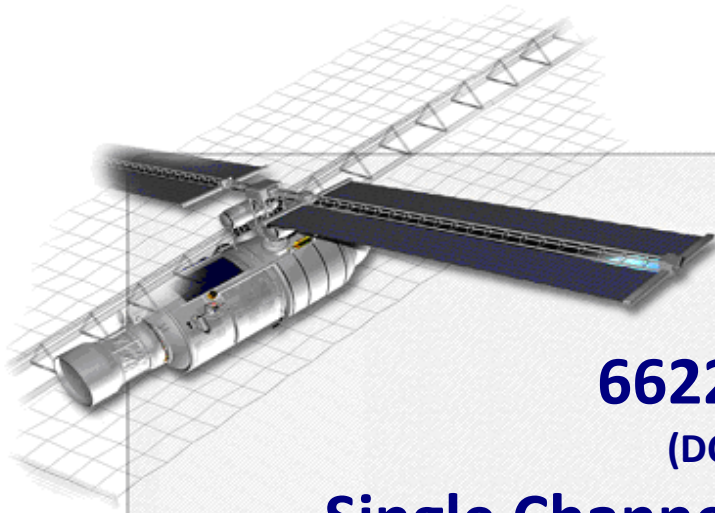




# NEUTRONS DISPLACEMENT DAMAGE TEST REPORT



## 66224-105 (DC1111) Single Channel Optocoupler From MICROPAC

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Issue : 0		
To: Marc POIZAT	Project/Program:	ESA Contract N°4000102571/10/NL/AF-Radiation Characterization of Laplace RH optocouplers, sensors and detectors

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## 1 INTRODUCTION

This report includes the test results of 66224-105, a Single Channel Optocoupler from MICROPAC to evaluate displacement damage effects under neutron irradiation. On November, week 45, 2011, TRAD characterized this device for neutron sensitivity at the SCK-CEN Facility, Belgium using their BR1 Neutron Irradiator.

The objectives of the test are:

- to detect and measure the degradation of device parameters as a function of neutron fluence,
- to determine if device parameters are within specified limits after exposure to final level of neutron fluence.

## 2 DOCUMENTS

### 2.1 Applicable Documents

AD	1.	ESA contract	N°4000102571/10/NL/AF-Radiation Characterization of Laplace RH optocouplers, sensors and detectors
AD	2.	Irradiation Test Plan	TRAD_ITP_TN_66224_MIC_ESA_1119, Iss.2, 28/06/11

### 2.2 Reference Documents

RD	1.	Datasheet 66224	PROTON RADIATION TOLERANT OPTOCOUPLER (Single Channel, Electrically Similar to 4N49) dated 29/09/2010
RD	2.	Manufacturer's certificate of traceability and conformance dated 25/07/2011	

## 3 DEVICE INFORMATION

### 3.1 Device description

The 66224 device is a single channel (electrically similar to 4N49) optocoupler (850 nm LED, "40 x 40" phototransistor) encapsulated in a hermetically sealed 6 pin leadless chip carrier (LCC). It contains an 850nm LED optically coupled to a silicon planar phototransistor.

This product has been designed to be more tolerant to proton radiation.

Type	66224-105
Manufacturer	MICROPAC
Function	Optocoupler
Package	LCC6
Date Code	1111
Sample size	4 parts (3 test parts + 1 control sample)

### 3.2 Procurement information

75 parts reference 66224-105 were delivered by MICROPAC through the French distributor ISOTOPE ELECTRONICS.

Their quality level defined by the 105 extension number which corresponds to a commercial standard operating in the temperature range of -55° to +125°C and screened to JANTXV level by the manufacturer prior delivery. Parts were delivered separated in two lots from two different date-codes (25 pcs DC1038 and 53 pcs DC1111) and together with a Certificate of Conformance [RD2]. Only parts from DC1111 were used for this irradiation test sequence.

### 3.3 External view

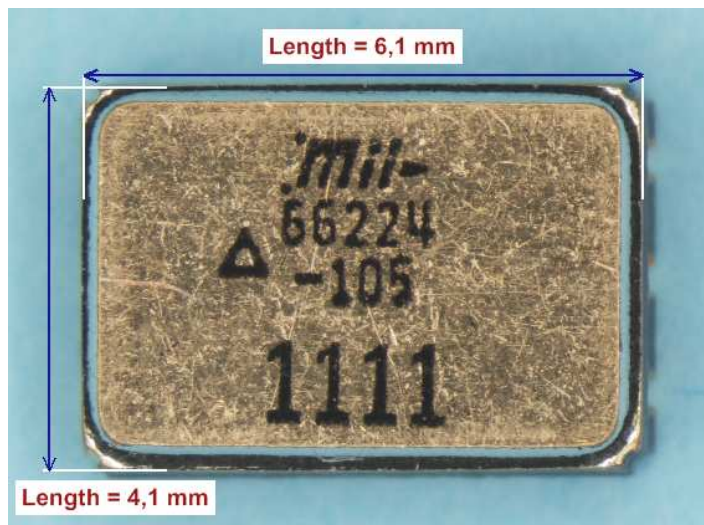


Figure 1: package marking

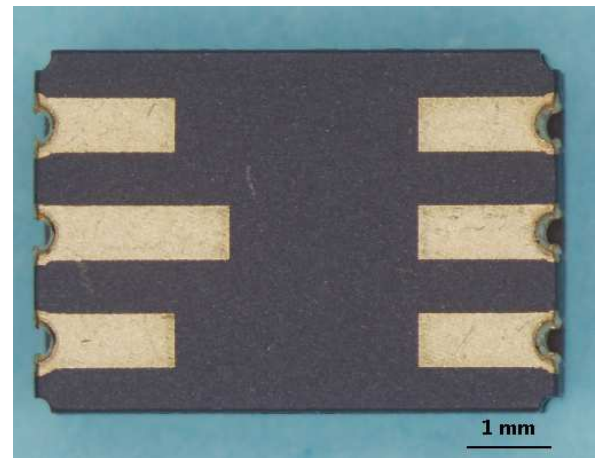


Figure 2: package back side

### 3.4 Internal view

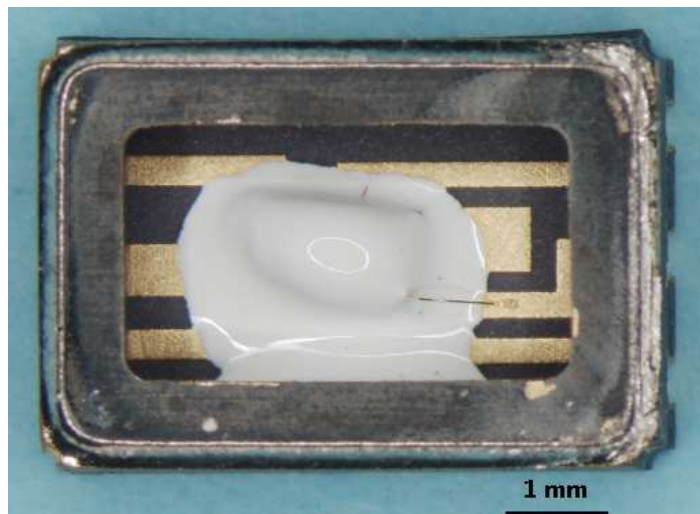


Figure 3: Internal view

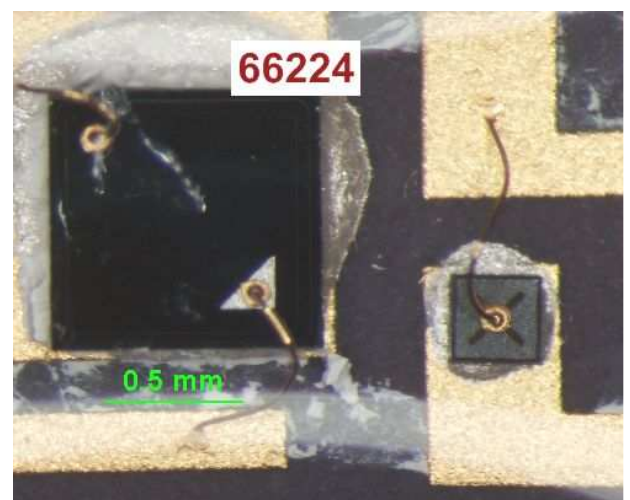


Figure 4: photodetector and LED view

### 3.5 Serialization

Each part is serialized to enable pre and post test identification and comparison.

Serial Number	Control sample	Test samples		
Serialization	1	2	3	4



## 4 IRRADIATION MEANS AND CONDITIONS

### 4.1 BR1 irradiation facility (Belgium)

The Reactor BR1 is a versatile neutron / gamma irradiation tool. The large cavity is used for this test. To obtain the required neutron flux, a 6cm Uranium shell is used. This spherical converter provides a 1 MeV equivalent neutron flux of  $2.86E+08n/cm^2.s$ , with a low ionizing dose rate of 2,5Gy/h.

All exposures are made at  $20^{\circ}C \pm 10^{\circ}C$ .

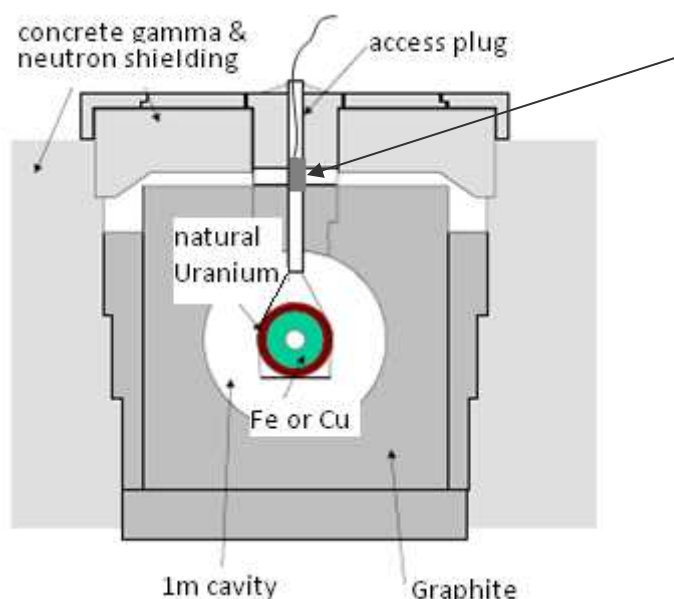
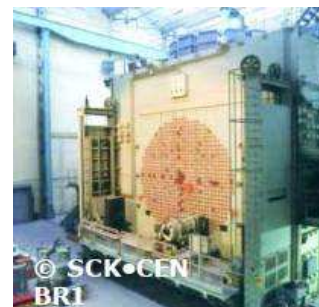


Figure 5: schematical view of the large cavity and its spherical drivers

The sample holder is a cylinder, dimensions of which are 3.5 cm diameter and 5.5 cm length made of high-density polyethylene.



Figure 6: view of the sample holder

### 4.2 Dose measurement

The SCK•CEN reactor dosimetry service is accredited by BELAC (Ministry of Economic Affairs from Belgium) under the accreditation number 015-TEST. The accreditation towards norms NBN EN ISO/IEC 17025 for the Standard Practice for Determining Neutron Fluence Rate, Fluence, and Spectra by Radioactivation Techniques (ASTM261 & ASTM262) is in progress.

### 4.3 Experimental conditions

An Equivalent total fluence of  $1E12 \text{ \#/cm}^2$  of 10 MeV protons is required [AD2] for this TNID (Total Non Ionizing Dose) evaluation test. Considering NIEL (Non Ionizing Energy Loss) value for 1 MeV neutron ( $1.14E-03 \text{ MeV cm}^2 \text{ g}^{-1}$ ), it corresponds to a total fluence of  $6.89E+12 \text{ \#/cm}^2$  for 1 MeV neutron.

Five steps are defined to determine the component degradation under 1 MeV neutron irradiation. The test devices have been exposed to the following neutron fluence levels:

	Step1	Step2	Step3	Step4	Step5
Fluence $n/cm^2$	5,00E+10	1,00E+11	5,00E+11	1,00E+12	7,00E+12
Flux $n/cm^2.s$	2,86E+08	2,86E+08	2,86E+08	2,86E+08	2,86E+08

### 4.4 Exposure set-up

The samples were exposed to neutron irradiation in an un-biased state and had all their terminal leads open.

## 5 ELECTRICAL TESTS

Electrical parameters to be measured in pre and post exposure tests are described in the following table. Electrical tests are performed on each part using the test set-up hereunder. All required data are recorded for each device. Test conditions and limits are given in the applicable irradiation test plan [AD2] and shown hereafter.

