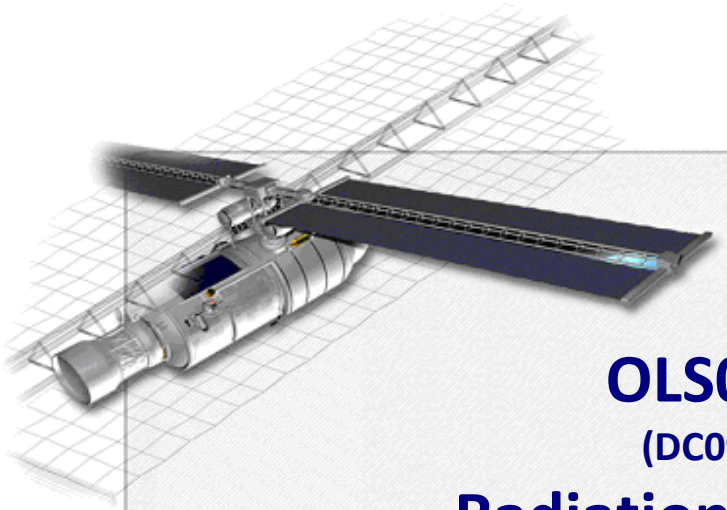
NEUTRONS DISPLACEMENT DAMAGE TEST REPORT



OLS0449
(DC0949)
Radiation Tolerant Hermetic Surface Mount Optocoupler From ISOLINK

TRAD/TN/OLS0449/XXX1/ESA/YP/1104		Labège, March 19th, 2012
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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 OLS0449, an hermetic surface mount Optocoupler from ISOLINK 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-OLS449-ISO-ESA-1119 Iss.4, dated 19/03/2012

2.2 Reference Documents

RD	1.	Datasheet OLS449	Radiation Tolerant Phototransistor Hermetic Surface Mount Optocouplers

3 DEVICE INFORMATION

3.1 Device description

The OL449 is designed for hi-rel and space applications requiring optical isolation in radiation environments such as gamma, neutron and proton radiation with high current transfer ratio (CTR) and low saturation Vce. OLH449 presents same reliable processing and construction as the well-known OLS249 but with higher CTR and using a GaAlAs LED generating three times more current.
Each optocoupler consists of a light emitting diode and a NPN silicon phototransistor electrically isolated but optically coupled inside a hermetic 6-pin leadless chip carrier package. Electrical parameters are similar to the JEDEC registered 4N49U optocoupler but with higher CTR and much better CTR degradation characteristics due to radiation exposure.

Type	OLS0449
Manufacturer	ISOLINK
Function	Optocoupler
Package	LCC4
Date Code	0949
Sample size	4 parts (3 test parts + 1 control sample)

3.2 Procurement information

75 parts OLS449 were procured from ISOLINK through the French representative EUROMIP. Parts delivered are OLS0449, containing same die than the OLS449 but packaged in a LCC4 instead of a LCC6.

