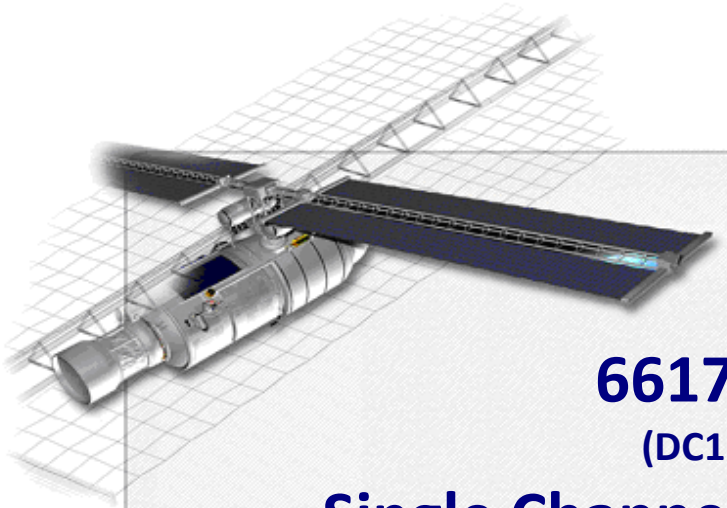
NEUTRONS DISPLACEMENT DAMAGE TEST REPORT



66179-002
(DC1124)
Single Channel Optocoupler
From
MICROPAC

TRAD/TN/66179/XXX1/ESA/YP/1104		Labège, March 5th, 2012
TRAD Tests & radiations — afaq ISO 9001 Qualité AFNOR CERTIFICATION		TRAD, Bât Gallium 907, Voie l'Occitane - 31670 LABEGE France ☏ : 05 61 00 95 60 Fax : 05 61 00 95 61 Email : trad@trad.fr Web Site: www.trad.fr SIRET 397 862 038 00056 - TVA FR59397862038
Written by	Verified by / Quality control	Approved by
A. SAMARAS **20/02/2012**	**M.SAUVAGNAC/Y.PADIE** **05/03/2012**	**C.CHATRY** **05/03/2012**
Issue : 0		
To: Marc POIZAT	Project/Program :	ESA Contract N°4000102571/10/NL/AF-Radiation Characterization of Laplace RH optocouplers, sensors and detectors

TABLE OF CONTENT

LIST OF FIGURES

1 INTRODUCTION

This report includes the test results of 66179-002, 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	ITP_TN_66179_MIC_ESA_1119, Iss.2, 27/06/11

2.2 Reference Documents

RD	3.	Datasheet 66179 by MICROPAC	GULL WING HERMETICALLY SEALED, SINGLE CHANNEL OPTOCOUPLER (Electrical Equivalent To 66099) dated 23/01/2007
RD	4.	MICROPAC certificate of traceability and conformance dated 25/07/2011	

3 DEVICE INFORMATION

3.1 Device description

This part is a Single channel radiation tolerant hermetic optocoupler. It is hermetically sealed into a 10 Pin Gull Wing package. The 66179 optocoupler contains a proton tolerant 660nm GaAlAs LED optically coupled to a silicon planar NPN Output phototransistor.

Type	66179-002
Manufacturer	MICROPAC
Function	Optocoupler
Package	10 Pin Gull Wing
Date Code	1124
Sample size	4 parts (3 test parts + 1 control sample)

3.2 Procurement information

75 parts reference 66179-002 were procured by TRAD and delivered by MICROPAC through its French distributor ISOTOPE ELECTRONICS.
Their quality level defined by the 002 extension number corresponds to a commercial standard operating in the temperature range of -55° to +100°C and temperature tested (hot & cold temperature) by the manufacturer prior delivery.
Parts were delivered separated in two lots (25 pcs and 50 pcs) from same date-code 1124 and together with a Certificate of Conformance [RD2].

3.3 External view

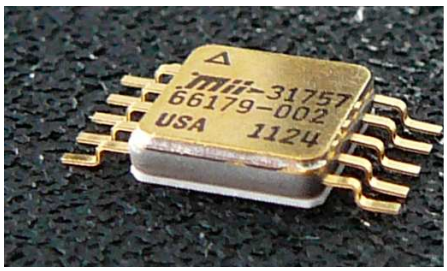


Figure 1: package marking

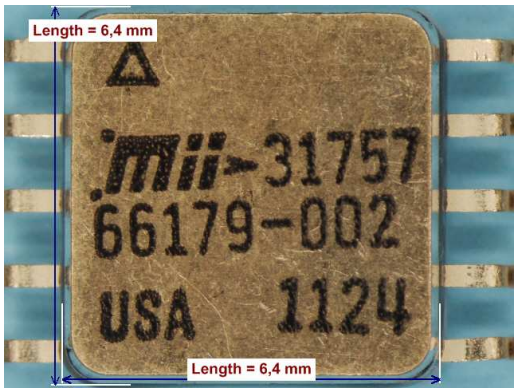


Figure 2: package marking

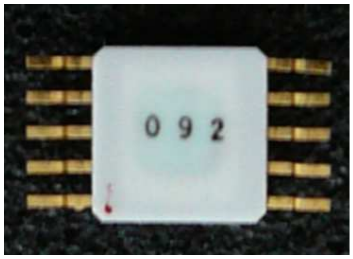


Figure 3: package back marking

3.4 Internal view

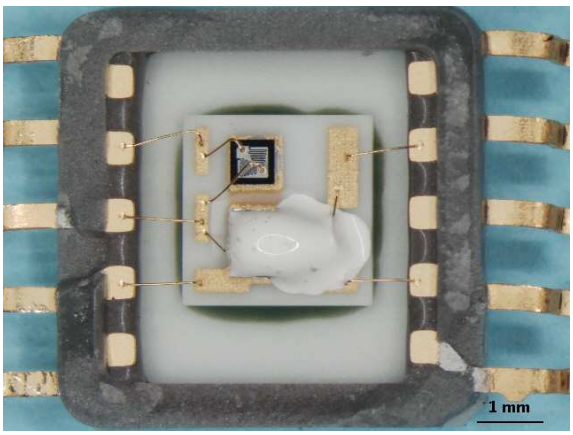


Figure 4: Internal view

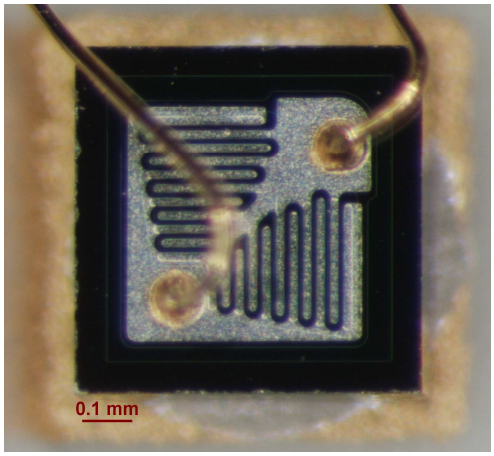


Figure 5: transistor die view

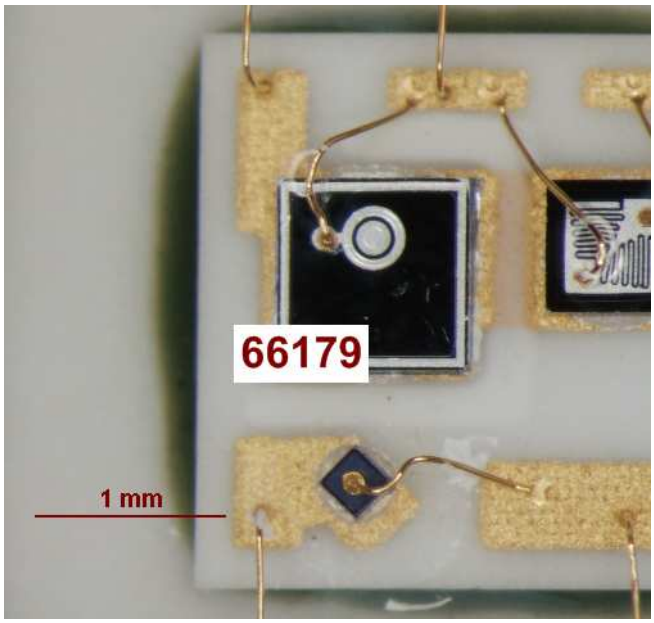


Figure 6: photodetector and LED view

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
Manufacturer serial marking	31	37	47	104

Manufacturer device's package back marking (see external view) correspondence is kept as traceability information.

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°C ±10°C.