### 5.1 Test set-up

TEST BOARD	TRAD/CT1/N/OPTO/ZIP14/BR/1109
TEST PROGRAM	66224_TN_XXX1_B1_V10.Ilb

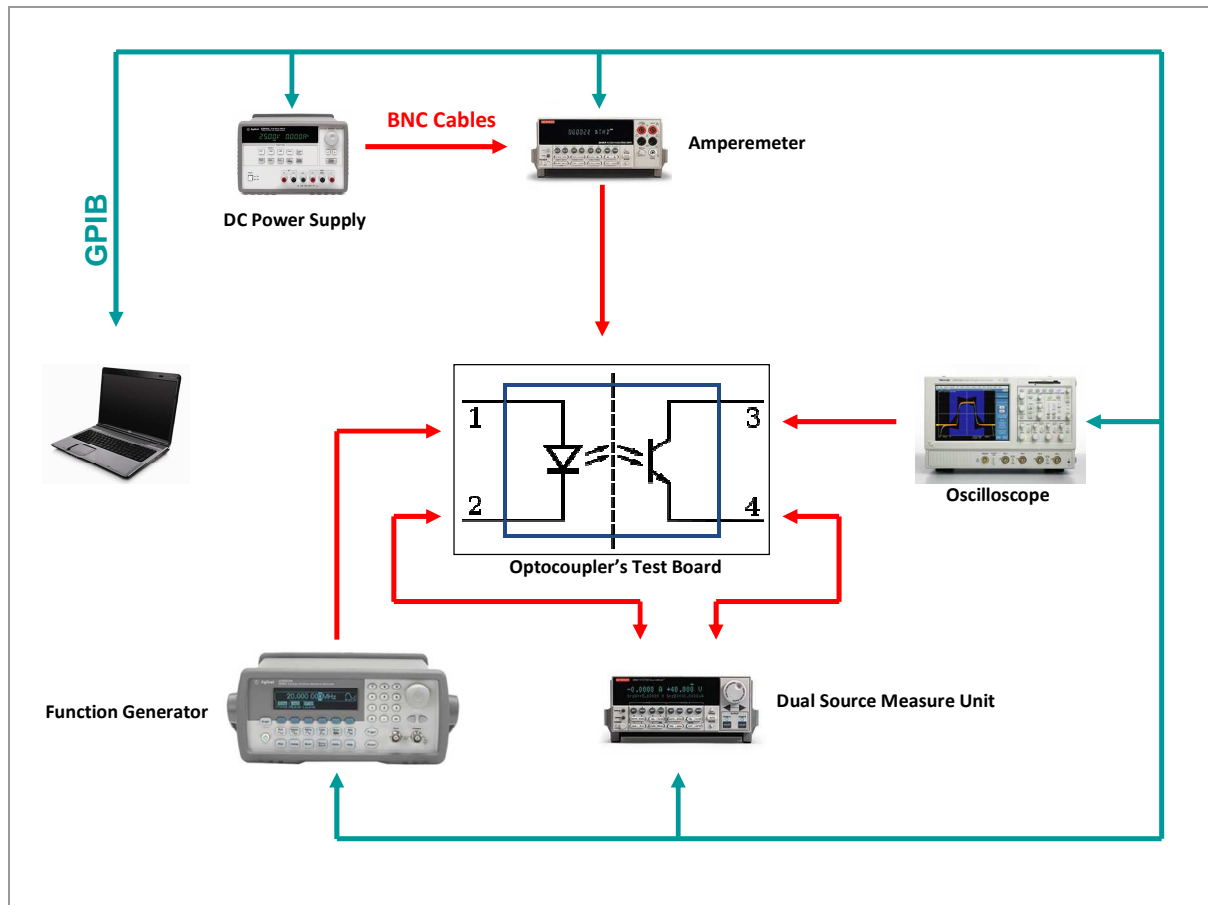


Figure 7: test principle

## 5.2 Electrical parameters

PARAMETER	SYMBOL	TEST CONDITION	MIN	MAX	UNIT
Input Diode Static Reverse Current	$I_R$	$V_R = 6 \text{ V}$		8	$\mu\text{A}$
Input Diode Static Forward Voltage	$V_F$	$I_F = 10 \text{ mA}$		1,6	V
Collector-Base Breakdown Voltage	$V_{(BR)CBO}$	$I_C = 100 \mu\text{A}, I_B = 0, I_F = 0$	45		V
Collector-Emitter Breakdown Voltage	$V_{(BR)CEO}$	$I_C = 1 \text{ mA}, I_B = 0, I_F = 0$	40		V
Emitter-Collector Breakdown Voltage	$V_{(BR)ECO}$	$I_C = 0 \text{ mA}, I_E = 100 \mu\text{A}, I_F = 0$	5		V
Off-State Collector Current	$I_{CEO}$	$V_{CE} = 20 \text{ V}, I_F = 0 \text{ mA}, I_B = 0$		100	nA
On State Collector Current	$I_{C(ON)}$	$V_{CE} = 5 \text{ V}, I_F = 1 \text{ mA}, I_B = 0^*$	2		mA
Rise Time- Phototransistor Operation	tr1	$V_{CC} = 10\text{V}, I_F = 5\text{mA}, R_L = 100\Omega, I_B = 0$		25	$\mu\text{s}$
Fall Time-Phototransistor Operation	tf1	$V_{CC} = 10\text{V}, I_F = 5\text{mA}, R_L = 100\Omega, I_B = 0$		25	$\mu\text{s}$
Rise Time-Photodiode Operation	tr2	$V_{CC} = 10\text{V}, I_F = 5\text{mA}, R_L = 100\Omega, I_E = 0$		3	$\mu\text{s}$
Fall Time-Photodiode Operation	tf2	$V_{CC} = 10\text{V}, I_F = 5\text{mA}, R_L = 100\Omega, I_E = 0$		3	$\mu\text{s}$
Current Transfer Ratio	CTR1	$V_{CE} = 5\text{V}, I_F = 1\text{mA}$	200		%
	CTR2	$V_{CE} = 5\text{V}, I_F = 2\text{mA}$			%
	CTR3	$V_{CE} = 5\text{V}, I_F = 10\text{mA}$			%
	CTR4	$V_{CE} = 5\text{V}, I_F = 50\text{mA}$			%
	CTR5	$V_{CE} = 30\text{V}, I_F = 5\text{mA}$			%
Input Diode Reverse Recovery Time	Trr	$I_F = 5\text{mA}, R_L = 100\Omega, I_{rec} = 10\% I_{rm}$			ns

(\*)This parameter must be measured using pulse techniques ( $t_W = 100 \mu\text{s}$  duty cycle  $< 1\%$ ).

Min/ Max values are those specified in the reference data-sheet [RD1].

Test measurements are performed at  $20^\circ\text{C} \pm 10^\circ\text{C}$ .

## 6 TEST HISTORY

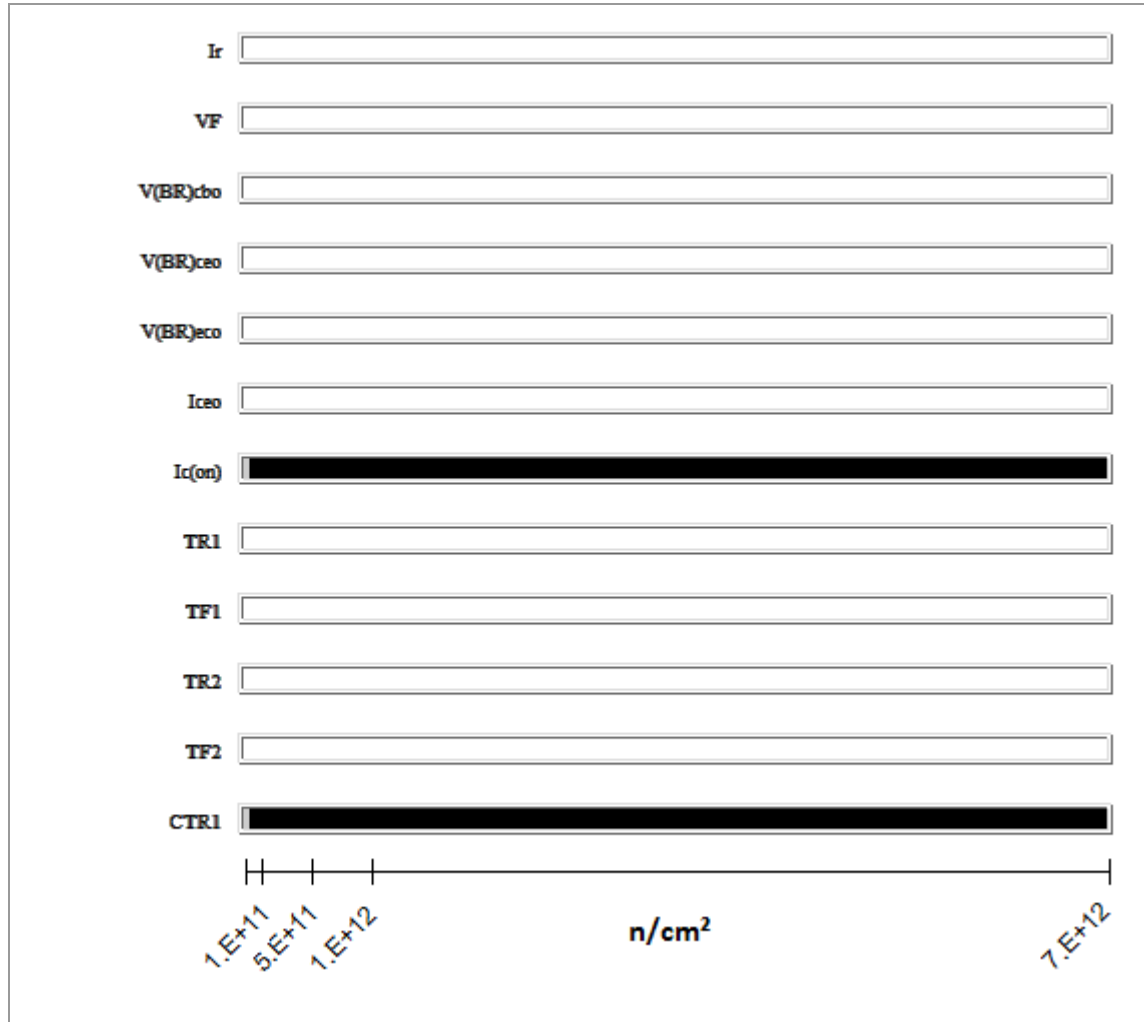
Test sequence and all required conditions were executed as described in the test plan.

No incident during the test was noticed.



## 7 SUMMARY RESULTS

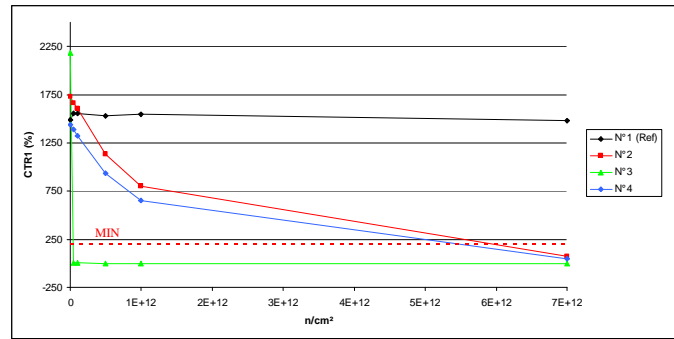
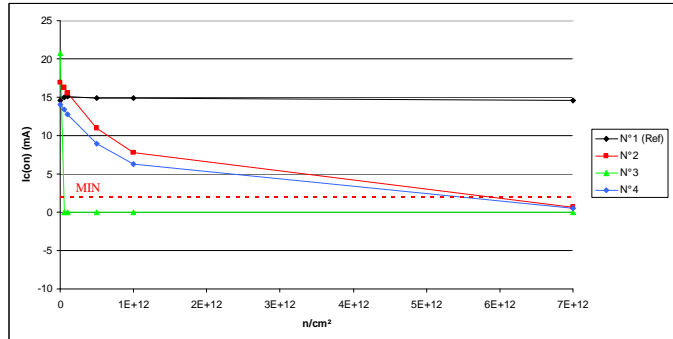
Only parameters with applicable test limits are shown hereunder.