3.2.1 External view

Figure 1: package marking

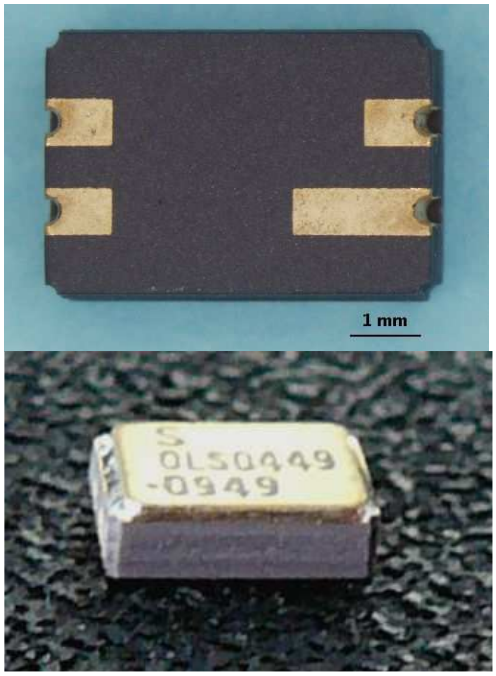


Figure 2: package view and back-side

3.2.2 Internal view

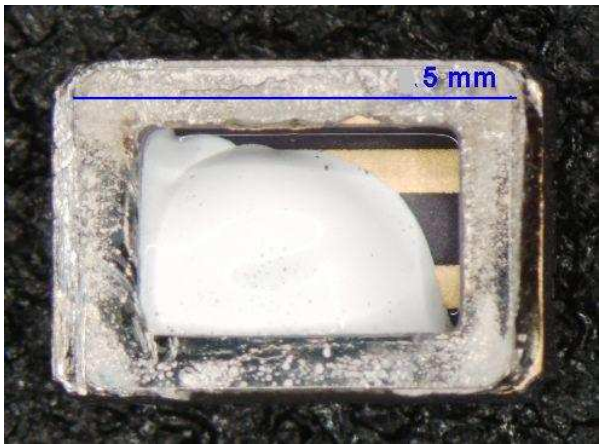


Figure 3: Internal overall view

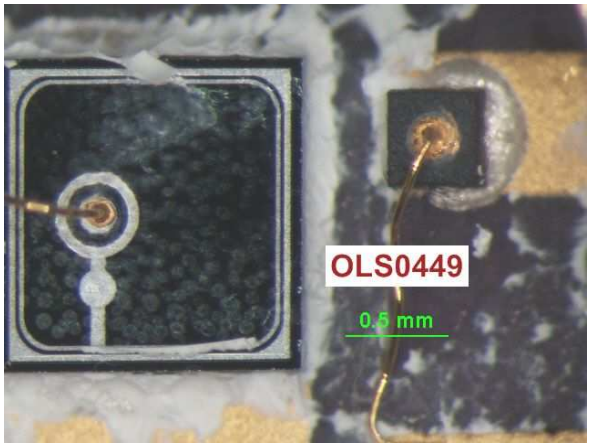


Figure 4: view of photodetector and LED

3.3 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°C ±10°C.

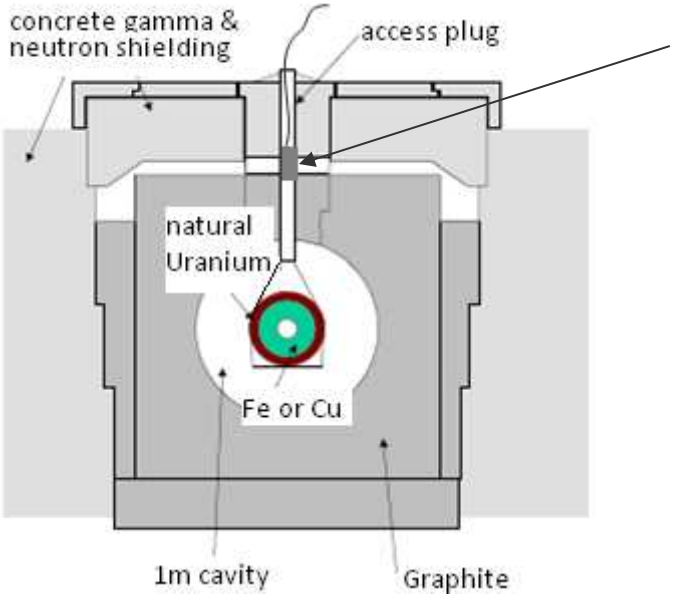


Figure 5: schematical view of the large cavity and its spherical drivers

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) 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 on 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	OLS0449_TN_XXX1_B1_V10.llb

