |
| 5 | 11 Jul 2011 10:36:06 | 13 Jul 2011 15:59:55 | 20.971 | 393 |
| 6 | 13 Jul 2011 16:44:34 | 15 Jul 2011 15:26:36 | 18.068 | 393 |
| 7 | 15 Jul 2011 16:46:44 | 18 Jul 2011 13:40:01 | 27.556 | 400 |

Michele Muschitiello (TEC-QEC Radiation Test E

All Laboration Head)

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