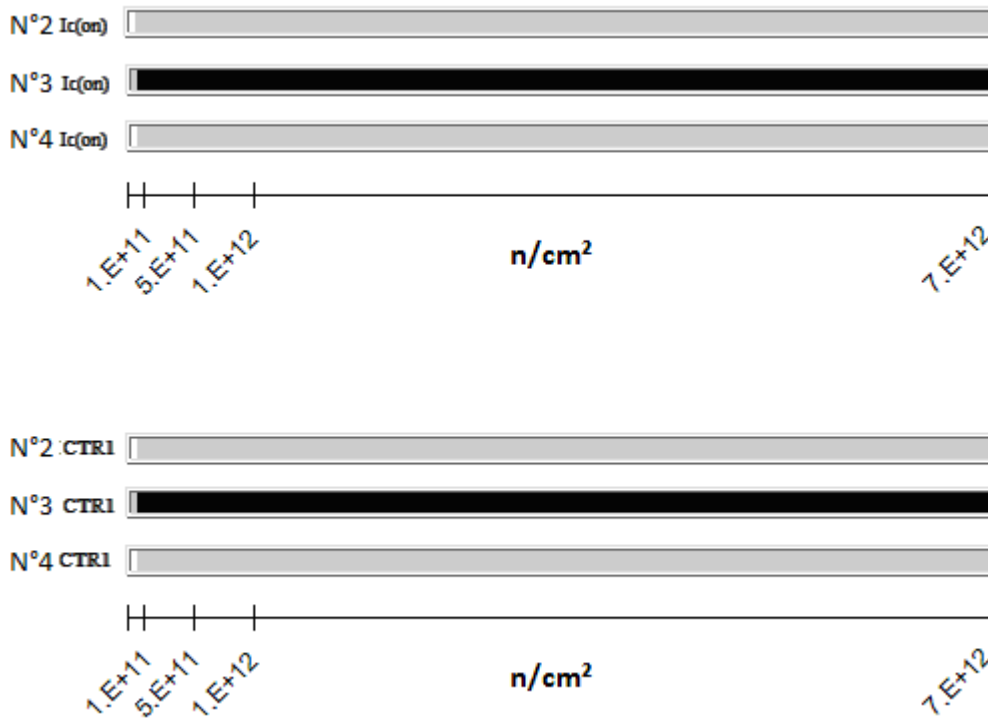
- Within specification
- Transition
- Out of specification or parameter not measurable

- In the worst case, the parameter Ic(on) is out of specification at 4.53E10.n/cm<sup>2</sup> by interpolation.
- In the worst case, the parameter CTR1 is out of specification at 4.55E10.n/cm<sup>2</sup> by interpolation.

As shown in detailed test results, the component N°3 is the more sensitive.



As shown in the next schematic results, at step 7E12 n/cm² components N°2 and N°4 are out of specification for Ic(on) and CTR1 parameters.



Next table shows total dose interpolation for each devices becoming non-compliant.

	Component N°2	Component N°3	Component N°4
Out of specification interpolation for Ic(on)	5.87E+12 n/cm²	4.53E+10 n/cm²	5.42E+12 n/cm²
Out of specification interpolation for CTR1	7.57E+12 n/cm²	4.55E+10 n/cm²	7.50E+12 n/cm²

This disparity is clearly visible for VBR(ceo), VBR(eco), Ic(on), CTR1, CTR2, CTR3, CTR4 and CTR5 parameters.

## 8 CONCLUSION

Total fluence steady-state irradiation test using neutrons has been applied on **66224**, a **Single Channel Optocoupler** from **MICROPAC** up to  $7E+12$  neutrons/cm<sup>2</sup>, with an energy of 1 MeV.

The results indicate that:

- In the worst case,  $I_{C(ON)}$  and CTR1 at step  $5E10$  n/cm<sup>2</sup> are out of specification

PARAMETERS	SYMBOLS	TEST CONDITIONS	Applicable specification			Worst Measurement at step $5E10$ n/cm <sup>2</sup>
			Min	Max	Unit	
On State Collector Current	$I_{C(ON)}$	$V_{CE} = 5 V, I_F = 1 mA, I_B=0$	2		mA	0.03
Current Transfer Ratio	CTR1	$V_{CE} = 5V, I_F = 1mA$	200		%	2.85

However it seems that the component N°3 is the more sensitive one. Indeed components N°2 and N°4 are out of specification, for  $I_{C(ON)}$  and CTR1 parameters, at the final step  $7E12$ n/cm<sup>2</sup>.

This sensitivity difference cannot be explained by a disparity in date code as all the three devices tested come from the same DC1111 lot.

- Average drift current transfer ratio are described in next table for each irradiation step and CTR configuration

PARAMETERS	SYMBOL	UNIT	STEP IRRADIATION					
			$0E10$ n/cm <sup>2</sup>	$5E10$ n/cm <sup>2</sup>	$1E11$ n/cm <sup>2</sup>	$5E11$ n/cm <sup>2</sup>	$1E12$ n/cm <sup>2</sup>	$7E12$ n/cm <sup>2</sup>
Average drift Current Transfer Ratio	$\overline{\Delta CTR1}$	%	0.00E+00	1.17E-01	1.19E-01	1.55E-01	1.95E-01	6.20E-01
	$\overline{\Delta CTR2}$	%	0.00E+00	9.15E-02	9.35E-02	1.17E-01	1.44E-01	4.72E-01
	$\overline{\Delta CTR3}$	%	0.00E+00	1.42E-02	1.55E-02	2.74E-02	4.22E-02	2.58E-01
	$\overline{\Delta CTR4}$	%	0.00E+00	6.92E-04	7.34E-04	1.09E-03	1.50E-03	8.74E-03
	$\overline{\Delta CTR5}$	%	0.00E+00	5.48E-02	5.66E-02	7.14E-02	8.61E-02	2.51E-01

- CTR4 configuration ( $V_{ce} = 5V$ ;  $I_f = 50 mA$ ) exhibits the smallest parameter drift at all steps.
- Conversely, CRT1 configuration ( $V_{ce} = 5V$ ;  $I_f = 1 mA$ ) exhibits the greater parameter drift.
- CTR1 configuration is the only one specified [RD1]. In accordance with the value given by the datasheet, CTR1 configuration is out of specification at step  $5E10$ n/cm<sup>2</sup>.

## 9 DETAILED TESTS RESULTS

The pre and post radiation test results are shown graphically in the following pages (9-2 to 9-18). The data is displayed in the following tables and graphs.

These graphs show parameter's shifts observed during the neutron testing sequence. The Control sample results are shown on each graph (black curve).

When available in the device data-sheet/specification, the maximum/minimum/typical values are also shown (red dotted line).

The tables include drift calculation between each measurement step and the "0" neutrons/cm<sup>2</sup> step.

For CTR values, the formula used is:

$$\text{Drift} = \frac{1}{\text{measurement (X neutrons /cm}^2\text{)}} - \frac{1}{\text{measurement (0 neutrons /cm}^2\text{)}}$$

For the other measurements the formula used is:

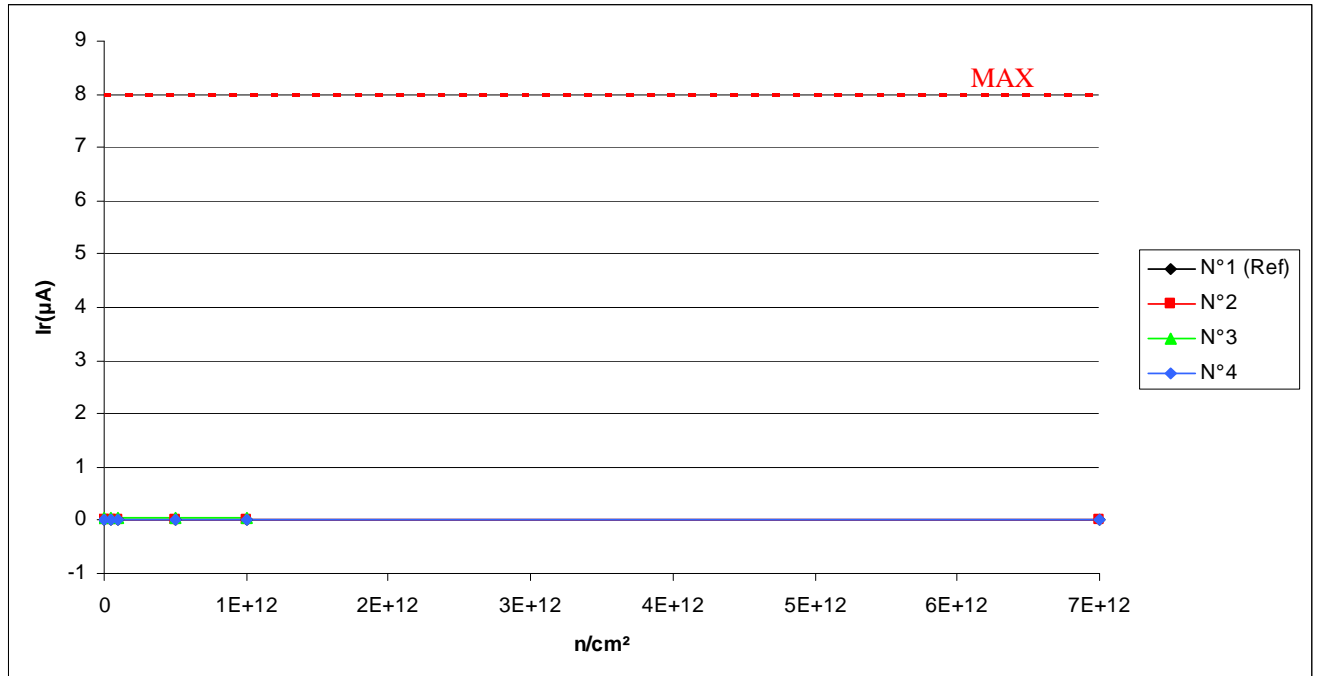
$$\text{Drift value} = \text{measurement (X neutrons/cm}^2\text{)} - \text{measurement (0 neutrons/cm}^2\text{)}$$

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## 1. Ir

Ta=25°C; Vr=6V



Ir. (µA)

Max = 8.0

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	3.073E-4	1.991E-4	2.865E-4	2.115E-4	2.118E-4	3.231E-4
N° 2	1.965E-4	2.749E-4	2.859E-4	3.187E-4	3.382E-4	1.300E-3
N° 3	3.139E-2	3.739E-2	3.474E-2	3.836E-2	4.252E-2	3.649E-2
N° 4	2.617E-4	2.870E-4	3.639E-4	3.727E-4	3.950E-4	1.139E-3

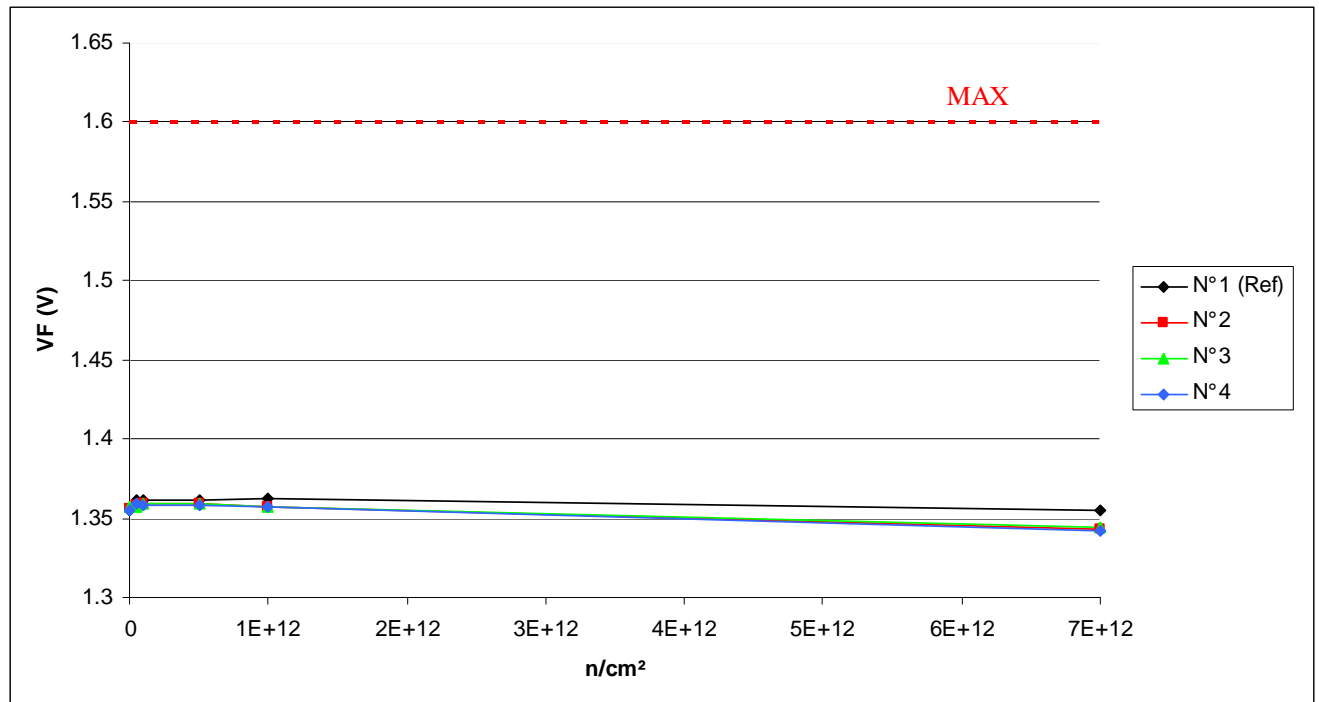
Delta [Ir]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-1.082E-4	-2.078E-5	-9.580E-5	-9.547E-5	1.581E-5
N° 2	---	7.843E-5	8.940E-5	1.222E-4	1.417E-4	1.103E-3
N° 3	---	6.004E-3	3.355E-3	6.971E-3	1.113E-2	5.106E-3
N° 4	---	2.529E-5	1.022E-4	1.110E-4	1.333E-4	8.768E-4
Average	---	2.036E-3	1.182E-3	2.401E-3	3.802E-3	2.362E-3
σ	---	3.437E-3	1.882E-3	3.957E-3	6.347E-3	2.379E-3
Average+3σ	---	1.235E-2	6.828E-3	1.427E-2	2.284E-2	9.500E-3
Average-3σ	---	-8.274E-3	-4.463E-3	-9.470E-3	-1.524E-2	-4.775E-3