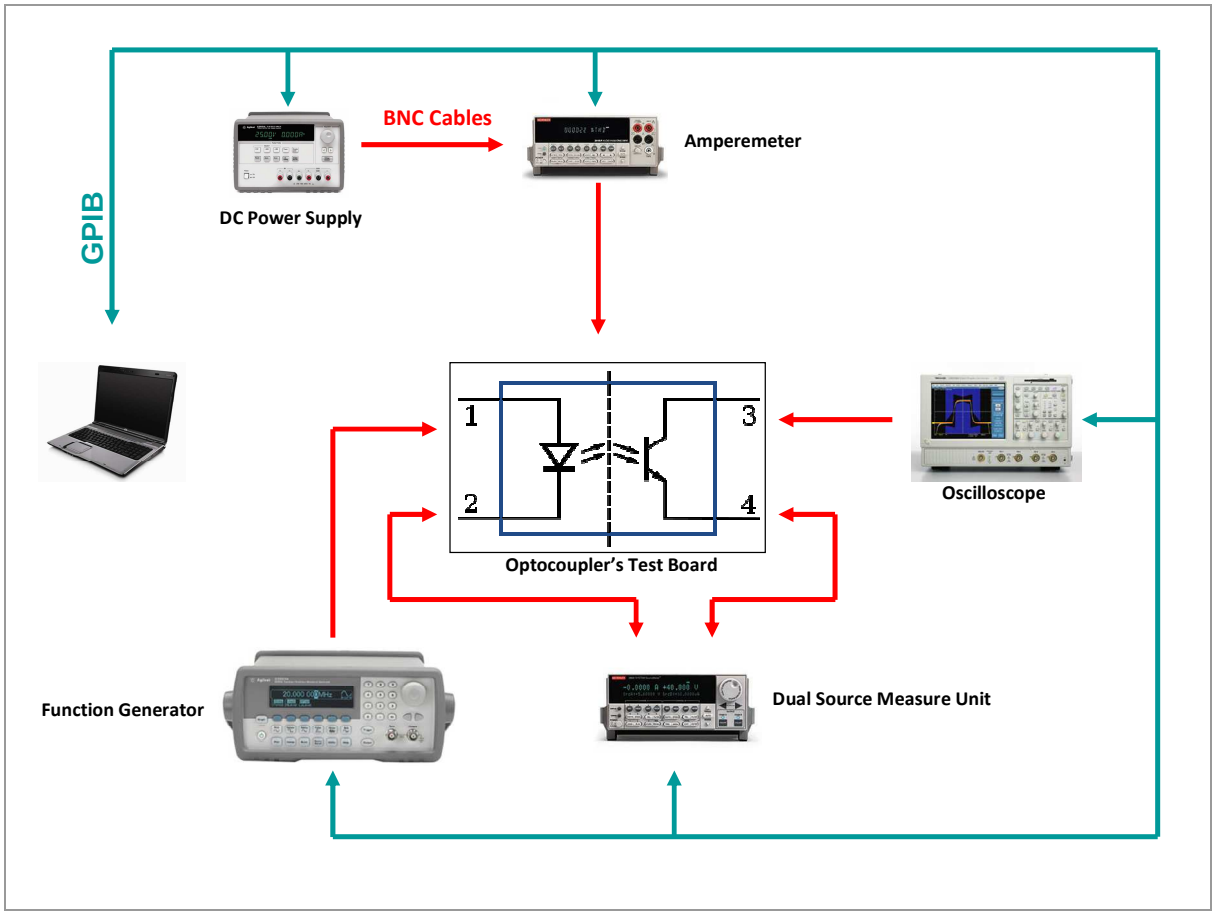


Figure 7: test principle

5.2 Electrical parameters

PARAMETER	SYMBOL	TEST CONDITION	MIN	MAX	UNIT
On-State Collector Current	CTR1/IC(ON)	IF = 1 mA, VCE = 5.0V	15	40	mA
Saturation Voltage	VCE(SAT)	IF = 1 mA, IC = 5.0mA		0,3	V
Breakdown Voltage Collector to Emitter	BV_{CEO}	ICE = 1mA	65		V
Breakdown Voltage Collector to Emitter	BV_{ECO}	IEC=100µA			V
Leakage Current Collector to Emitter	ICE(OFF)	VCE = 20V		100	nA
Input Forward Voltage	VF	IF = 10mA	1,2	1,7	V
Input Reverse Current	IR	VR = 2.0V		100	µA
Rise Time	tr	VCC = 10V, RL = 100Ω, IF = 5mA		25	µs
Fall Time	tf	VCC = 10V, RL = 100Ω, IF = 5mA		25	µs
Current transfer ratio	CTR1	IF = 1 mA, Vce = 5.0V	1500	4000	%
	CTR2	If = 2mA, Vce = 5V			%
	CTR3	If = 10mA, Vce = 5V			%
	CTR4	If = 40mA, Vce = 5V			%
	CTR5	If = 10mA, Vce = 32V			%
Input Diode Reverse Recovery Time	Trr	If = 2mA, Rl = 100Ω, Irec = 10% Irm			ns

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

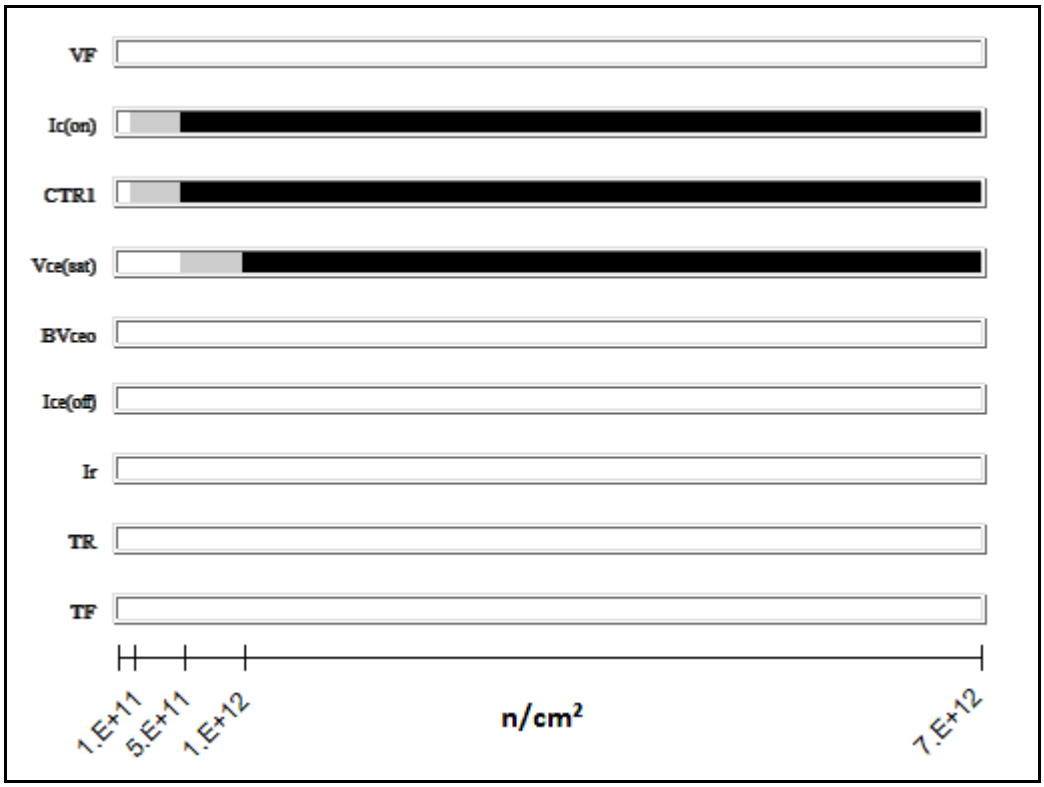
Test measurements are performed at 20°C ± 10°C.