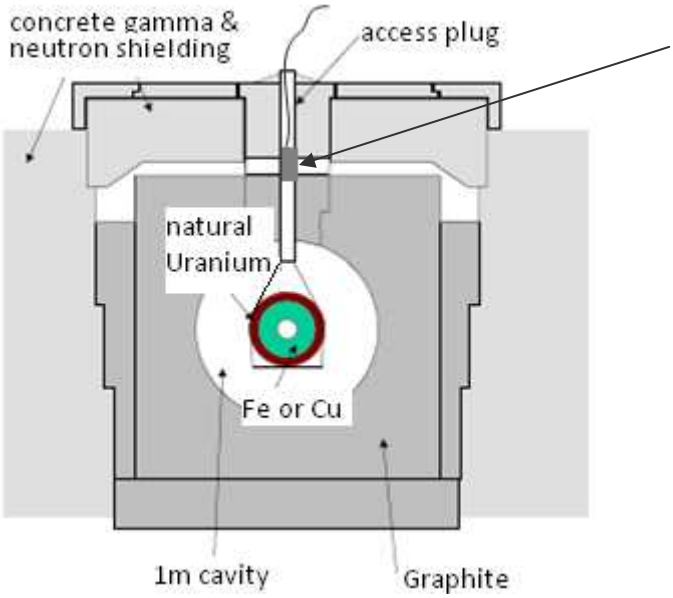


Figure 7: schematical view of the large cavity and its spherical drivers

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 8: 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 #/cm² 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 MeV cm2 g^{-1}), it corresponds to a total fluence of 6.89E+12 #/cm² 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	66179_TN_XXX1_B1_V10.llb

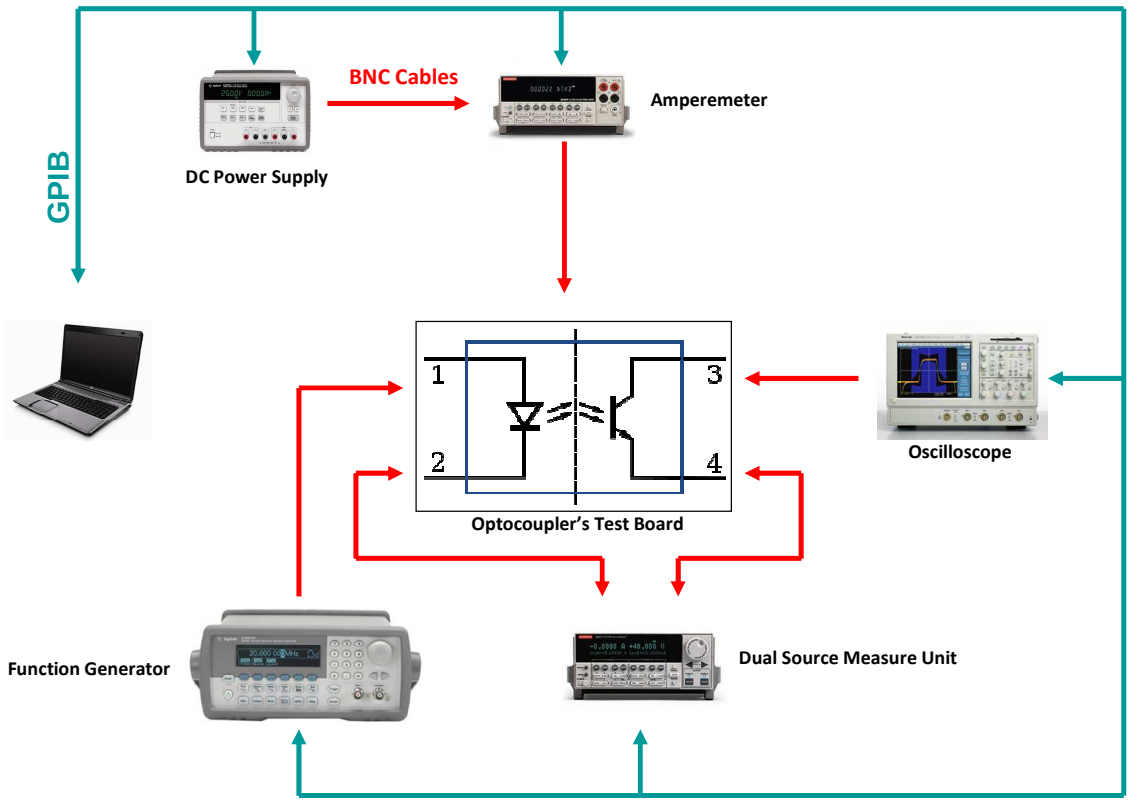


Figure 9: test principle

5.2 Electrical parameters

PARAMETER	SYMBOL	TEST CONDITION	MIN	MAX	UNIT
Input Diode Static Reverse Current	I_R	V_R = 2V		100	µA
Input Diode Static Forward Voltage	V_F	I_F = 10mA	0,8	2	V
Collector-Base Breakdown Voltage	$V_{(BR)CBO}$	I_C = 100µA, I_F = 0	40		V
Collector-EmitterBreakdown Voltage	$V_{(BR)CEO}$	I_C = 1mA, I_B = 0, I_F = 0	40		V
Emitter-Base Breakdown Voltage	$V_{(BR)EBO}$	I_C = 0mA, I_E = 100µA, I_F = 0	4		V
Collector-Emitter Cutoff Current	I_{CEO}	V_{CE} = 20V		100	nA
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	I_F = 20mA, I_C = 10mA		0,3	V
Rise Time	tr	V_{CC}=10V,I_F=10mA, R_L=100Ω		20	µs
Fall Time	tf	V_{CC}=10V,I_F=10mA, R_L=100Ω		20	µs
Current Transfer Ratio	CTR1	V_{CE} = 5V, I_F = 1mA			%
Current Transfer Ratio	CTR2	V_{CE} = 5V, I_F = 2mA			%
Current Transfer Ratio	CTR3	V_{CE} = 5V, I_F = 10mA			%
Current Transfer Ratio	CTR4	V_{CE} = 5V, I_F = 20mA			%
Current Transfer Ratio	CTR5	V_{CE} = 20V, I_F = 10mA			%

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

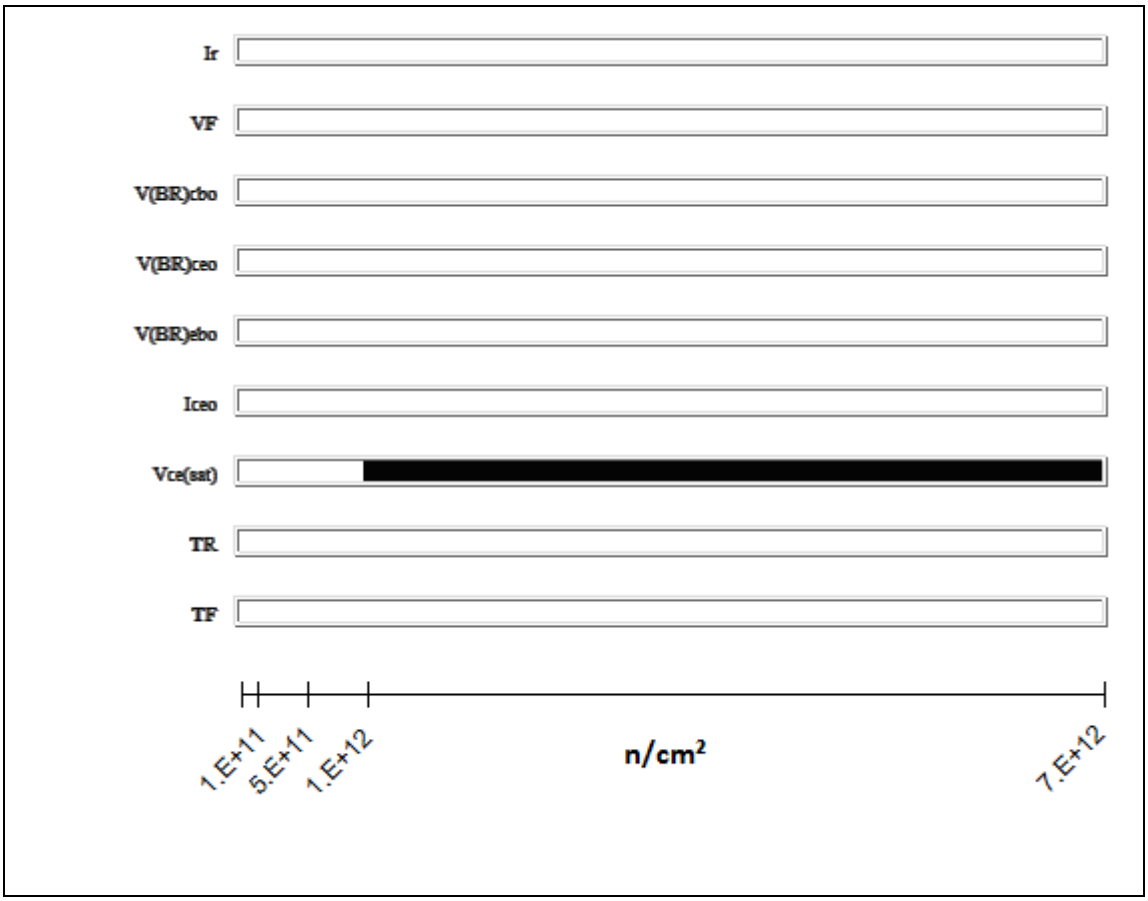
Test measurements are performed at 20°C ± 10°C.

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

For all three devices tested, the parameter **Vce(sat)** is not measurable at step **7 E12.n/cm².**
Indeed the measured voltage at step 7 E12.n/cm² is higher than 100V (test equipment limit).

8 CONCLUSION

Total fluence steady-state irradiation test using neutrons has been applied on **66179-002, Single Channel Optocoupler** from **MICROPAC** up to 7E+12 neutrons/cm², with an energy of 1 MeV.

The results indicate that:

- For the three components tested, Vce(sat) at step 7E12 n/cm² is out of specification.

PARAMETERS	SYMBOLS	TEST CONDITIONS	Applicable specification			Measurement at step 7E12 n/cm²
			Min	Max	Unit	
Collector-Emitter Saturation Voltage	VCE(SAT)	IF = 20mA, IC = 10mA		0.3	V	>100V*

(*) test equipment limit

Nevertheless, all devices are functional up to 1 E+12 neutrons/cm² total fluence level.

As per the irradiation step and CTR configuration, average drift current transfer ratio is described in next table.