## 2. VF

Ta=25°C; If=10mA



VF. (V)

Max = 1.6

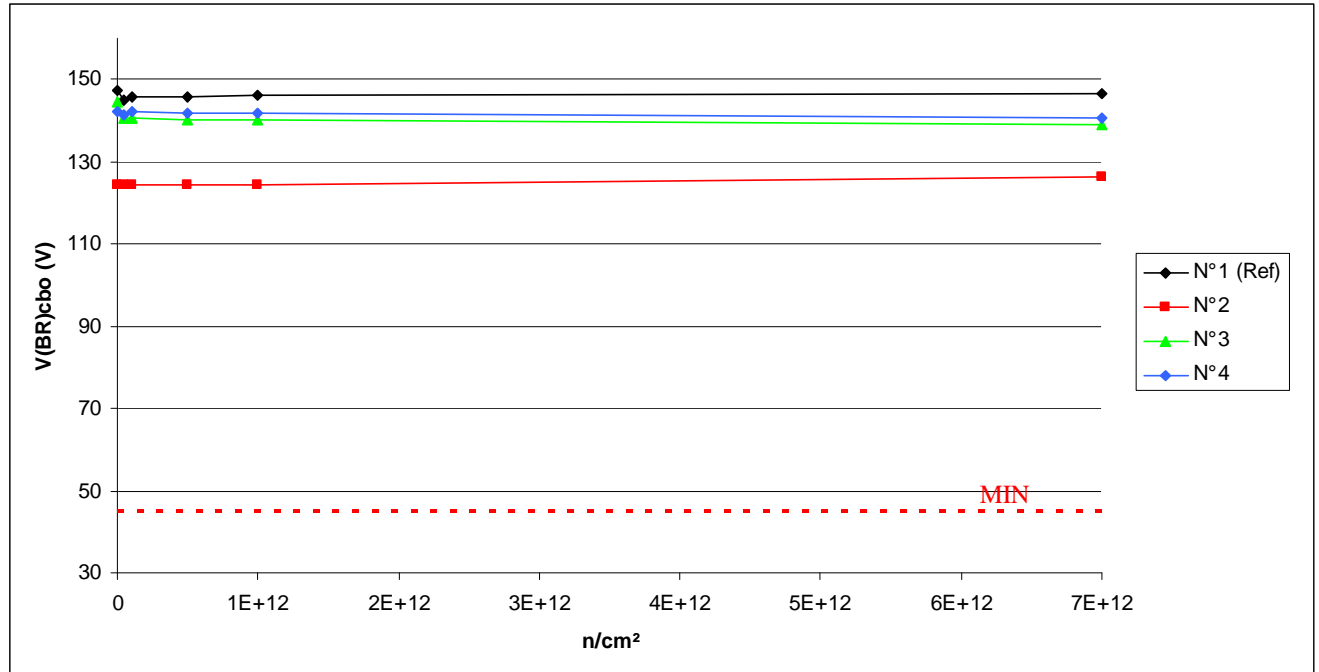
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1.355	1.361	1.361	1.361	1.362	1.355
N° 2	1.356	1.358	1.359	1.359	1.357	1.343
N° 3	1.357	1.357	1.359	1.359	1.357	1.344
N° 4	1.355	1.359	1.358	1.358	1.357	1.342

Delta [VF]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	6.103E-3	5.932E-3	5.444E-3	6.295E-3	1.280E-4
N° 2	---	1.422E-3	3.064E-3	2.624E-3	1.006E-3	-1.328E-2
N° 3	---	7.630E-4	2.491E-3	2.499E-3	8.350E-4	-1.306E-2
N° 4	---	4.117E-3	2.754E-3	3.495E-3	1.975E-3	-1.251E-2
Average	---	2.101E-3	2.770E-3	2.873E-3	1.272E-3	-1.295E-2
σ	---	1.777E-3	2.868E-4	5.426E-4	6.148E-4	4.002E-4
Average+3σ	---	7.432E-3	3.630E-3	4.500E-3	3.116E-3	-1.175E-2
Average-3σ	---	-3.230E-3	1.909E-3	1.245E-3	-5.724E-4	-1.415E-2

### 3. V(BR)cbo

Ta=25°C; Ic=100μA; Ib=0; If=0



V(BR)cbo . (V)

Min = 45.0

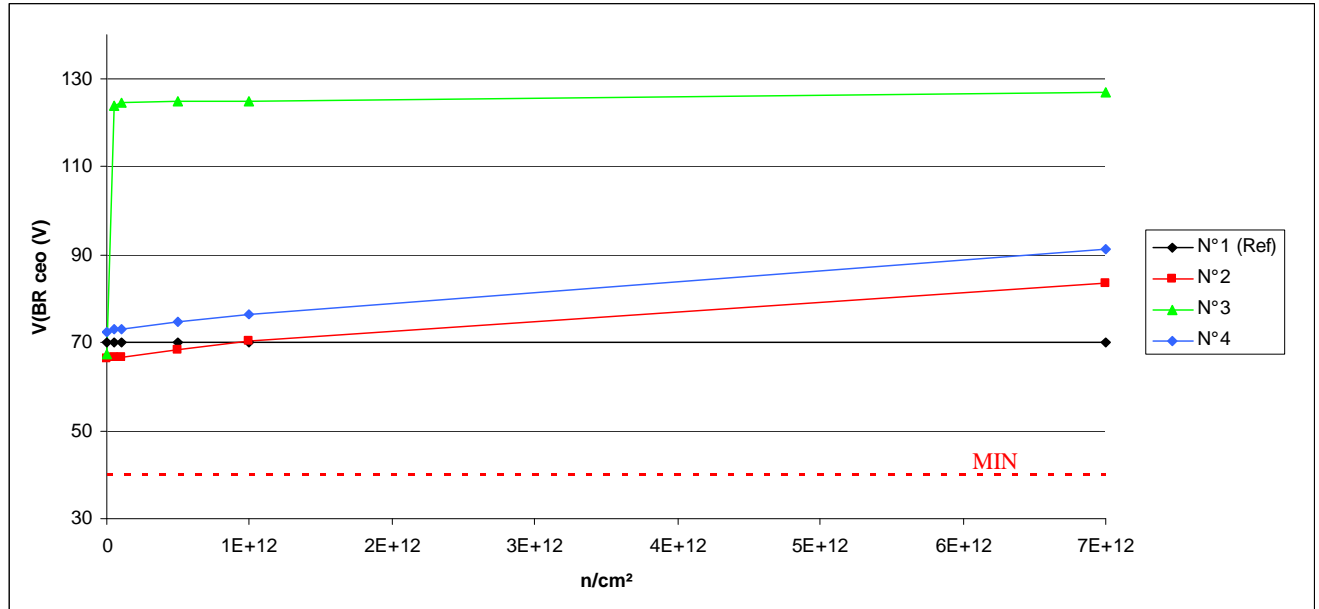
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	147.4	145.1	145.7	145.9	146.0	146.4
N° 2	124.2	124.2	124.2	124.4	124.5	126.3
N° 3	144.4	140.5	140.5	140.3	140.1	139.1
N° 4	142.0	141.5	142.1	141.9	141.9	140.5

Delta [V(BR)cbo]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-2.309E+0	-1.665E+0	-1.470E+0	-1.426E+0	-9.669E-1
N° 2	---	9.800E-3	1.150E-2	1.452E-1	2.657E-1	2.113E+0
N° 3	---	-3.954E+0	-3.960E+0	-4.142E+0	-4.327E+0	-5.370E+0
N° 4	---	-4.514E-1	1.298E-1	-8.580E-2	-1.142E-1	-1.451E+0
Average (ON)	---	-1.465E+0	-1.273E+0	-1.361E+0	-1.392E+0	-1.570E+0
σ (ON)	---	2.168E+0	2.328E+0	2.411E+0	2.549E+0	3.743E+0
Average+3σ (ON)	---	5.038E+0	5.710E+0	5.873E+0	6.255E+0	9.658E+0
Average-3σ (ON)	---	-7.968E+0	-8.256E+0	-8.595E+0	-9.039E+0	-1.280E+1

#### 4. V(BR)ceo

Ta=25°C; Ic=1mA; Ib=0; If=0



V(BR)ceo . (V)

Min = 40.0

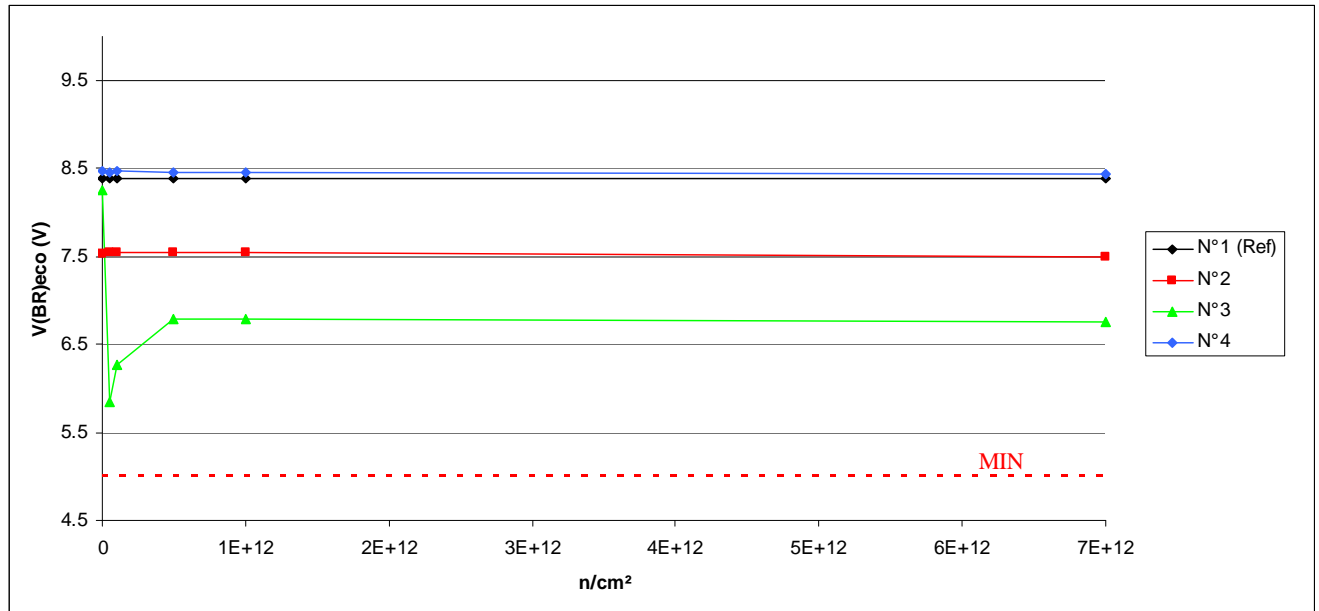
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	69.9	69.9	69.9	69.9	69.9	70.0
N° 2	66.4	66.7	66.8	68.5	70.2	83.6
N° 3	67.4	124.0	124.6	124.7	124.9	126.8
N° 4	72.5	72.9	73.0	74.7	76.5	91.2

Delta [V(BR)ceo]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-3.870E-3	-2.214E-2	-1.937E-2	-2.430E-2	7.363E-2
N° 2	---	2.475E-1	4.248E-1	2.125E+0	3.810E+0	1.719E+1
N° 3	---	5.662E+1	5.718E+1	5.734E+1	5.747E+1	5.940E+1
N° 4	---	3.319E-1	4.777E-1	2.208E+0	3.962E+0	1.871E+1
Average (ON)	---	1.907E+1	1.936E+1	2.056E+1	2.175E+1	3.177E+1
σ (ON)	---	3.252E+1	3.275E+1	3.185E+1	3.094E+1	2.394E+1
Average+3σ (ON)	---	1.166E+2	1.176E+2	1.161E+2	1.146E+2	1.036E+2
Average-3σ (ON)	---	-7.850E+1	-7.890E+1	-7.500E+1	-7.106E+1	-4.005E+1

## 5. V(BR)<sub>eco</sub>

T<sub>a</sub>=25°C; I<sub>c</sub>=0; I<sub>e</sub>=100μA; I<sub>f</sub>=0



V(BR)<sub>eco</sub> . (V)