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

- In the worst case, the parameter Vce(sat) is out of specification at 5.23E11.n/cm² by interpolation.
  Moreover Vce(sat) is no more measurable at 7E12 n/cm² step. Indeed voltage measured at step 7 E12.n/cm² is higher than 100V (limit test condition).
- In the worst case, Ic(on) and CTR1 are out of specification at 3.5 E11.n/cm² by interpolation.

8 CONCLUSION

Total fluence steady-state irradiation test using neutrons has been carried out on three devices from OLS0449 type, Radiation Tolerant Phototransistor Hermetic Surface Mount Optocoupler from ISOLINK up to 7E12 neutrons/cm², with an energy of 1 MeV.

The results indicate that:

- For the three components tested, Ic(on) and CTR1 are out of specification at step 5E11n/cm². Vce(sat) is out of specification at step 1E12 n/cm²

PARAMETERS	SYMBOLS	TEST CONDITIONS	Applicable specification	Worst Measurement at step 5E11 n/cm²
On-State Collector Current	IC(ON)	IF = 1 mA, VCE = 5.0V	MIN : 15 mA	12.11 mA
Current Transfer Ratio	CTR1	IF = 1 mA, VCE = 5.0V	MIN: 1500 %	1211 %

PARAMETERS	SYMBOLS	TEST CONDITIONS	Applicable specification	Worst Measurement at step 1E12 n/cm²
Saturation Voltage	VCE(SAT)	IF = 1mA, IC =5.0mA	MAX : 0.3 V	0.59 V

However, all devices are functional up to 1 E+11 neutrons/cm² total fluence level.

- Average drift current transfer ratio are describe in next table function of the irradiation step and CTR configuration.

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	3.11E-05	6.17E-05	3.49E-04	8.54E-04	7.28E-02
	$\overline{\Delta CTR2}$	%	0.00E+00	1.76E-05	2.58E-05	1.52E-04	4.67E-04	4.11E-02
	$\overline{\Delta CTR3}$	%	0.00E+00	4.50E-05	6.65E-05	2.85E-04	5.29E-04	1.26E-02
	$\overline{\Delta CTR4}$	%	0.00E+00	1.01E-04	1.52E-04	6.32E-04	1.18E-03	8.00E-03
	$\overline{\Delta CTR5}$	%	0.00E+00	9.69E-06	1.85E-05	8.16E-05	1.56E-04	7.48E-03

- CTR5 configuration (If = 10 mA, Vce = 32V) is the least sensitive configuration at all irradiation steps.
- Conversely, CRT4 configuration (If = 40 mA, Vce = 5V) exhibits the greatest parameter degradation up to 1E12n/cm² irradiation steps.
- CRT1 configuration (If = 1 mA, Vce = 5V) exhibits the greatest parameter degradation at 7E12n/cm² step and is out of specification at step 5E11 n/cm².