PARAMETERS	SYMBOL	UNIT	STEP IRRADIATION					
			0E10 n/cm²	5E10 n/cm²	1E11 n/cm²	5E11 n/cm²	1E12 n/cm²	7E12 n/cm²
Average drift Current Transfer Ratio	$\overline{\Delta CTR1}$	%	0.00E+00	4.74E-04	9.74E-04	5.88E-03	1.51E-02	9.37E-01
	$\overline{\Delta CTR2}$	%	0.00E+00	3.53E-04	7.07E-04	4.06E-03	1.02E-02	5.74E-01
	$\overline{\Delta CTR3}$	%	0.00E+00	1.88E-04	3.65E-04	1.94E-03	4.57E-03	2.11E-01
	$\overline{\Delta CTR4}$	%	0.00E+00	1.48E-04	2.86E-04	1.49E-03	3.41E-03	1.40E-01
	$\overline{\Delta CTR5}$	%	0.00E+00	1.68E-04	3.33E-04	1.80E-03	4.25E-03	1.85E-01

CTR4 configuration (Vce = 5V; If = 20 mA) exhibits the smallest average parameter drift at all irradiation steps.
Conversely, CRT1 configuration (Vce = 5V; If = 1 mA) exhibits the greater parameter degradation at all steps.

9 DETAILED TESTS RESULTS

The pre and post radiation test results are shown graphically in the following pages (9-2 to 9-15). 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/cm² step.

For CTR values, the formula used is:

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

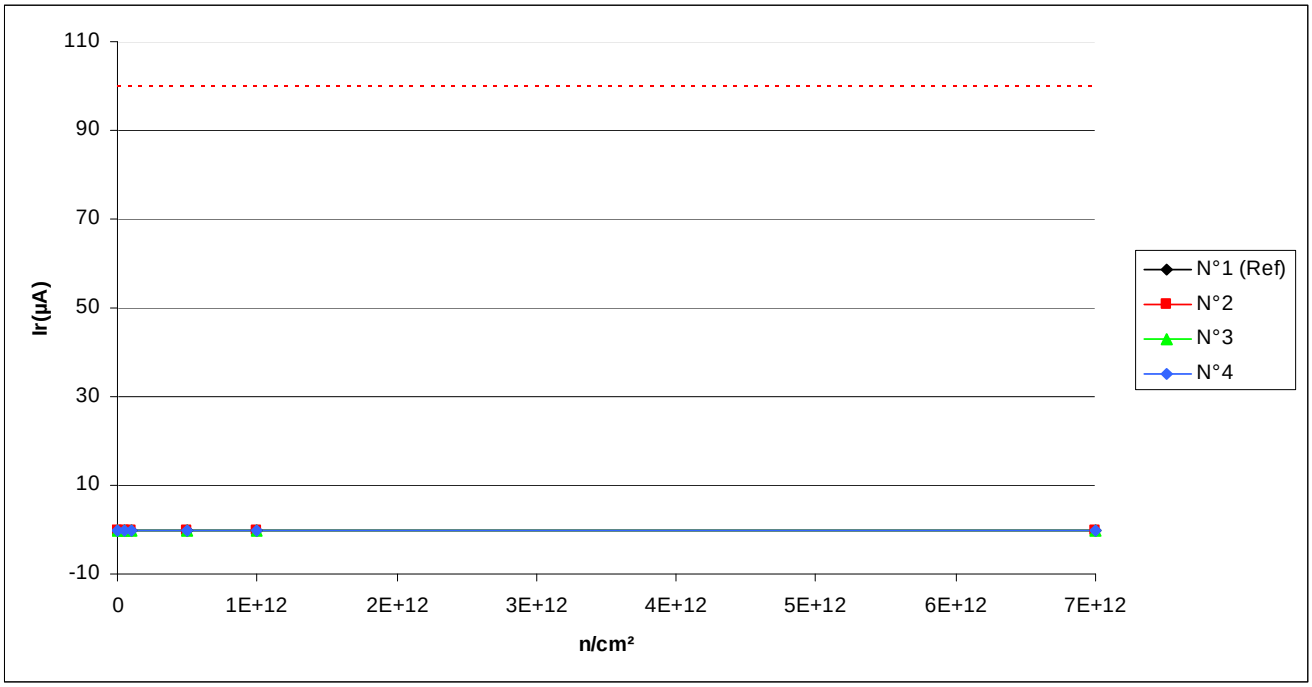
For the other measurements the formula used is:

Drift value= measurement (X neutrons/cm²) - measurement (0 neutrons/cm²)

CONTENT

1. Ir

Ta=20°C; VR = 2 V



Ir. (µA) **Max = 100.0**

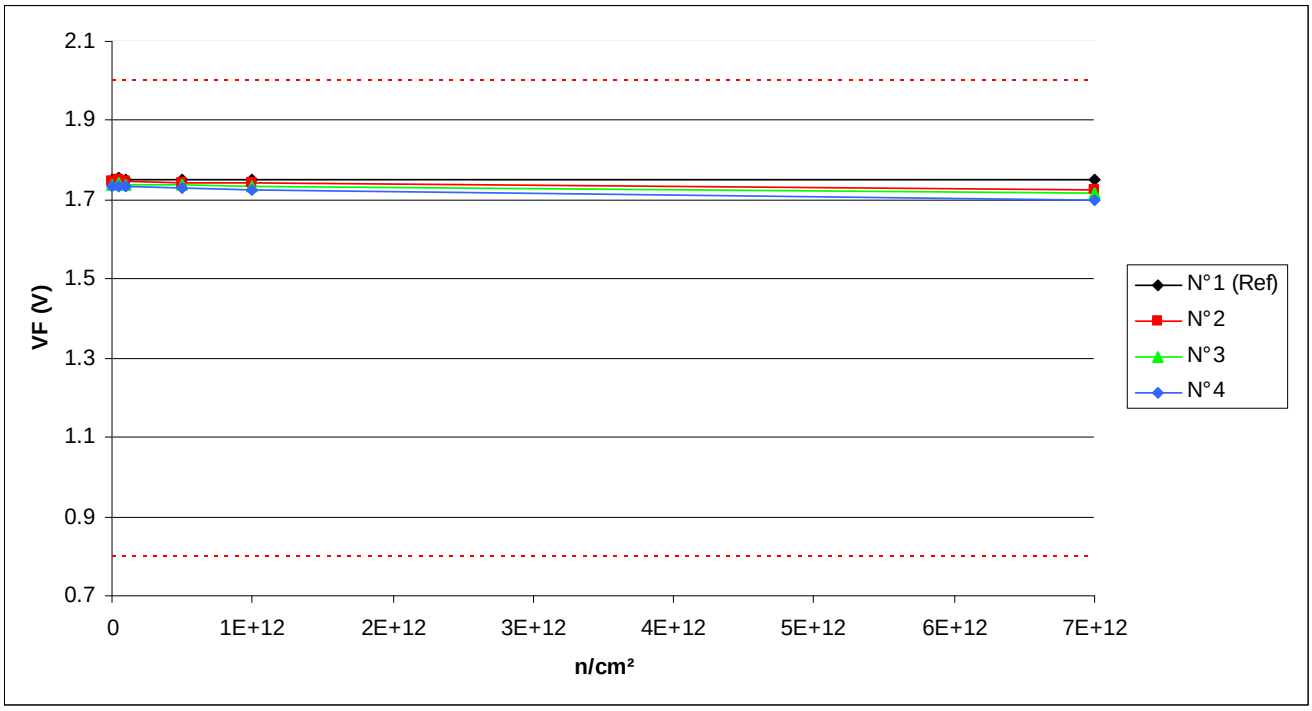
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	5.712E-6	2.621E-5	1.775E-5	4.093E-5	1.742E-4	3.137E-5
N° 2	3.301E-5	6.377E-5	2.609E-5	1.067E-4	2.672E-5	3.950E-5
N° 3	2.587E-5	1.113E-5	2.077E-5	3.845E-5	4.169E-6	3.363E-5
N° 4	2.796E-6	7.443E-6	2.316E-5	9.324E-6	3.009E-4	2.798E-5

Delta [Ir]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	2.050E-5	1.204E-5	3.521E-5	1.685E-4	2.566E-5
N° 2	---	3.075E-5	-6.919E-6	7.367E-5	-6.294E-6	6.492E-6
N° 3	---	-1.474E-5	-5.100E-6	1.258E-5	-2.170E-5	7.763E-6
N° 4	---	4.647E-6	2.036E-5	6.528E-6	2.981E-4	2.518E-5
Average	---	6.888E-6	2.781E-6	3.093E-5	9.004E-5	1.315E-5
σ	---	2.283E-5	1.525E-5	3.714E-5	1.804E-4	1.044E-5
Average+3σ	---	7.538E-5	4.854E-5	1.424E-4	6.311E-4	4.448E-5
Average-3σ	---	-6.160E-5	-4.298E-5	-8.050E-5	-4.511E-4	-1.818E-5