Min = 5.0

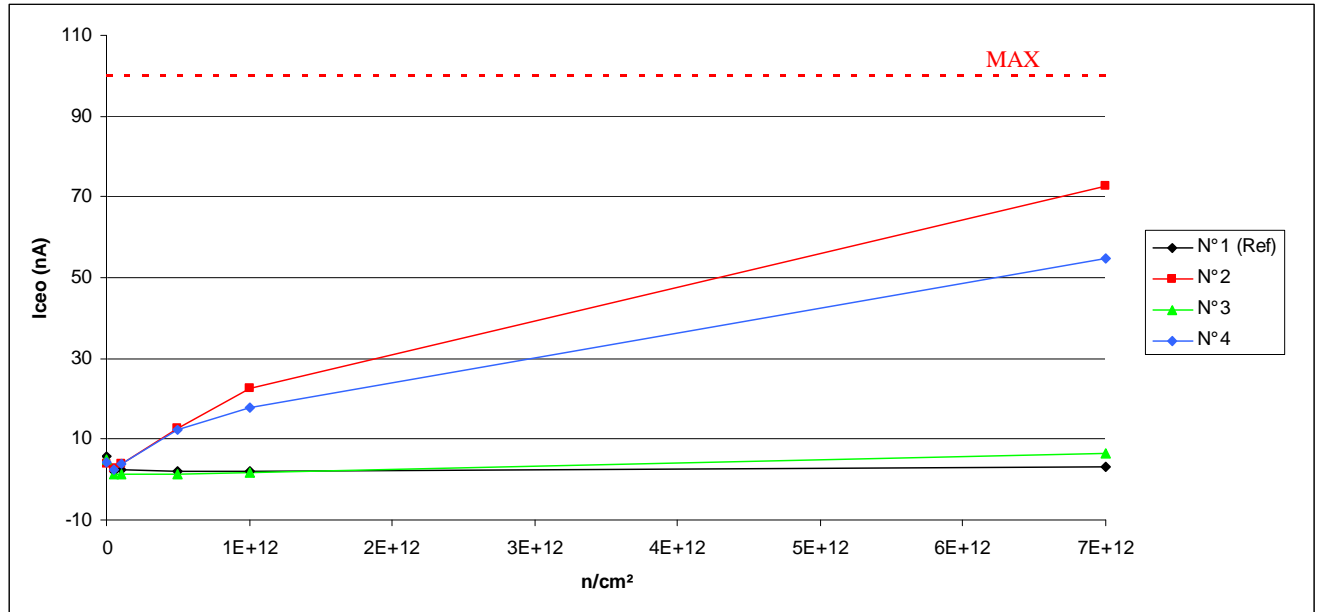
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	8.386	8.388	8.388	8.388	8.388	8.387
N° 2	7.534	7.547	7.551	7.551	7.547	7.501
N° 3	8.251	5.853	6.262	6.783	6.781	6.760
N° 4	8.463	8.460	8.463	8.453	8.448	8.435

Delta [V(BR)<sub>eco</sub>]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.484E-3	1.396E-3	1.289E-3	1.522E-3	5.110E-4
N° 2	---	1.376E-2	1.693E-2	1.748E-2	1.358E-2	-3.309E-2
N° 3	---	-2.398E+0	-1.989E+0	-1.468E+0	-1.470E+0	-1.491E+0
N° 4	---	-2.827E-3	1.330E-4	-9.142E-3	-1.415E-2	-2.725E-2
Average (ON)	---	-7.957E-1	-6.572E-1	-4.865E-1	-4.902E-1	-5.172E-1
σ (ON)	---	1.388E+0	1.153E+0	8.500E-1	8.488E-1	8.435E-1
Average+3σ (ON)	---	3.367E+0	2.802E+0	2.063E+0	2.056E+0	2.013E+0
Average-3σ (ON)	---	-4.959E+0	-4.117E+0	-3.036E+0	-3.036E+0	-3.048E+0

## 6. Iceo

Ta=25°C; Vce=20V; If=0; Ib=0



**Iceo . (nA)**

**Max = 100.0**

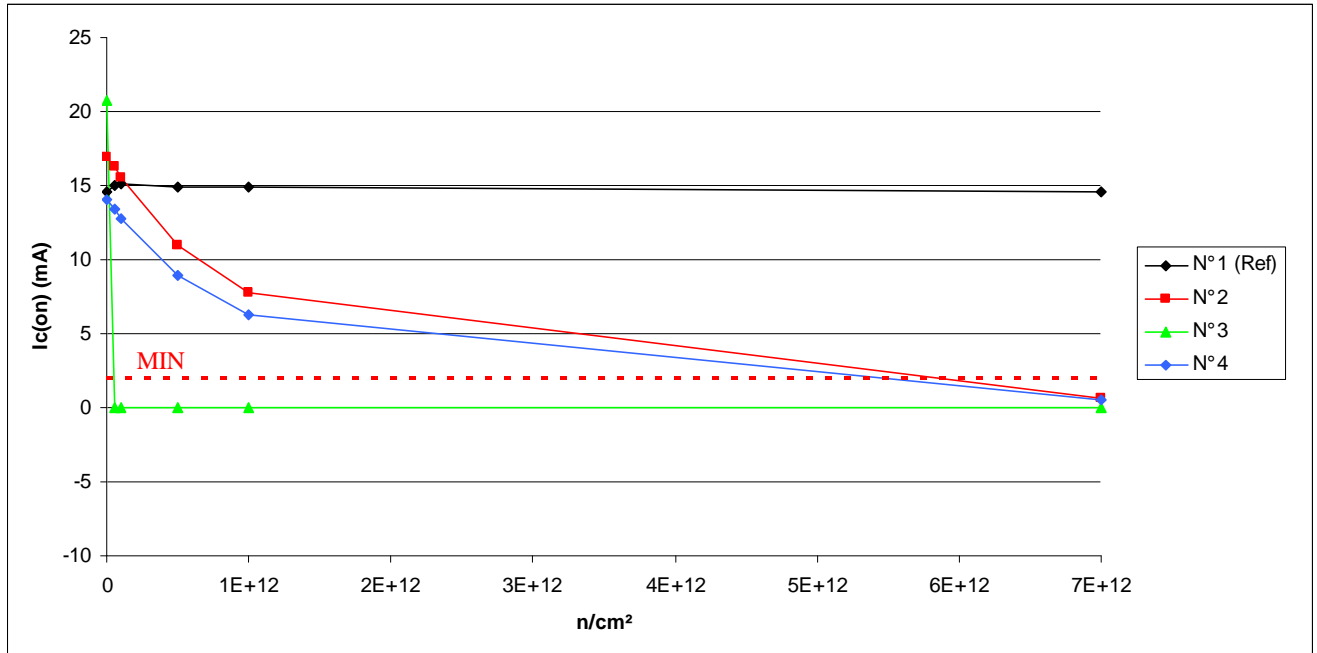
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	5.785	2.052	2.530	1.950	2.044	3.143
N° 2	4.028	2.722	3.910	12.527	22.678	72.569
N° 3	4.831	1.166	1.360	1.453	1.815	6.514
N° 4	4.215	2.597	3.951	12.497	17.751	54.595

**Delta [Iceo]**

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-3.732E+0	-3.255E+0	-3.835E+0	-3.740E+0	-2.642E+0
N° 2	---	-1.306E+0	-1.181E-1	8.499E+0	1.865E+1	6.854E+1
N° 3	---	-3.665E+0	-3.471E+0	-3.378E+0	-3.016E+0	1.683E+0
N° 4	---	-1.618E+0	-2.641E-1	8.282E+0	1.354E+1	5.038E+1
Average (ON)	---	-2.196E+0	-1.284E+0	4.467E+0	9.723E+0	4.020E+1
σ (ON)	---	1.281E+0	1.895E+0	6.795E+0	1.132E+1	3.457E+1
Average+3σ (ON)	---	1.647E+0	4.400E+0	2.485E+1	4.370E+1	1.439E+2
Average-3σ (ON)	---	-6.039E+0	-6.969E+0	-1.592E+1	-2.425E+1	-6.351E+1

## 7. Ic(on)

Ta=25°C; If=1mA; Ib=0; Vce = 5V



Ic(on) . (mA)

Min = 2.0

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	14.522	14.992	15.108	14.885	14.935	14.525
N° 2	16.937	16.227	15.563	10.956	7.770	0.657
N° 3	20.787	0.028	0.028	0.021	0.017	0.005
N° 4	14.009	13.430	12.765	8.923	6.228	0.485

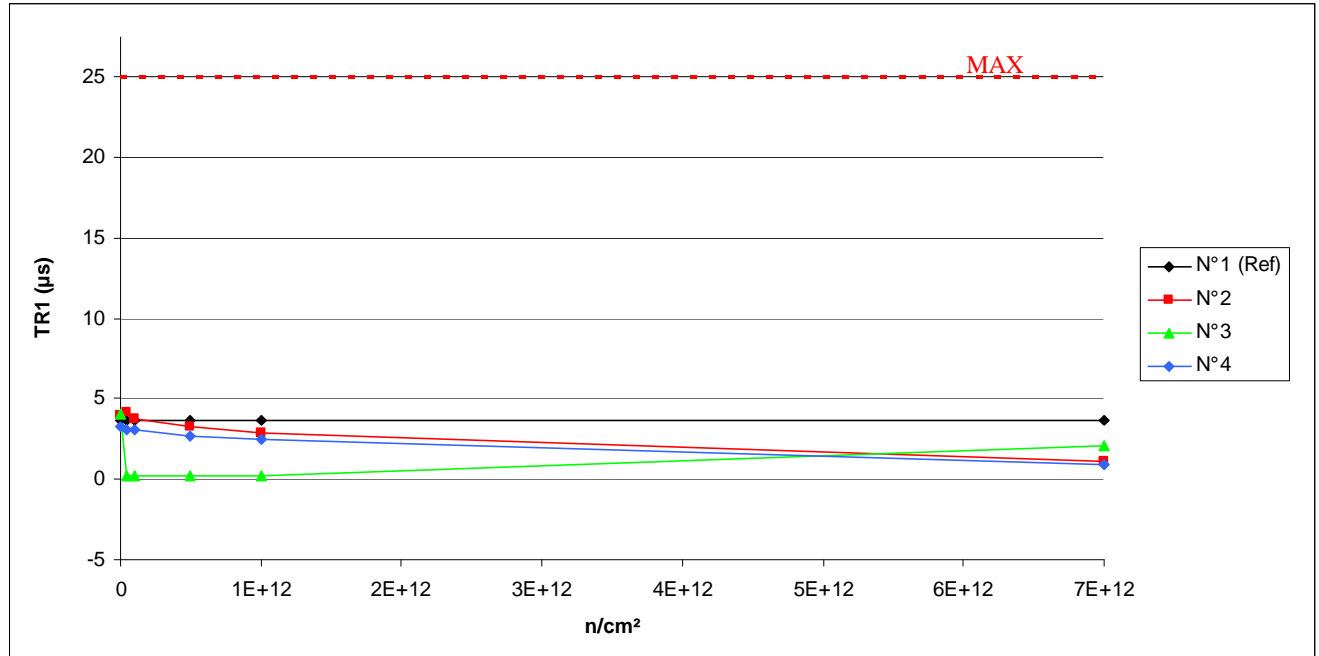
Delta [Ic(on)]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	4.699E-1	5.857E-1	3.625E-1	4.127E-1	2.630E-3
N° 2	---	-7.094E-1	-1.373E+0	-5.980E+0	-9.166E+0	-1.628E+1
N° 3	---	-2.076E+1	-2.076E+1	-2.077E+1	-2.077E+1	-2.078E+1
N° 4	---	-5.789E-1	-1.243E+0	-5.085E+0	-7.780E+0	-1.352E+1
Average (ON)	---	-7.349E+0	-7.792E+0	-1.061E+1	-1.257E+1	-1.686E+1
σ (ON)	---	1.161E+1	1.123E+1	8.806E+0	7.134E+0	3.664E+0
Average+3σ (ON)	---	2.749E+1	2.590E+1	1.581E+1	8.828E+0	-5.870E+0
Average-3σ (ON)	---	-4.219E+1	-4.148E+1	-3.703E+1	-3.397E+1	-2.785E+1