9 DETAILED TESTS RESULTS

The pre and post radiation test results are shown graphically in the following pages (9-2 to 9-16). 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:

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

For other parameters, the formula used is:

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

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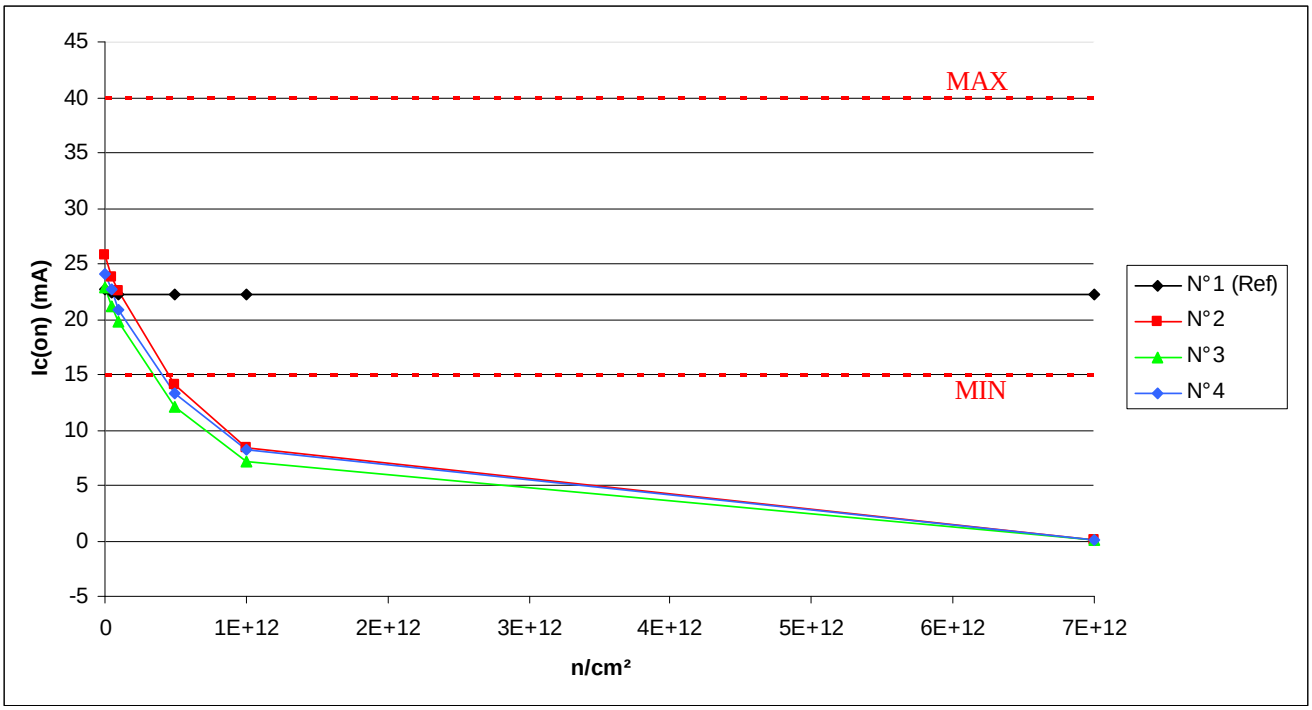
1. IC(on)

Ta = 25°C ; IF = 1mA ; Vce = 5V



Ic(on) . (mA) **Min = 15.0 Max = 40**

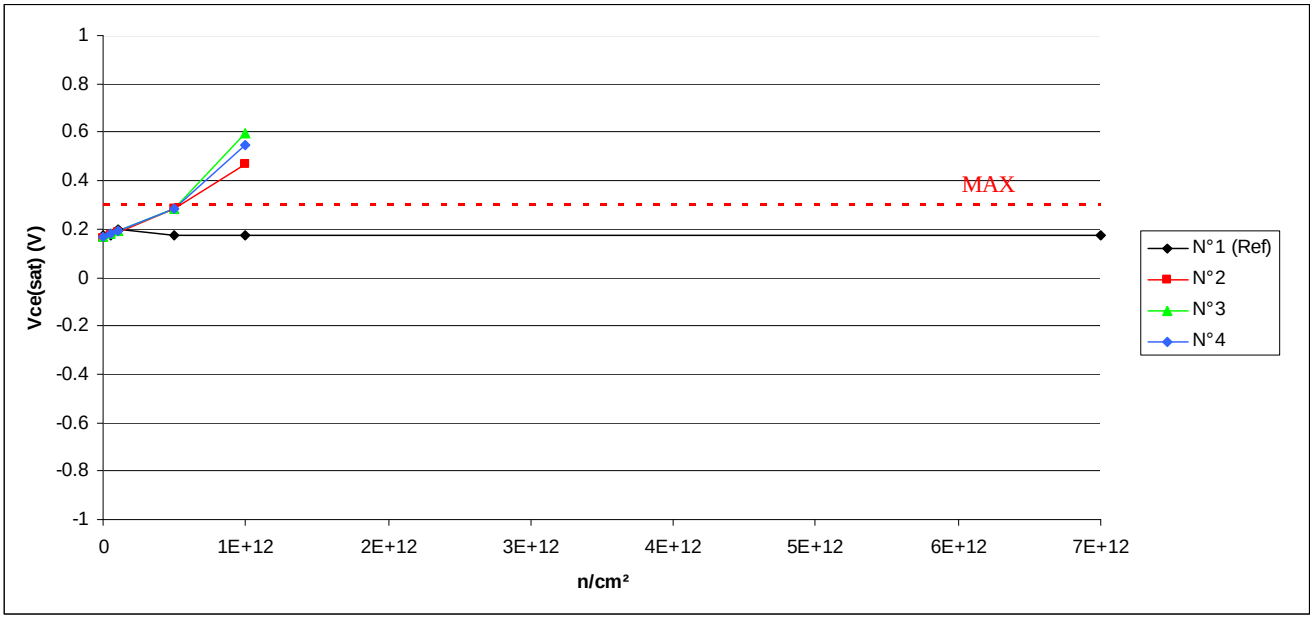
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	22.754	22.369	22.178	22.272	22.283	22.238
N° 2	25.818	23.821	22.531	14.006	8.369	0.147
N° 3	22.783	21.092	19.820	12.108	7.207	0.116
N° 4	24.046	22.646	20.885	13.363	8.190	0.153