2. VF1

Ta=20°C; If=10mA



VF. (V) **Min = 0.8 Max = 2.0**

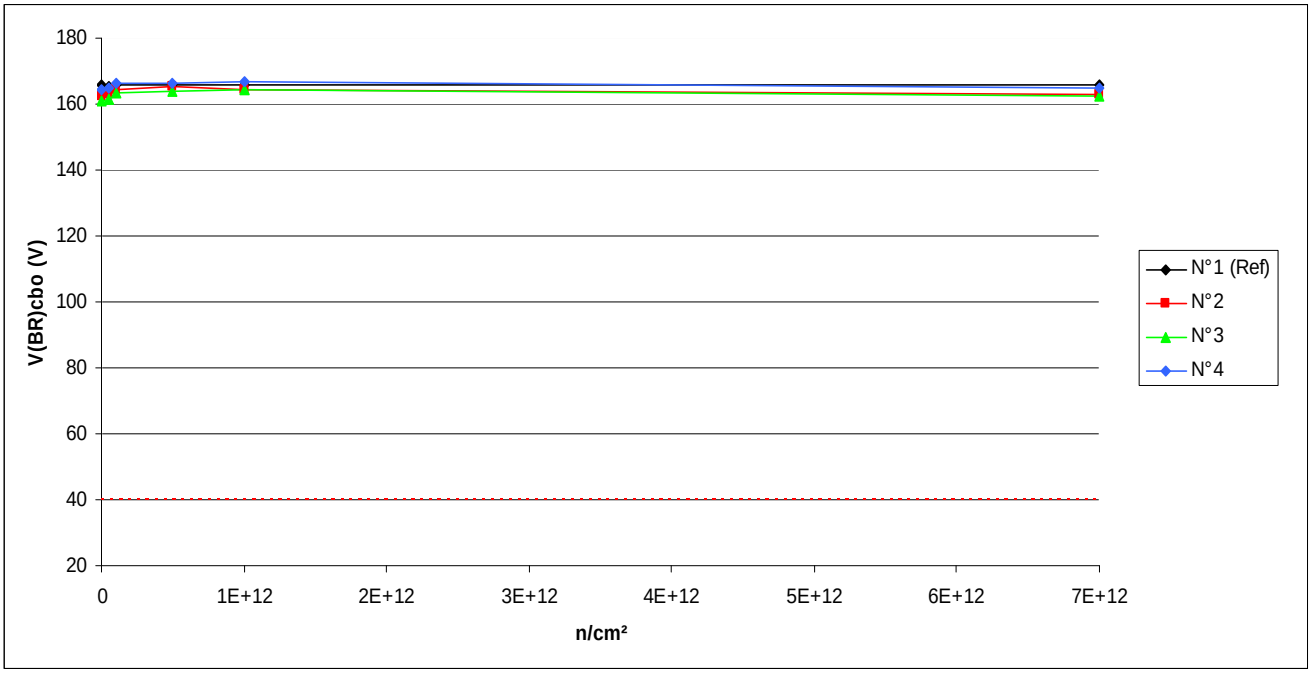
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1.751	1.754	1.752	1.753	1.752	1.753
N° 2	1.748	1.749	1.748	1.744	1.741	1.727
N° 3	1.740	1.741	1.740	1.737	1.732	1.716
N° 4	1.733	1.734	1.733	1.729	1.725	1.699

Delta [VF]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	2.959E-3	1.551E-3	2.470E-3	7.880E-4	1.842E-3
N° 2	---	1.459E-3	5.000E-5	-3.524E-3	-6.875E-3	-2.107E-2
N° 3	---	1.143E-3	2.900E-4	-2.877E-3	-7.686E-3	-2.419E-2
N° 4	---	1.275E-3	2.930E-4	-3.770E-3	-8.191E-3	-3.346E-2
Average	---	1.292E-3	2.110E-4	-3.390E-3	-7.584E-3	-2.624E-2
σ	---	1.587E-4	1.394E-4	4.613E-4	6.639E-4	6.447E-3
Average+3σ	---	1.768E-3	6.293E-4	-2.007E-3	-5.592E-3	-6.899E-3
Average-3σ	---	8.162E-4	-2.073E-4	-4.774E-3	-9.576E-3	-4.558E-2

3. V(BR)cbo

Ta=20°C; Ic = 100 µA; If = 0



V(BR)cbo . (V) **Min = 40.0**

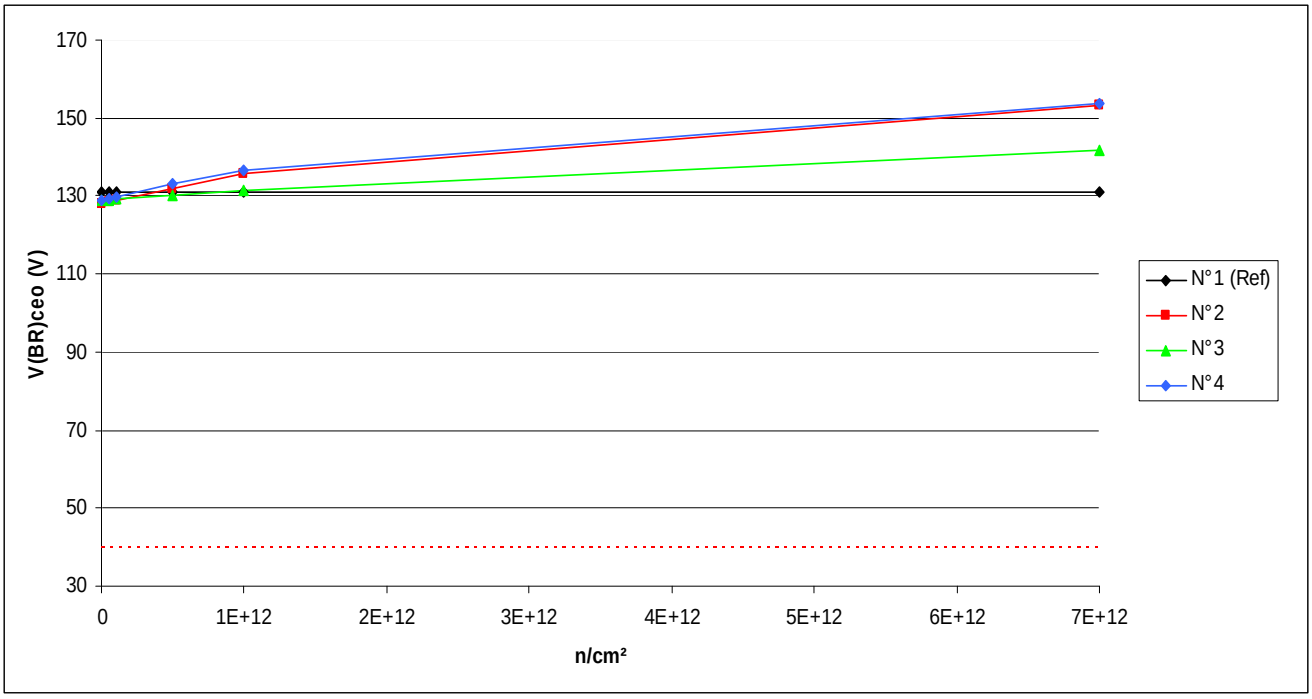
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	165.6	165.4	165.7	165.6	165.9	166.0
N° 2	162.5	163.2	164.2	165.3	164.6	162.9
N° 3	161.1	161.6	163.5	164.0	164.5	162.6
N° 4	164.3	164.7	166.3	166.6	166.9	164.7

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)	---	-2.102E-1	2.990E-2	2.160E-2	2.815E-1	3.398E-1
N° 2	---	6.251E-1	1.645E+0	2.772E+0	2.089E+0	3.857E-1
N° 3	---	4.658E-1	2.399E+0	2.892E+0	3.404E+0	1.487E+0
N° 4	---	3.854E-1	1.956E+0	2.261E+0	2.544E+0	4.109E-1
Average	---	4.921E-1	2.000E+0	2.641E+0	2.679E+0	7.613E-1
σ	---	1.220E-1	3.786E-1	3.352E-1	6.675E-1	6.289E-1
Average+3σ	---	8.581E-1	3.136E+0	3.647E+0	4.682E+0	2.648E+0
Average-3σ	---	1.261E-1	8.643E-1	1.636E+0	6.765E-1	-1.125E+0

4. V(BR)ceo

Ta=20°C; Ic = 1 mA; Ib = 0; If = 0



V(BR)ceo . (V) **Min = 40.0**

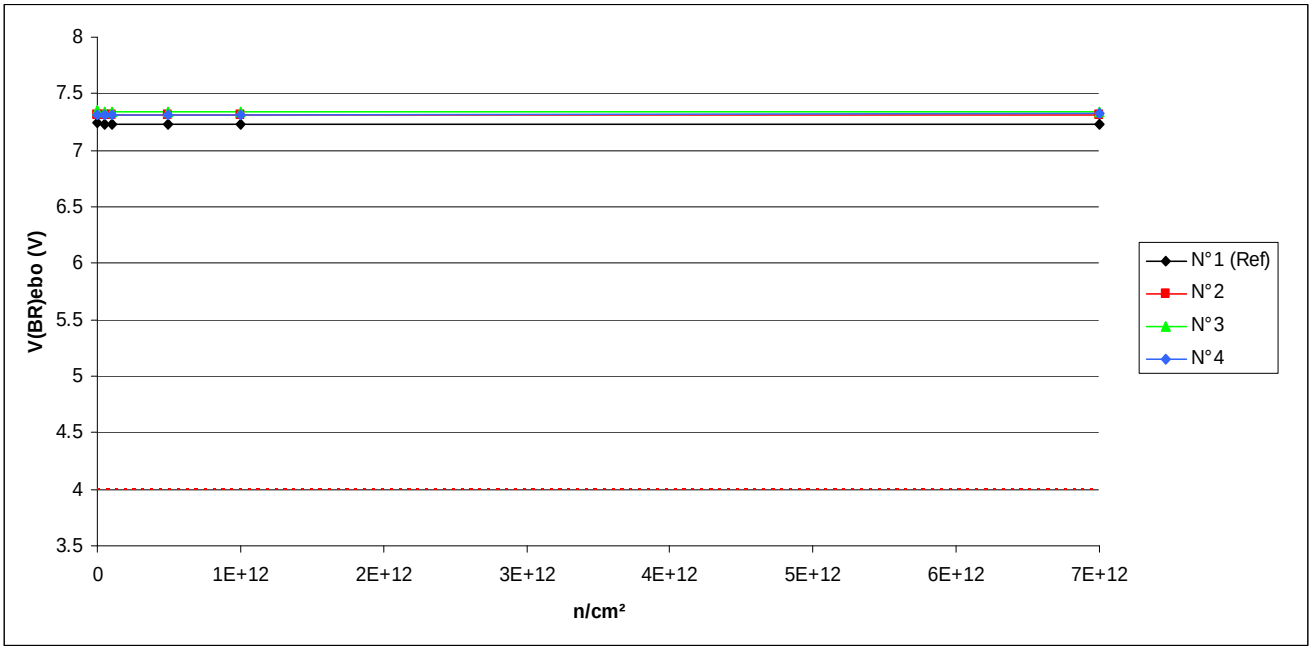
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	131.0	131.0	131.0	131.0	131.1	131.1
N° 2	128.0	128.5	129.0	132.1	135.7	153.3
N° 3	128.8	129.1	129.3	130.4	131.3	141.7
N° 4	128.9	129.4	129.8	133.1	136.6	153.6