## 8. TR1

Ta=25°C; Vcc=10V; If=5mA; RL=100 Ohms ; Ib=0



**TR1. (µs)** **Max = 25.0**

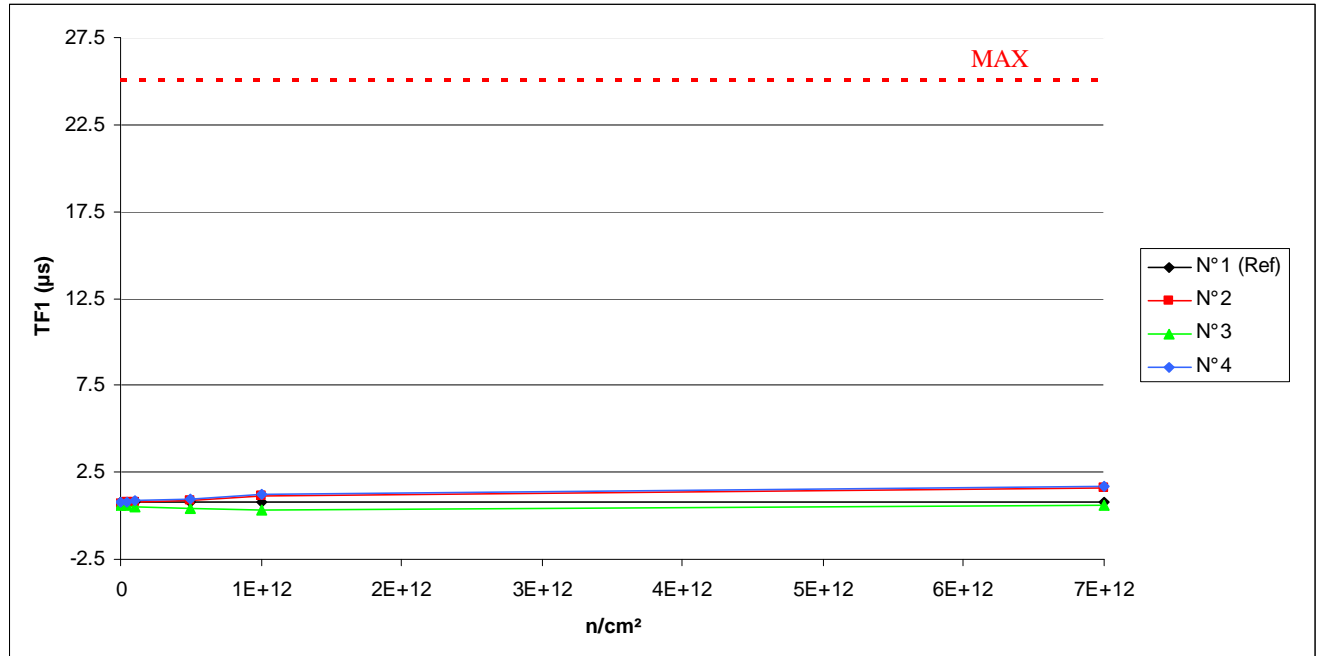
	0.n/cm <sup>2</sup>	5E10.n/cm <sup>2</sup>	1E11.n/cm <sup>2</sup>	5E11.n/cm <sup>2</sup>	1E12.n/cm <sup>2</sup>	7E12.n/cm <sup>2</sup>
N° 1 (Ref)	3.64	3.68	3.64	3.64	3.68	3.64
N° 2	3.96	4.16	3.80	3.24	2.92	1.08
N° 3	4.04	0.20	0.21	0.26	0.20	2.12
N° 4	3.24	3.12	3.08	2.68	2.48	0.88

**Delta [TR1]**

	0.n/cm <sup>2</sup>	5E10.n/cm <sup>2</sup>	1E11.n/cm <sup>2</sup>	5E11.n/cm <sup>2</sup>	1E12.n/cm <sup>2</sup>	7E12.n/cm <sup>2</sup>
N° 1 (Ref)	---	4.000E-2	0.000E+0	0.000E+0	4.000E-2	0.000E+0
N° 2	---	2.000E-1	-1.600E-1	-7.200E-1	-1.040E+0	-2.880E+0
N° 3	---	-3.840E+0	-3.830E+0	-3.780E+0	-3.840E+0	-1.920E+0
N° 4	---	-1.200E-1	-1.600E-1	-5.600E-1	-7.600E-1	-2.360E+0
Average (ON)	---	-1.253E+0	-1.383E+0	-1.687E+0	-1.880E+0	-2.387E+0
σ (ON)	---	2.246E+0	2.119E+0	1.815E+0	1.703E+0	4.806E-1
Average+3σ (ON)	---	5.484E+0	4.973E+0	3.757E+0	3.230E+0	-9.450E-1
Average-3σ (ON)	---	-7.991E+0	-7.740E+0	-7.131E+0	-6.990E+0	-3.828E+0

## 9. TF1

Ta=25°C; Vcc=10V; If=5mA; RL=100 Ohms ; Ib=0



**TF1. (µs) Max = 25.0**

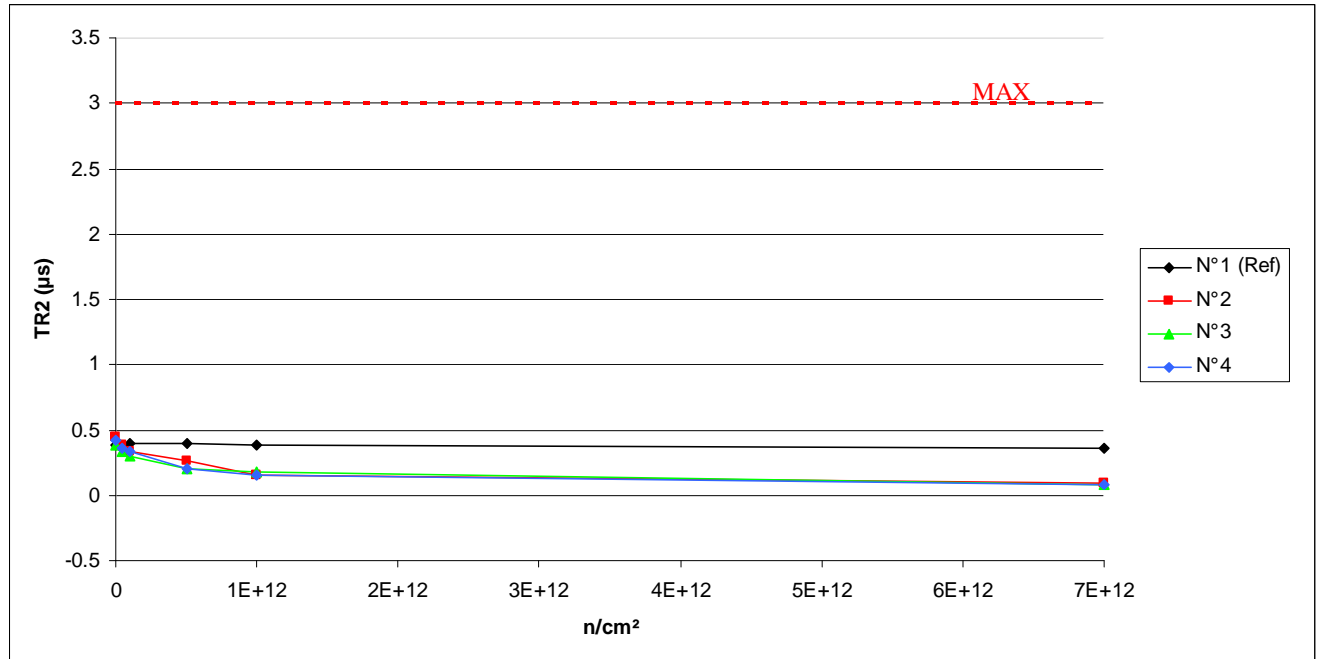
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	0.80	0.80	0.80	0.80	0.80	0.80
N° 2	0.72	0.76	0.76	0.88	1.12	1.60
N° 3	0.64	0.56	0.48	0.38	0.32	0.64
N° 4	0.80	0.80	0.84	0.96	1.24	1.72

**Delta [TF1]**

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	0.000E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0
N° 2	---	4.000E-2	4.000E-2	1.600E-1	4.000E-1	8.800E-1
N° 3	---	-8.000E-2	-1.600E-1	-2.600E-1	-3.200E-1	0.000E+0
N° 4	---	0.000E+0	4.000E-2	1.600E-1	4.400E-1	9.200E-1
Average (ON)	---	-1.333E-2	-2.667E-2	2.000E-2	1.733E-1	6.000E-1
σ (ON)	---	6.110E-2	1.155E-1	2.425E-1	4.277E-1	5.200E-1
Average+3σ (ON)	---	1.700E-1	3.197E-1	7.475E-1	1.456E+0	2.160E+0
Average-3σ (ON)	---	-1.966E-1	-3.731E-1	-7.075E-1	-1.110E+0	-9.600E-1

## 10.TR2

Ta=25°C; Vcc=10V; If=5mA; RL=100 Ohms ; Ie=0



**TR2. (µs) Max = 3.0**

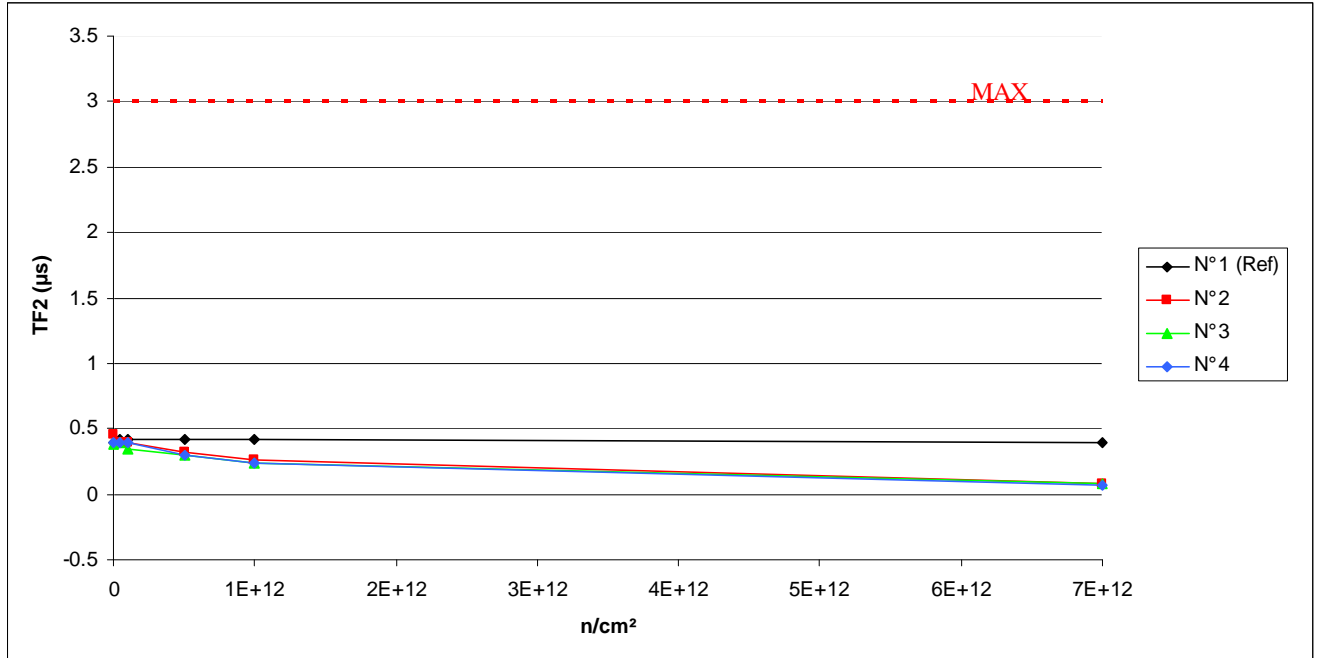
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	0.38	0.36	0.40	0.40	0.38	0.36
N° 2	0.44	0.38	0.34	0.26	0.16	0.09
N° 3	0.38	0.34	0.30	0.20	0.18	0.08
N° 4	0.42	0.36	0.34	0.20	0.16	0.08

**Delta [TR2]**

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-2.000E-2	2.000E-2	2.000E-2	0.000E+0	-2.000E-2
N° 2	---	-6.000E-2	-1.000E-1	-1.800E-1	-2.800E-1	-3.500E-1
N° 3	---	-4.000E-2	-8.000E-2	-1.800E-1	-2.000E-1	-3.000E-1
N° 4	---	-6.000E-2	-8.000E-2	-2.200E-1	-2.600E-1	-3.380E-1
Average (ON)	---	-5.333E-2	-8.667E-2	-1.933E-1	-2.467E-1	-3.293E-1
σ (ON)	---	1.155E-2	1.155E-2	2.309E-2	4.163E-2	2.610E-2
Average+3σ (ON)	---	-1.869E-2	-5.203E-2	-1.241E-1	-1.218E-1	-2.510E-1
Average-3σ (ON)	---	-8.797E-2	-1.213E-1	-2.626E-1	-3.716E-1	-4.076E-1