Delta [Ic(on)]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-3.845E-1	-5.753E-1	-4.820E-1	-4.704E-1	-5.151E-1
N° 2	---	-1.997E+0	-3.287E+0	-1.181E+1	-1.745E+1	-2.567E+1
N° 3	---	-1.691E+0	-2.964E+0	-1.067E+1	-1.558E+1	-2.267E+1
N° 4	---	-1.400E+0	-3.161E+0	-1.068E+1	-1.586E+1	-2.389E+1
Average	---	-1.696E+0	-3.137E+0	-1.106E+1	-1.629E+1	-2.408E+1
σ	---	2.987E-1	1.630E-1	6.542E-1	1.011E+0	1.510E+0
Average+3σ	---	-8.002E-1	-2.648E+0	-9.094E+0	-1.326E+1	-1.955E+1
Average-3σ	---	-2.592E+0	-3.626E+0	-1.302E+1	-1.933E+1	-2.861E+1

2. Vce(sat)

Ta = 20°C ; IF = 1mA ; Ic = 5mA



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)	0.174	0.174	0.199	0.173	0.174	0.172
N° 2	0.164	0.174	0.188	0.284	0.466	Not Measurable*
N° 3	0.167	0.179	0.192	0.285	0.599	Not Measurable*
N° 4	0.169	0.180	0.191	0.284	0.544	Not Measurable*

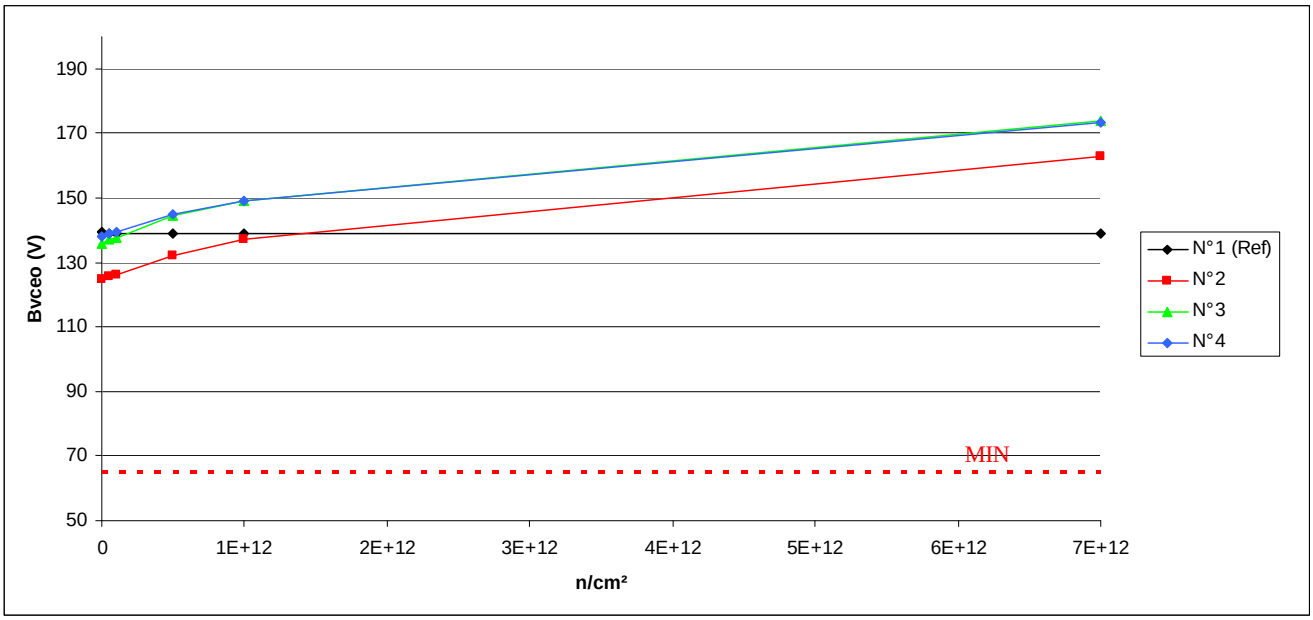
Delta [Vce(sat)]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	5.737E-4	2.536E-2	-9.769E-4	5.650E-5	-1.631E-3
N° 2	---	1.047E-2	2.359E-2	1.198E-1	3.015E-1	NaN
N° 3	---	1.234E-2	2.492E-2	1.183E-1	4.320E-1	NaN
N° 4	---	1.184E-2	2.266E-2	1.152E-1	3.756E-1	NaN
Average	---	1.155E-2	2.372E-2	1.178E-1	3.697E-1	NaN
σ	---	9.659E-4	1.139E-3	2.319E-3	6.546E-2	0.000E+0
Average+3σ	---	1.445E-2	2.714E-2	1.247E-1	5.661E-1	NaN
Average-3σ	---	8.652E-3	2.031E-2	1.108E-1	1.733E-1	NaN