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)	---	-1.910E-2	4.000E-3	1.100E-3	5.690E-2	9.310E-2
N° 2	---	4.916E-1	1.010E+0	4.110E+0	7.760E+0	2.535E+1
N° 3	---	2.802E-1	5.258E-1	1.622E+0	2.539E+0	1.289E+1
N° 4	---	4.468E-1	8.943E-1	4.214E+0	7.682E+0	2.468E+1
Average	---	4.062E-1	8.101E-1	3.316E+0	5.994E+0	2.097E+1
σ	---	1.114E-1	2.529E-1	1.468E+0	2.992E+0	7.011E+0
Average+3σ	---	7.404E-1	1.569E+0	7.718E+0	1.497E+1	4.201E+1
Average-3σ	---	7.202E-2	5.128E-2	-1.087E+0	-2.983E+0	-5.907E-2

5. V(BR)ebo

Ta=20°C; Ic = 0 mA; Ie = 100 µA; If = 0



V(BR)ebo . (V) **Min = 4.0**

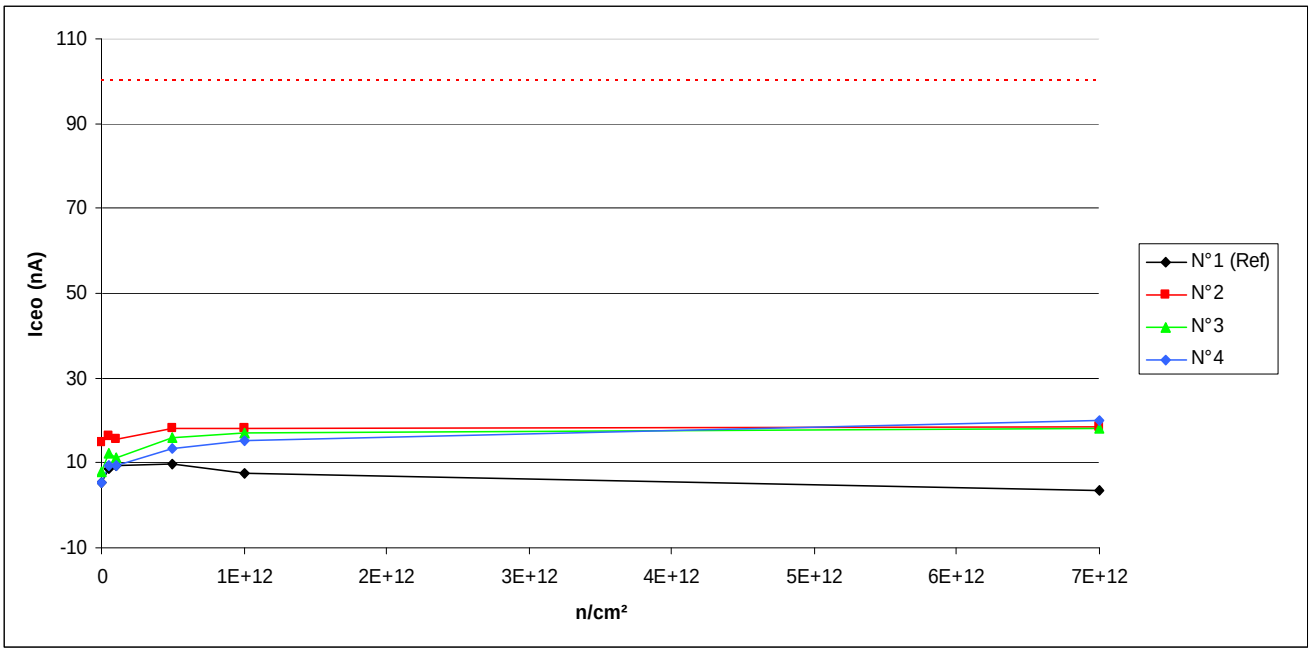
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	7.237	7.229	7.232	7.230	7.234	7.233
N° 2	7.312	7.307	7.309	7.310	7.311	7.312
N° 3	7.347	7.343	7.344	7.343	7.346	7.346
N° 4	7.314	7.310	7.311	7.312	7.314	7.320

Delta [V(BR)ebo]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-7.261E-3	-4.717E-3	-6.530E-3	-2.331E-3	-3.924E-3
N° 2	---	-5.059E-3	-2.909E-3	-1.966E-3	-1.106E-3	7.300E-4
N° 3	---	-3.723E-3	-3.337E-3	-3.743E-3	-7.970E-4	-1.533E-3
N° 4	---	-3.929E-3	-2.561E-3	-1.780E-3	6.700E-5	6.388E-3
Average	---	-4.237E-3	-2.936E-3	-2.496E-3	-6.120E-4	1.862E-3
σ	---	7.193E-4	3.887E-4	1.084E-3	6.080E-4	4.080E-3
Average+3σ	---	-2.079E-3	-1.770E-3	7.546E-4	1.212E-3	1.410E-2
Average-3σ	---	-6.395E-3	-4.102E-3	-5.747E-3	-2.436E-3	-1.038E-2

6. Iceo

Ta=20°C; Vce = 20 V



Iceo . (nA) **Max = 100.0**

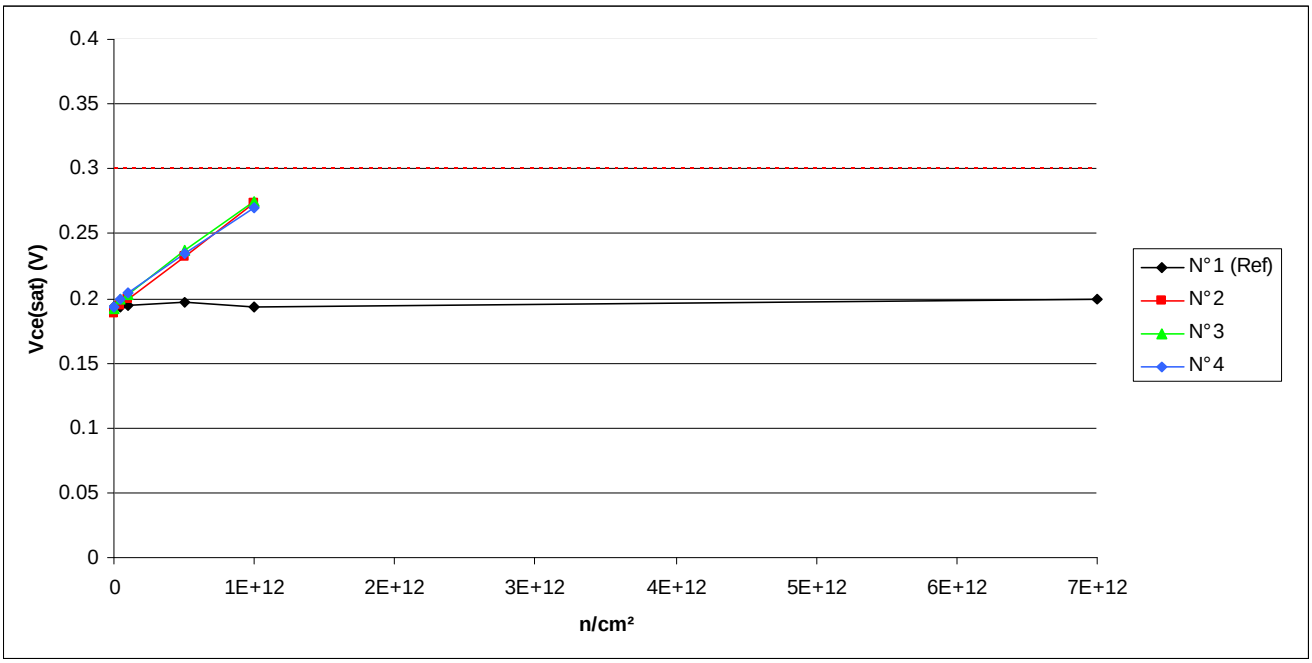
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	5.272	8.723	9.235	9.880	7.565	3.451
N° 2	14.815	16.291	15.475	18.210	18.148	18.627
N° 3	7.820	12.152	11.360	15.862	16.910	18.272
N° 4	5.228	9.452	9.283	13.413	15.130	20.108

Delta [Iceo]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	3.451E+0	3.963E+0	4.608E+0	2.293E+0	-1.820E+0
N° 2	---	1.476E+0	6.599E-1	3.395E+0	3.333E+0	3.812E+0
N° 3	---	4.332E+0	3.540E+0	8.042E+0	9.090E+0	1.045E+1
N° 4	---	4.224E+0	4.054E+0	8.185E+0	9.902E+0	1.488E+1
Average	---	3.344E+0	2.751E+0	6.541E+0	7.442E+0	9.714E+0
σ	---	1.618E+0	1.829E+0	2.725E+0	3.581E+0	5.571E+0
Average+3σ	---	8.199E+0	8.240E+0	1.472E+1	1.819E+1	2.643E+1
Average-3σ	---	-1.511E+0	-2.737E+0	-1.635E+0	-3.303E+0	-6.998E+0