## 11.TF2

Ta=25°C; Vcc=10V; If=5mA; RL=100 Ohms ; Ie=0



**TF2. (µs) Max = 3.0**

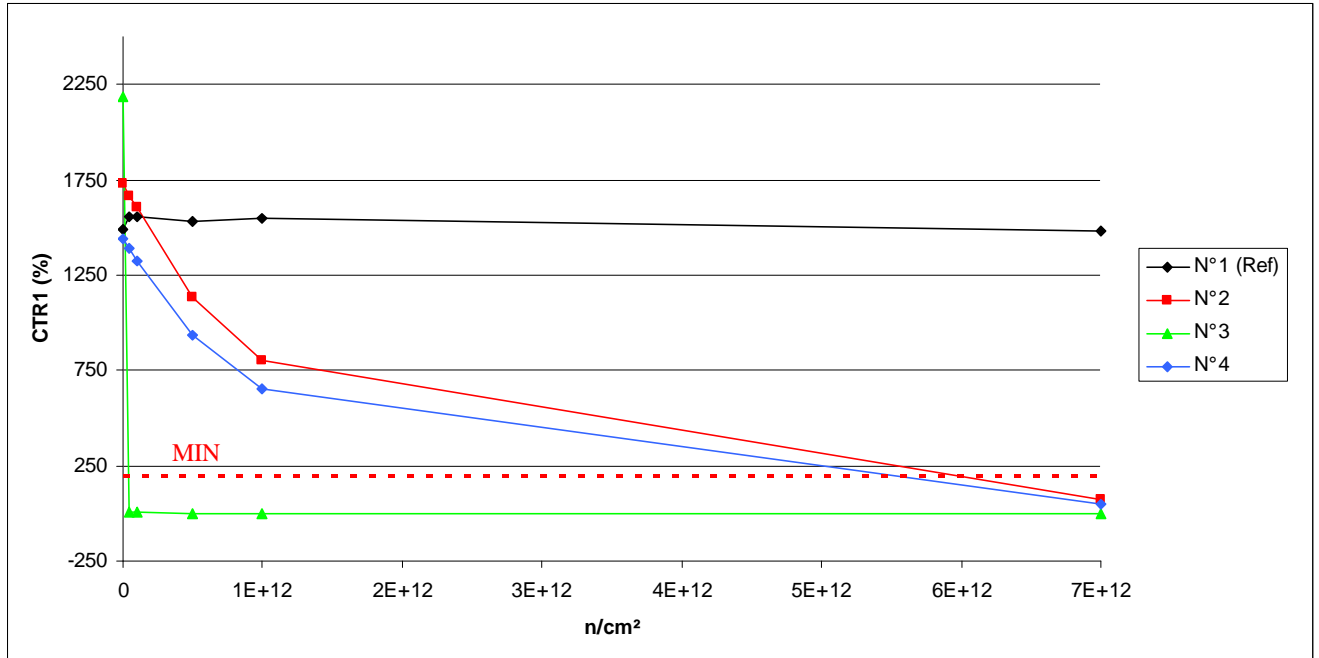
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	0.40	0.42	0.42	0.42	0.42	0.40
N° 2	0.46	0.40	0.40	0.32	0.26	0.08
N° 3	0.38	0.40	0.34	0.30	0.24	0.08
N° 4	0.40	0.40	0.40	0.30	0.24	0.07

**Delta [TF2]**

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	2.000E-2	2.000E-2	2.000E-2	2.000E-2	0.000E+0
N° 2	---	-6.000E-2	-6.000E-2	-1.400E-1	-2.000E-1	-3.800E-1
N° 3	---	2.000E-2	-4.000E-2	-8.000E-2	-1.400E-1	-3.000E-1
N° 4	---	0.000E+0	0.000E+0	-1.000E-1	-1.600E-1	-3.280E-1
Average (ON)	---	-1.333E-2	-3.333E-2	-1.067E-1	-1.667E-1	-3.360E-1
σ (ON)	---	4.163E-2	3.055E-2	3.055E-2	3.055E-2	4.060E-2
Average+3σ (ON)	---	1.116E-1	5.832E-2	-1.502E-2	-7.502E-2	-2.142E-1
Average-3σ (ON)	---	-1.382E-1	-1.250E-1	-1.983E-1	-2.583E-1	-4.578E-1

## 12.CTR1

Ta=25°C; Vce=5V; If=1mA



CTR1 . (%)

Min = 200.0

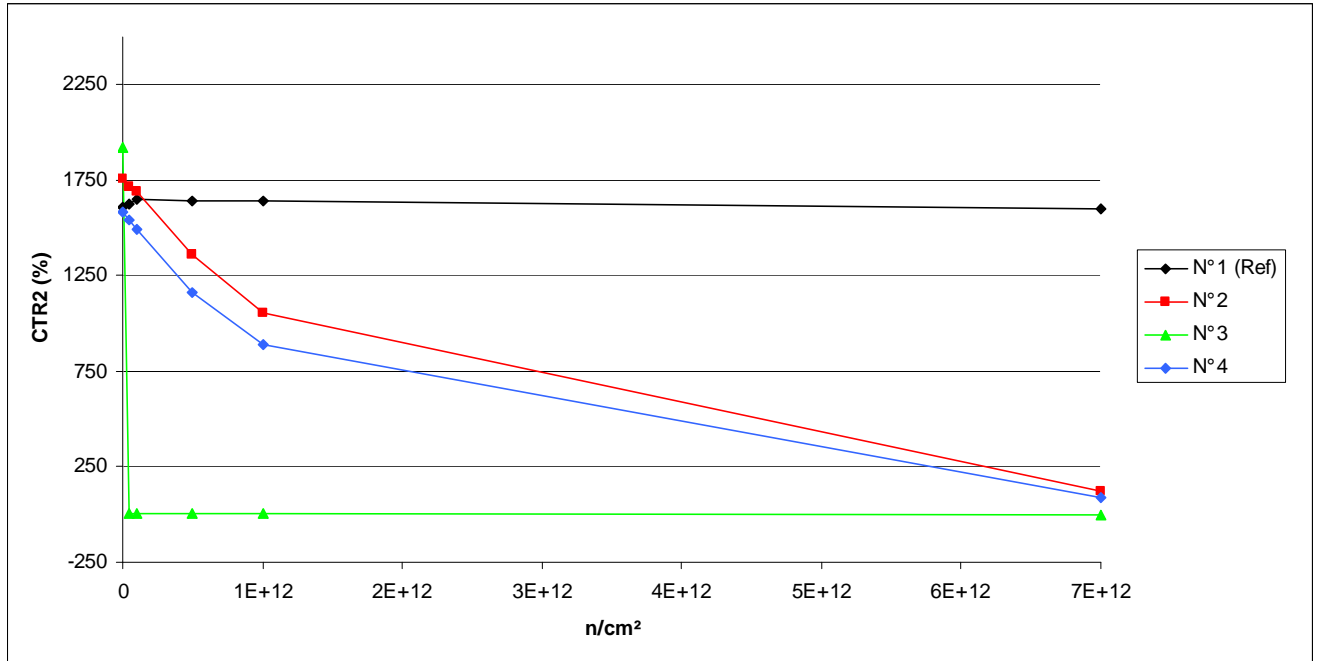
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1490.203	1552.052	1557.253	1534.095	1543.954	1484.299
N° 2	1729.920	1659.265	1601.539	1135.181	805.428	71.232
N° 3	2185.238	2.853	2.796	2.151	1.716	0.547
N° 4	1435.954	1393.343	1319.855	931.510	651.376	51.853

1/Delta [CTR1]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-2.674E-5	-2.889E-5	-1.920E-5	-2.336E-5	2.669E-6
N° 2	---	2.462E-5	4.634E-5	3.029E-4	6.635E-4	1.346E-2
N° 3	---	3.500E-1	3.572E-1	4.645E-1	5.824E-1	1.828E+0
N° 4	---	2.130E-5	6.126E-5	3.771E-4	8.388E-4	1.859E-2
Average (ON)	---	1.167E-1	1.191E-1	1.550E-1	1.946E-1	6.200E-1
σ (ON)	---	2.021E-1	2.062E-1	2.680E-1	3.358E-1	1.046E+0
Average+3σ (ON)	---	7.229E-1	7.378E-1	9.589E-1	1.202E+0	3.758E+0
Average-3σ (ON)	---	-4.895E-1	-4.995E-1	-6.488E-1	-8.128E-1	-2.518E+0

### 13.CTR2

Ta=25°C; Vce=5V; If=2mA



#### CTR2. (%)

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1606.988	1621.436	1645.501	1637.359	1640.876	1599.400
N° 2	1758.691	1719.139	1692.725	1361.033	1051.600	123.808
N° 3	1922.043	3.638	3.560	2.860	2.323	0.715
N° 4	1582.126	1543.718	1490.027	1164.009	885.581	90.143

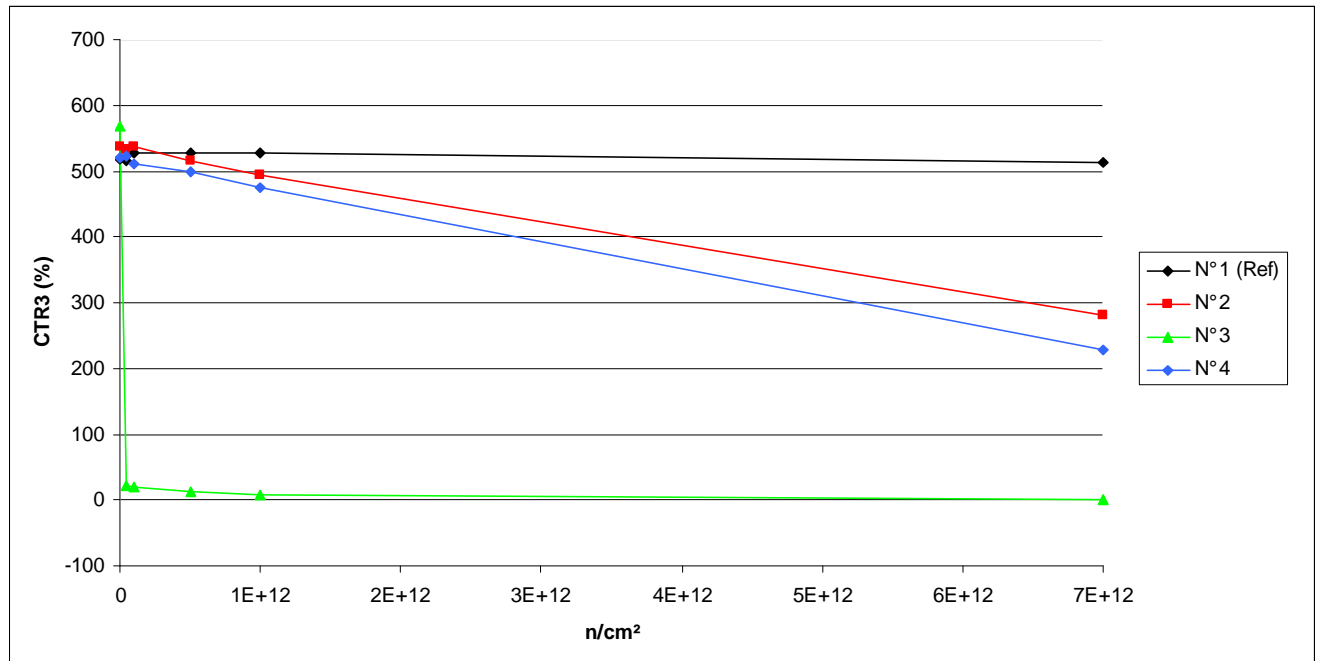
#### 1/Delta [CTR2]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-5.545E-6	-1.456E-5	-1.154E-5	-1.285E-5	2.952E-6
N° 2	---	1.308E-5	2.216E-5	1.661E-4	3.823E-4	7.508E-3
N° 3	---	2.743E-1	2.803E-1	3.491E-1	4.300E-1	1.398E+0
N° 4	---	1.573E-5	3.907E-5	2.270E-4	4.971E-4	1.046E-2
Average (ON)	---	9.145E-2	9.347E-2	1.165E-1	1.436E-1	4.721E-1
σ (ON)	---	1.584E-1	1.618E-1	2.015E-1	2.480E-1	8.021E-1
Average+3σ (ON)	---	5.666E-1	5.790E-1	7.209E-1	8.876E-1	2.878E+0
Average-3σ (ON)	---	-3.837E-1	-3.921E-1	-4.879E-1	-6.004E-1	-1.934E+0