* The parameter is not measurable with this test condition

3. BVceo

Ta = 20°C ; Ice = 1mA



BVceo . (V) **Min = 65.0**

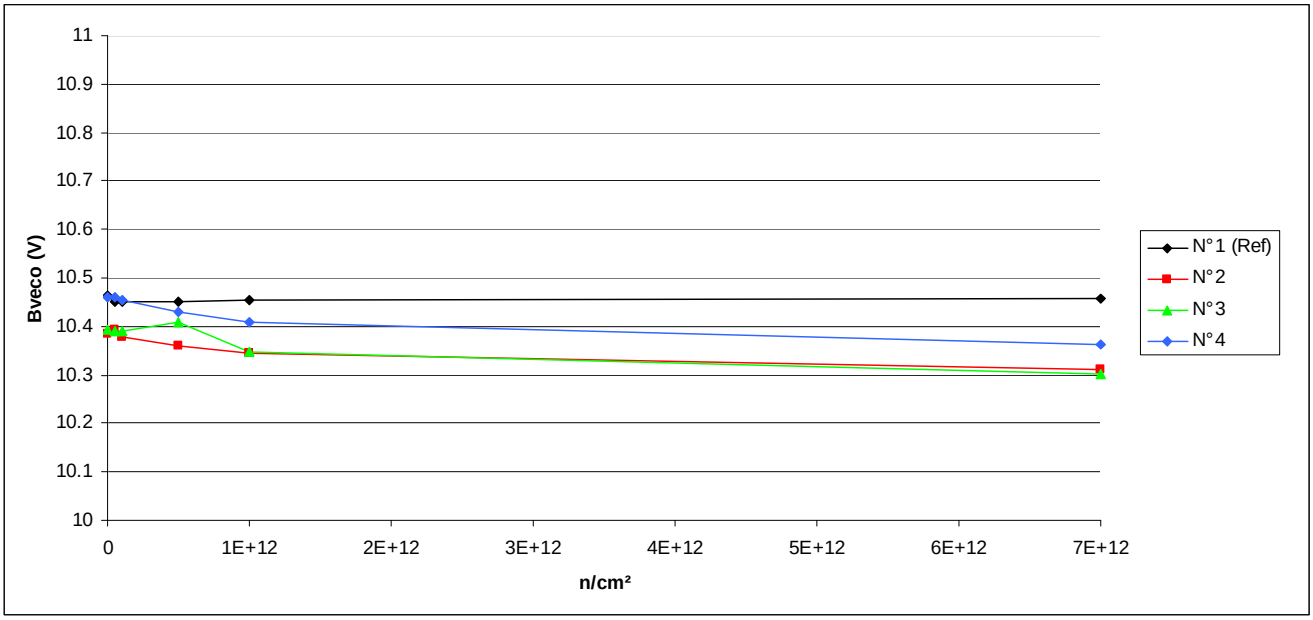
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	139.3	139.0	139.0	139.0	139.1	139.1
N° 2	124.7	125.7	126.3	132.0	137.1	162.8
N° 3	136.0	137.0	137.8	144.5	149.0	173.9
N° 4	137.9	138.9	139.5	144.9	149.0	173.2