7. Vce(sat)

Ta=20°C; If = 20 mA; Ic = 10 mA



Vce(sat) . (V) **Max = 0.3**

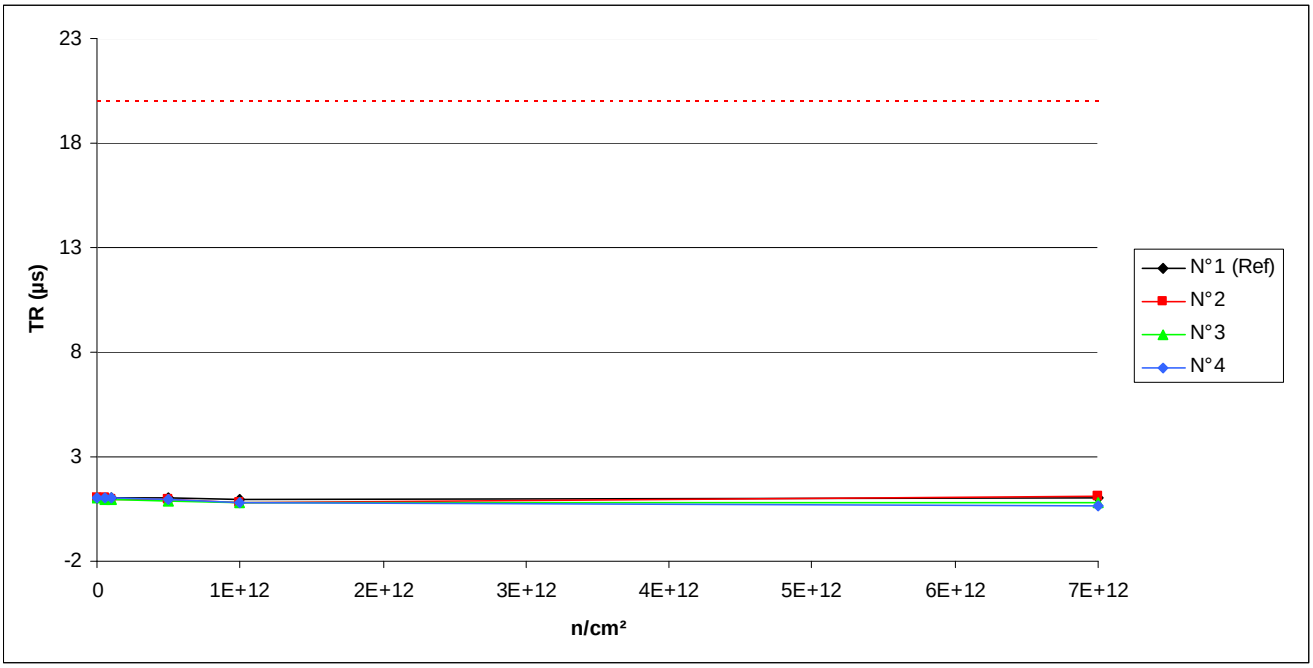
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	0.193	0.193	0.194	0.197	0.193	0.199
N° 2	0.189	0.195	0.199	0.232	0.274	Not Measurable
N° 3	0.192	0.199	0.203	0.237	0.275	Not Measurable
N° 4	0.193	0.200	0.204	0.235	0.270	Not Measurable

Delta [Vce(sat)]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	6.000E-4	1.292E-3	4.349E-3	-6.310E-5	6.484E-3
N° 2	---	6.509E-3	1.009E-2	4.376E-2	8.545E-2	NaN
N° 3	---	7.342E-3	1.154E-2	4.500E-2	8.336E-2	NaN
N° 4	---	6.917E-3	1.074E-2	4.231E-2	7.721E-2	NaN
Average	---	6.923E-3	1.079E-2	4.369E-2	8.201E-2	NaN
σ	---	4.164E-4	7.257E-4	1.348E-3	4.281E-3	0.000E+0
Average+3σ	---	8.172E-3	1.297E-2	4.773E-2	9.485E-2	NaN
Average-3σ	---	5.673E-3	8.617E-3	3.965E-2	6.916E-2	NaN

8. TR

Ta=20°C; Vcc = 10 V; If = 10 mA; RL = 100 Ohms



TR. (µs) **Max = 20.0**

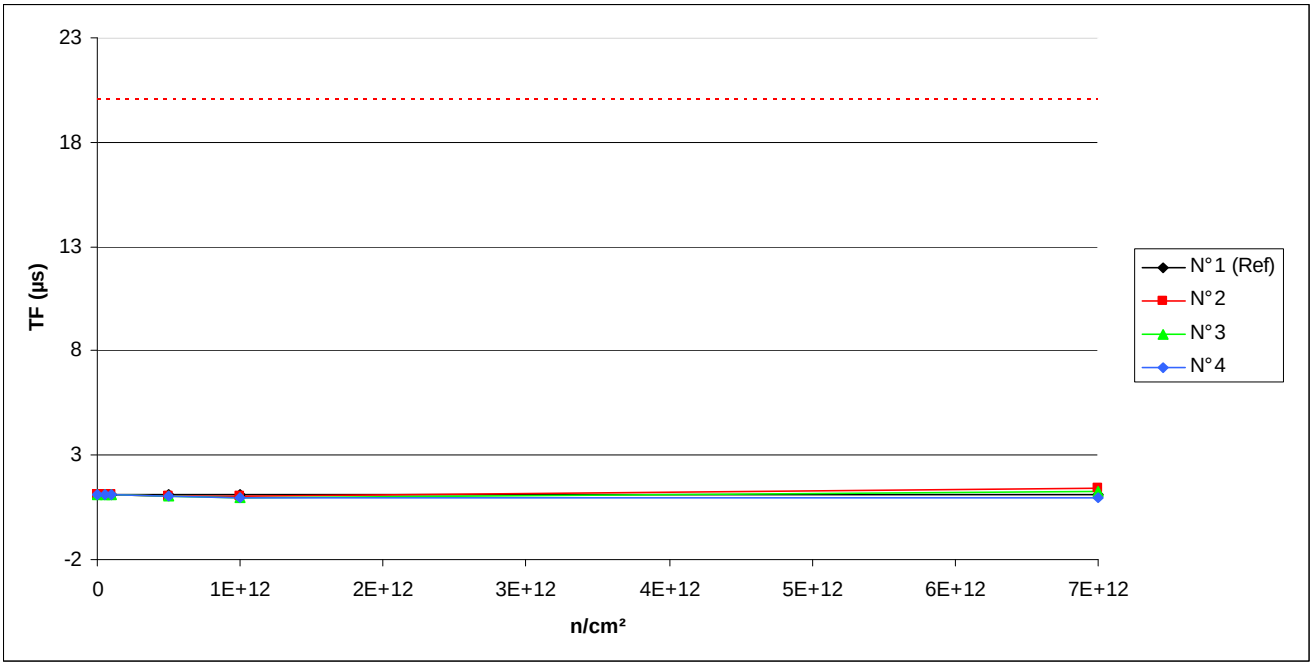
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1.00	0.96	1.00	1.00	0.96	1.00
N° 2	1.04	1.00	0.96	0.92	0.84	1.12
N° 3	1.04	0.96	0.96	0.88	0.80	0.84
N° 4	1.00	1.00	1.00	0.92	0.80	0.68

Delta [TR]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-4.000E-2	0.000E+0	0.000E+0	-4.000E-2	0.000E+0
N° 2	---	-4.000E-2	-8.000E-2	-1.200E-1	-2.000E-1	8.000E-2
N° 3	---	-8.000E-2	-8.000E-2	-1.600E-1	-2.400E-1	-2.000E-1
N° 4	---	0.000E+0	0.000E+0	-8.000E-2	-2.000E-1	-3.200E-1
Average	---	-4.000E-2	-5.333E-2	-1.200E-1	-2.133E-1	-1.467E-1
σ	---	4.000E-2	4.619E-2	4.000E-2	2.309E-2	2.053E-1
Average+3σ	---	8.000E-2	8.523E-2	1.110E-16	-1.441E-1	4.691E-1
Average-3σ	---	-1.600E-1	-1.919E-1	-2.400E-1	-2.826E-1	-7.625E-1

9. TF

Ta=20°C; Vcc = 10 V; If = 10 mA; RL = 100 Ohms



TF. (µs) **Max = 20.0**

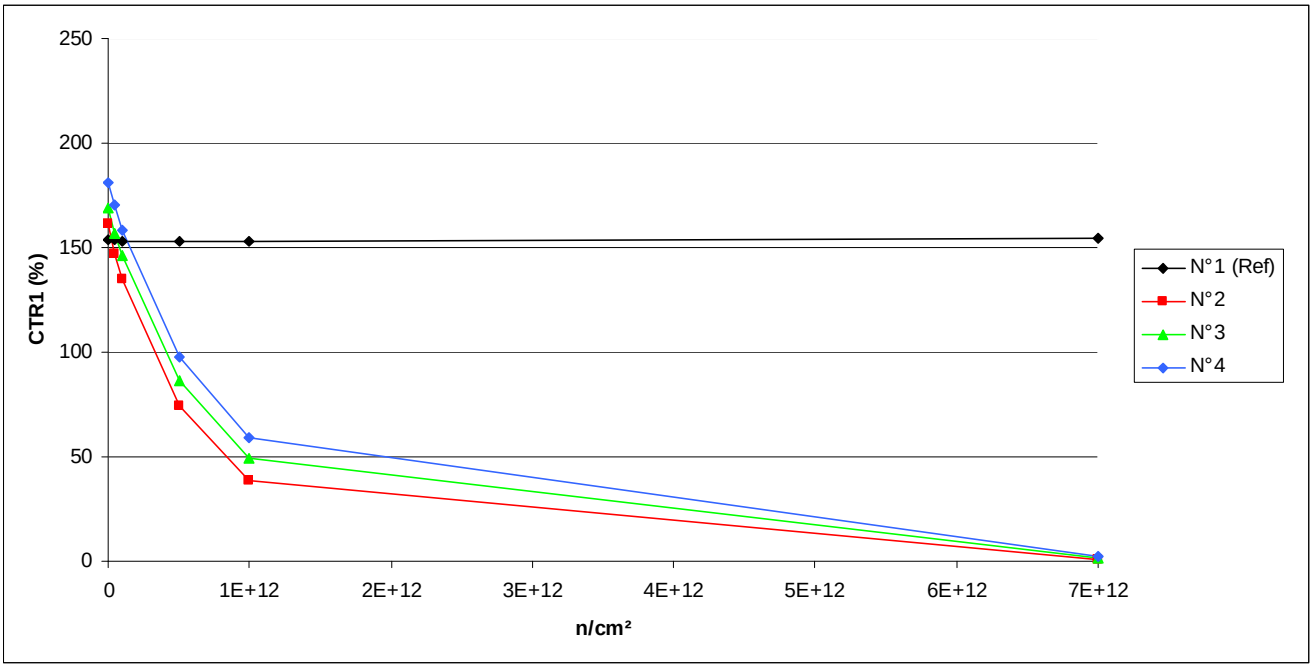
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1.08	1.08	1.08	1.12	1.08	1.08
N° 2	1.08	1.08	1.08	1.04	1.04	1.40
N° 3	1.12	1.08	1.08	1.04	1.00	1.28
N° 4	1.12	1.08	1.08	1.04	1.00	1.00