## 14.CTR3

Ta=25°C; Vce=5V; If=10mA



### CTR3. (%)

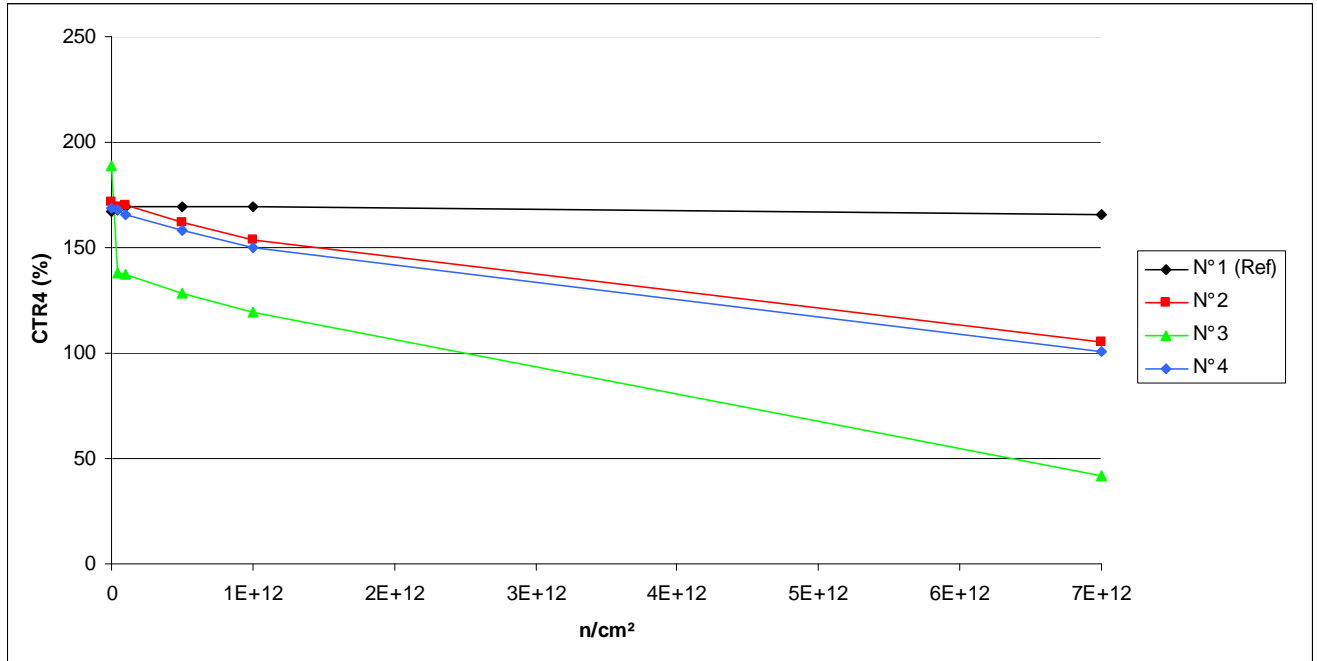
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	518.805	514.883	527.907	527.596	527.961	513.413
N° 2	538.289	533.040	536.547	515.335	492.910	280.500
N° 3	567.192	22.585	20.763	11.920	7.807	1.299
N° 4	521.547	521.879	511.584	497.951	475.400	228.072

### 1/Delta [CTR3]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.468E-5	-3.324E-5	-3.212E-5	-3.343E-5	2.024E-5
N° 2	---	1.829E-5	6.031E-6	8.275E-5	1.710E-4	1.707E-3
N° 3	---	4.251E-2	4.640E-2	8.213E-2	1.263E-1	7.682E-1
N° 4	---	-1.219E-6	3.734E-5	9.086E-5	1.861E-4	2.467E-3
Average (ON)	---	1.418E-2	1.548E-2	2.743E-2	4.223E-2	2.575E-1
σ (ON)	---	2.454E-2	2.678E-2	4.737E-2	7.283E-2	4.423E-1
Average+3σ (ON)	---	8.780E-2	9.581E-2	1.695E-1	2.607E-1	1.584E+0
Average-3σ (ON)	---	-5.945E-2	-6.485E-2	-1.147E-1	-1.763E-1	-1.069E+0

## 15.CTR4

Ta=25°C; Vce=5V; If=50mA



### CTR4. (%)

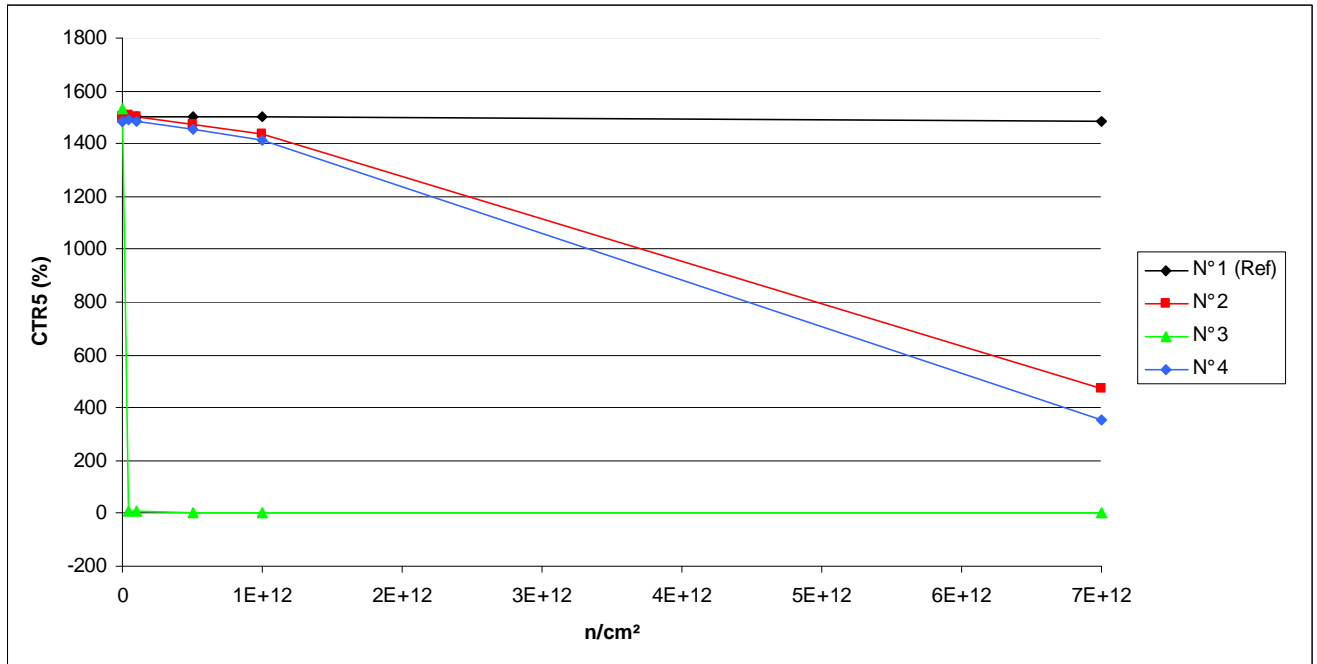
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	167.505	167.861	169.360	169.204	169.274	165.852
N° 2	171.992	169.696	170.121	161.871	153.751	105.276
N° 3	189.071	137.940	136.972	128.157	119.331	41.960
N° 4	168.860	167.826	165.374	158.555	150.333	101.032

### 1/Delta [CTR4]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-1.265E-5	-6.537E-5	-5.993E-5	-6.238E-5	5.951E-5
N° 2	---	7.866E-5	6.394E-5	3.635E-4	6.898E-4	3.685E-3
N° 3	---	1.961E-3	2.012E-3	2.514E-3	3.091E-3	1.854E-2
N° 4	---	3.649E-5	1.248E-4	3.849E-4	7.298E-4	3.976E-3
Average (ON)	---	6.919E-4	7.335E-4	1.087E-3	1.504E-3	8.735E-3
σ (ON)	---	1.099E-3	1.107E-3	1.235E-3	1.375E-3	8.496E-3
Average+3σ (ON)	---	3.988E-3	4.056E-3	4.794E-3	5.628E-3	3.422E-2
Average-3σ (ON)	---	-2.605E-3	-2.589E-3	-2.619E-3	-2.621E-3	-1.675E-2

## 16.CTR5

Ta=25°C; Vce=30V; If=5mA



### CTR5 . (%)

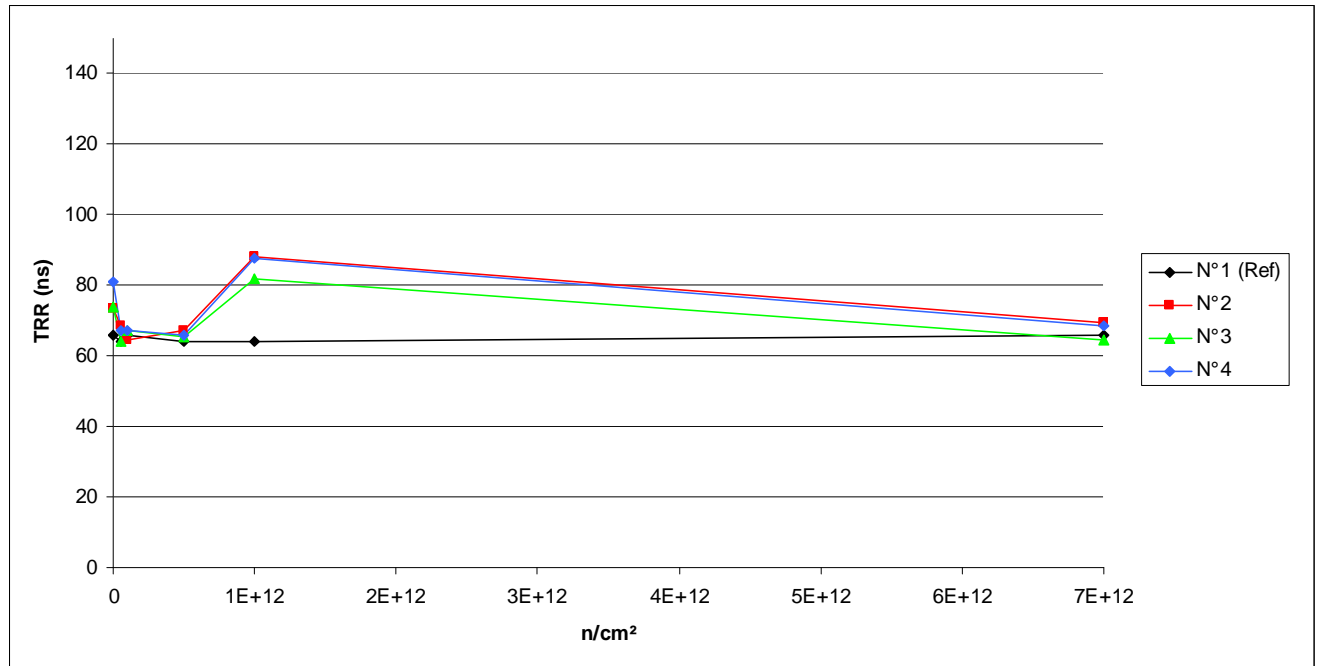
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1485.439	1503.230	1502.231	1503.254	1504.497	1487.411
N° 2	1500.923	1505.474	1502.008	1475.381	1434.403	475.057
N° 3	1533.101	6.064	5.868	4.653	3.863	1.331
N° 4	1486.462	1493.193	1485.521	1457.408	1411.073	351.234

### 1/Delta [CTR5]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-7.967E-6	-7.525E-6	-7.978E-6	-8.528E-6	-8.925E-7
N° 2	---	-2.014E-6	-4.813E-7	1.153E-5	3.090E-5	1.439E-3
N° 3	---	1.643E-1	1.698E-1	2.143E-1	2.582E-1	7.507E-1
N° 4	---	-3.033E-6	4.261E-7	1.341E-5	3.594E-5	2.174E-3
Average (ON)	---	5.475E-2	5.659E-2	7.143E-2	8.609E-2	2.514E-1
σ (ON)	---	9.484E-2	9.802E-2	1.237E-1	1.491E-1	4.324E-1
Average+3σ (ON)	---	3.393E-1	3.506E-1	4.425E-1	5.333E-1	1.549E+0
Average-3σ (ON)	---	-2.298E-1	-2.375E-1	-2.997E-1	-3.611E-1	-1.046E+0

## 17.TRR

Ta=25°C; If=5mA; RL=100Ohms ; Irec = 10% Irm



### TRR. (ns)

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	66.00	64.00	65.67	64.00	64.00	66.00
N° 2	73.27	68.63	64.71	67.33	88.00	69.42
N° 3	74.00	64.00	67.33	65.35	82.00	64.46
N° 4	81.19	67.33	67.21	66.00	87.60	68.63

### Delta [TRR]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-2.000E+0	-3.300E-1	-2.000E+0	-2.000E+0	0.000E+0
N° 2	---	-4.640E+0	-8.560E+0	-5.940E+0	1.473E+1	-3.850E+0
N° 3	---	-1.000E+1	-6.670E+0	-8.650E+0	8.000E+0	-9.540E+0
N° 4	---	-1.386E+1	-1.398E+1	-1.519E+1	6.410E+0	-1.256E+1
Average (ON)	---	-9.500E+0	-9.737E+0	-9.927E+0	9.713E+0	-8.650E+0
$\sigma$ (ON)	---	4.630E+0	3.794E+0	4.755E+0	4.417E+0	4.423E+0
Average+3 $\sigma$ (ON)	---	4.391E+0	1.647E+0	4.339E+0	2.296E+1	4.618E+0
Average-3 $\sigma$ (ON)	---	-2.339E+1	-2.112E+1	-2.419E+1	-3.537E+0	-2.192E+1