Delta [TF]

	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	4.000E-2	0.000E+0	0.000E+0
N° 2	---	0.000E+0	0.000E+0	-4.000E-2	-4.000E-2	3.200E-1
N° 3	---	-4.000E-2	-4.000E-2	-8.000E-2	-1.200E-1	1.600E-1
N° 4	---	-4.000E-2	-4.000E-2	-8.000E-2	-1.200E-1	-1.200E-1
Average	---	-2.667E-2	-2.667E-2	-6.667E-2	-9.333E-2	1.200E-1
σ	---	2.309E-2	2.309E-2	2.309E-2	4.619E-2	2.227E-1
Average+3σ	---	4.262E-2	4.262E-2	2.615E-3	4.523E-2	7.881E-1
Average-3σ	---	-9.595E-2	-9.595E-2	-1.359E-1	-2.319E-1	-5.481E-1

10.CTR1

Ta=20°C; Vce = 5V; If = 1 mA



CTR1 . (%)

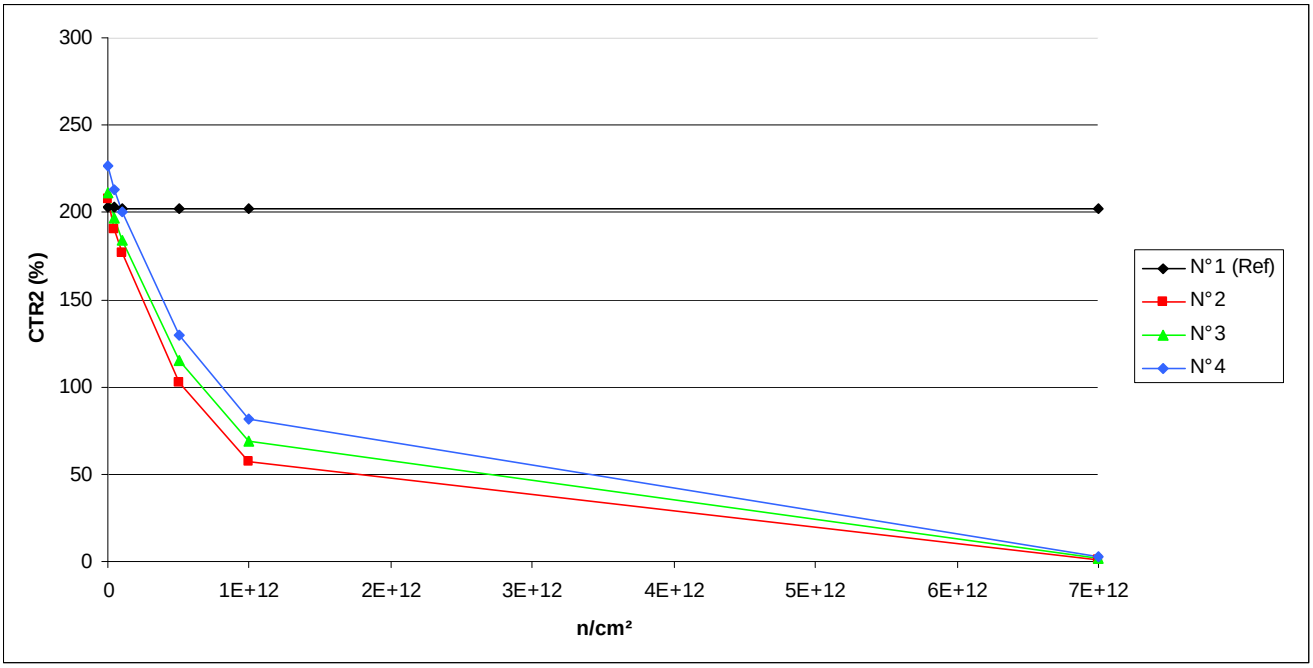
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	154.038	153.688	153.357	152.811	153.214	154.352
N° 2	161.364	147.109	135.060	74.168	38.779	0.632
N° 3	168.948	156.584	145.929	86.299	49.493	1.325
N° 4	181.088	170.162	158.657	97.994	59.300	2.034

1/Delta [CTR1]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.480E-5	2.884E-5	5.211E-5	3.492E-5	-1.321E-5
N° 2	---	6.005E-4	1.207E-3	7.286E-3	1.959E-2	1.576E+0
N° 3	---	4.674E-4	9.336E-4	5.669E-3	1.429E-2	7.487E-1
N° 4	---	3.546E-4	7.808E-4	4.683E-3	1.134E-2	4.860E-1
Average	---	4.742E-4	9.738E-4	5.879E-3	1.507E-2	9.370E-1
σ	---	1.231E-4	2.159E-4	1.314E-3	4.180E-3	5.690E-1
Average+3σ	---	8.435E-4	1.622E-3	9.822E-3	2.761E-2	2.644E+0
Average-3σ	---	1.048E-4	3.260E-4	1.936E-3	2.532E-3	-7.700E-1

11.CTR2

Ta=20°C; Vce = 5V; If = 2 mA



CTR2. (%)

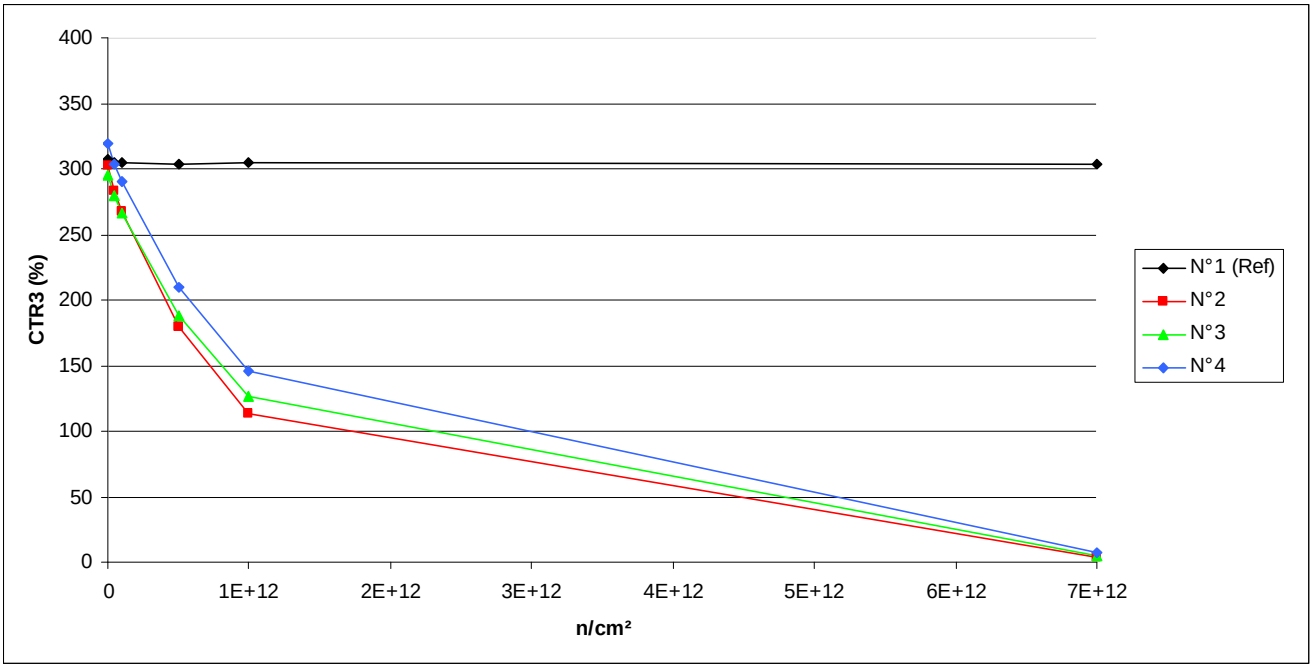
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	203.196	202.611	202.315	201.683	202.255	202.372
N° 2	207.648	190.706	176.405	102.683	56.729	1.091
N° 3	211.356	196.557	184.336	114.933	68.774	2.057
N° 4	226.538	213.312	200.507	129.714	81.274	3.012

1/Delta [CTR2]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.420E-5	2.142E-5	3.691E-5	2.289E-5	2.004E-5
N° 2	---	4.279E-4	8.529E-4	4.923E-3	1.281E-2	9.115E-1
N° 3	---	3.562E-4	6.935E-4	3.969E-3	9.809E-3	4.814E-1
N° 4	---	2.737E-4	5.731E-4	3.295E-3	7.890E-3	3.276E-1
Average	---	3.526E-4	7.065E-4	4.062E-3	1.017E-2	5.735E-1
σ	---	7.715E-5	1.404E-4	8.179E-4	2.481E-3	3.026E-1
Average+3σ	---	5.840E-4	1.128E-3	6.516E-3	1.761E-2	1.481E+0
Average-3σ	---	1.211E-4	2.854E-4	1.609E-3	2.728E-3	-3.344E-1

12.CTR3

Ta=20°C; Vce = 5V; If = 10 mA



CTR3. (%)

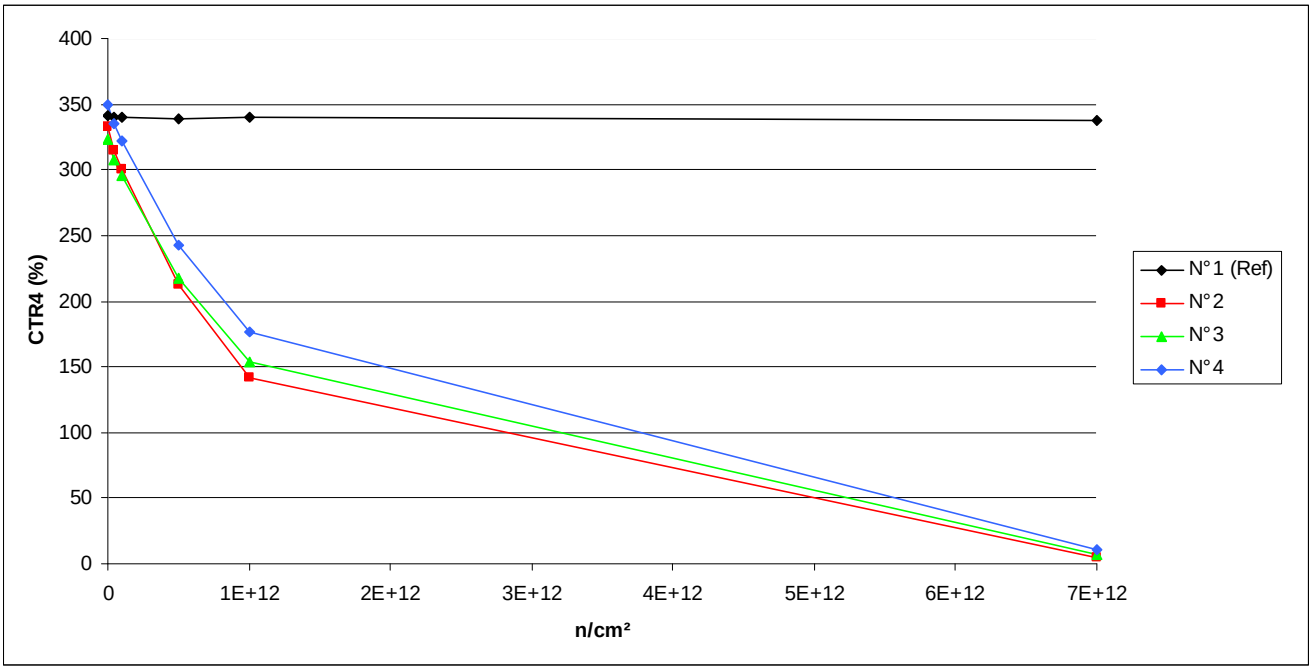
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	306.742	305.124	305.074	304.141	305.337	303.823
N° 2	301.850	282.994	267.710	179.562	113.526	3.228
N° 3	295.326	279.737	266.404	187.918	126.818	5.211
N° 4	319.162	304.174	290.854	210.207	146.303	7.117

1/Delta [CTR3]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.728E-5	1.782E-5	2.788E-5	1.500E-5	3.132E-5
N° 2	---	2.207E-4	4.225E-4	2.256E-3	5.496E-3	3.065E-1
N° 3	---	1.887E-4	3.676E-4	1.935E-3	4.499E-3	1.885E-1
N° 4	---	1.544E-4	3.049E-4	1.624E-3	3.702E-3	1.374E-1
Average	---	1.879E-4	3.650E-4	1.939E-3	4.566E-3	2.108E-1
σ	---	3.318E-5	5.881E-5	3.161E-4	8.987E-4	8.675E-2
Average+3σ	---	2.875E-4	5.414E-4	2.887E-3	7.262E-3	4.710E-1
Average-3σ	---	8.839E-5	1.886E-4	9.902E-4	1.870E-3	-4.944E-2

13.CTR4

Ta=20°C; Vce = 5V; If = 20 mA



CTR4. (%)

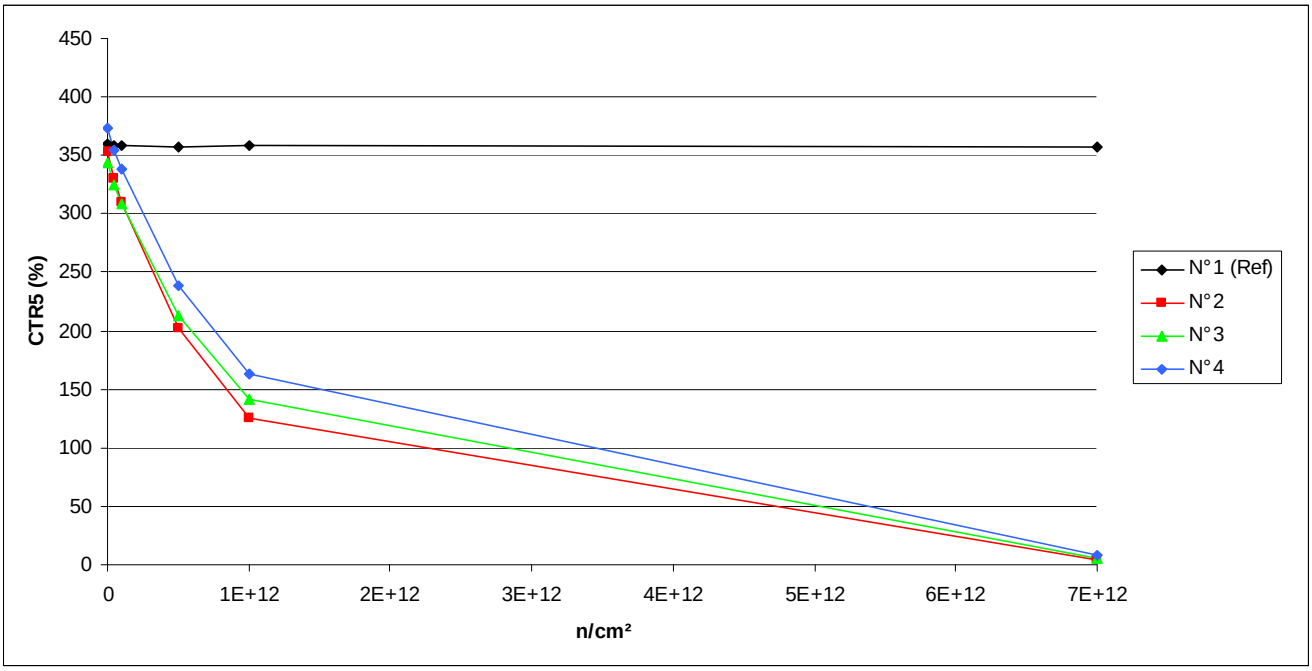
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	341.468	340.021	339.922	338.941	340.227	338.117
N° 2	333.167	315.140	300.432	212.371	141.948	4.950
N° 3	322.707	307.909	295.170	217.879	154.299	7.685
N° 4	349.369	334.967	322.253	242.732	176.502	10.322

1/Delta [CTR4]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.246E-5	1.332E-5	2.184E-5	1.068E-5	2.903E-5
N° 2	---	1.717E-4	3.270E-4	1.707E-3	4.043E-3	1.990E-1
N° 3	---	1.489E-4	2.891E-4	1.491E-3	3.382E-3	1.270E-1
N° 4	---	1.231E-4	2.409E-4	1.257E-3	2.803E-3	9.402E-2
Average	---	1.479E-4	2.857E-4	1.485E-3	3.410E-3	1.400E-1
σ	---	2.433E-5	4.320E-5	2.249E-4	6.205E-4	5.369E-2
Average+3σ	---	2.209E-4	4.153E-4	2.160E-3	5.271E-3	3.011E-1
Average-3σ	---	7.489E-5	1.561E-4	8.104E-4	1.548E-3	-2.105E-2

14.CTR5

Ta=20°C; Vce = 20V; If = 10 mA



CTR5. (%)

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	359.781	358.885	358.602	357.588	358.601	356.386
N° 2	353.226	329.850	310.342	202.138	125.603	3.690
N° 3	343.779	325.117	308.389	212.653	141.123	5.941
N° 4	372.680	354.768	338.054	238.976	163.521	8.090

1/Delta [CTR5]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	6.938E-6	9.140E-6	1.705E-5	9.151E-6	2.648E-5
N° 2	---	2.006E-4	3.912E-4	2.116E-3	5.131E-3	2.682E-1
N° 3	---	1.670E-4	3.338E-4	1.794E-3	4.177E-3	1.654E-1
N° 4	---	1.355E-4	2.748E-4	1.501E-3	3.432E-3	1.209E-1
Average	---	1.677E-4	3.333E-4	1.804E-3	4.247E-3	1.848E-1
σ	---	3.258E-5	5.819E-5	3.075E-4	8.513E-4	7.551E-2
Average+3σ	---	2.654E-4	5.078E-4	2.726E-3	6.801E-3	4.114E-1
Average-3σ	---	6.994E-5	1.587E-4	8.811E-4	1.693E-3	-4.171E-2