Delta [BVceo]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-2.242E-1	-2.157E-1	-2.271E-1	-1.971E-1	-1.671E-1
N° 2	---	9.892E-1	1.606E+0	7.294E+0	1.239E+1	3.811E+1
N° 3	---	1.067E+0	1.807E+0	8.500E+0	1.302E+1	3.797E+1
N° 4	---	9.778E-1	1.564E+0	6.981E+0	1.105E+1	3.524E+1
Average	---	1.011E+0	1.659E+0	7.592E+0	1.216E+1	3.710E+1
σ	---	4.837E-2	1.302E-1	8.018E-1	1.007E+0	1.618E+0
Average+3σ	---	1.156E+0	2.050E+0	9.997E+0	1.518E+1	4.196E+1
Average-3σ	---	8.661E-1	1.269E+0	5.186E+0	9.134E+0	3.225E+1

4. BVeco

Ta = 25°C ; Iec = 100µA



BVeco . (V)

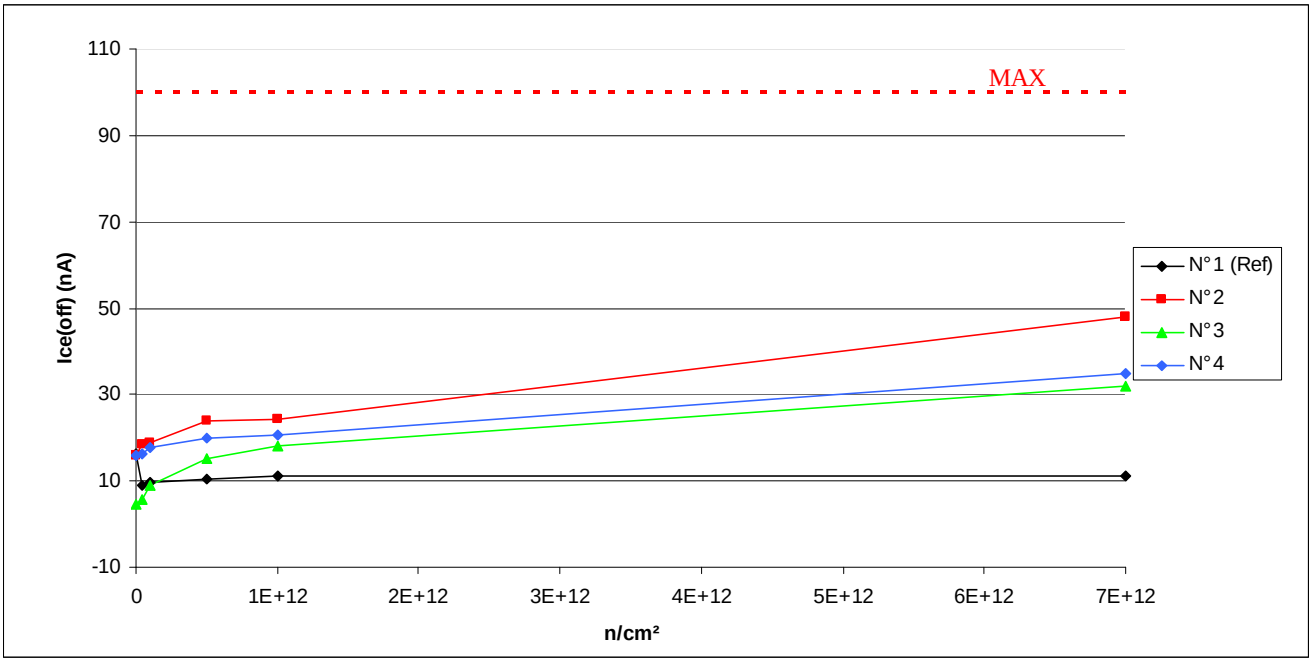
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	10.462	10.452	10.451	10.452	10.455	10.459
N° 2	10.384	10.395	10.378	10.361	10.345	10.312
N° 3	10.394	10.390	10.389	10.408	10.348	10.301
N° 4	10.461	10.460	10.454	10.429	10.409	10.362

Delta [BVeco]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-9.870E-3	-1.071E-2	-9.820E-3	-7.070E-3	-3.590E-3
N° 2	---	1.066E-2	-5.450E-3	-2.299E-2	-3.866E-2	-7.177E-2
N° 3	---	-3.450E-3	-4.910E-3	1.445E-2	-4.589E-2	-9.281E-2
N° 4	---	-1.640E-3	-7.670E-3	-3.199E-2	-5.171E-2	-9.884E-2
Average	---	1.857E-3	-6.010E-3	-1.351E-2	-4.542E-2	-8.781E-2
σ	---	7.677E-3	1.463E-3	2.463E-2	6.538E-3	1.421E-2
Average+3σ	---	2.489E-2	-1.622E-3	6.038E-2	-2.581E-2	-4.517E-2
Average-3σ	---	-2.118E-2	-1.040E-2	-8.740E-2	-6.503E-2	-1.304E-1

5. Ice(off)

Ta = 20°C ; Vce = 20V



Ice(off) . (nA) **Max = 100.0**

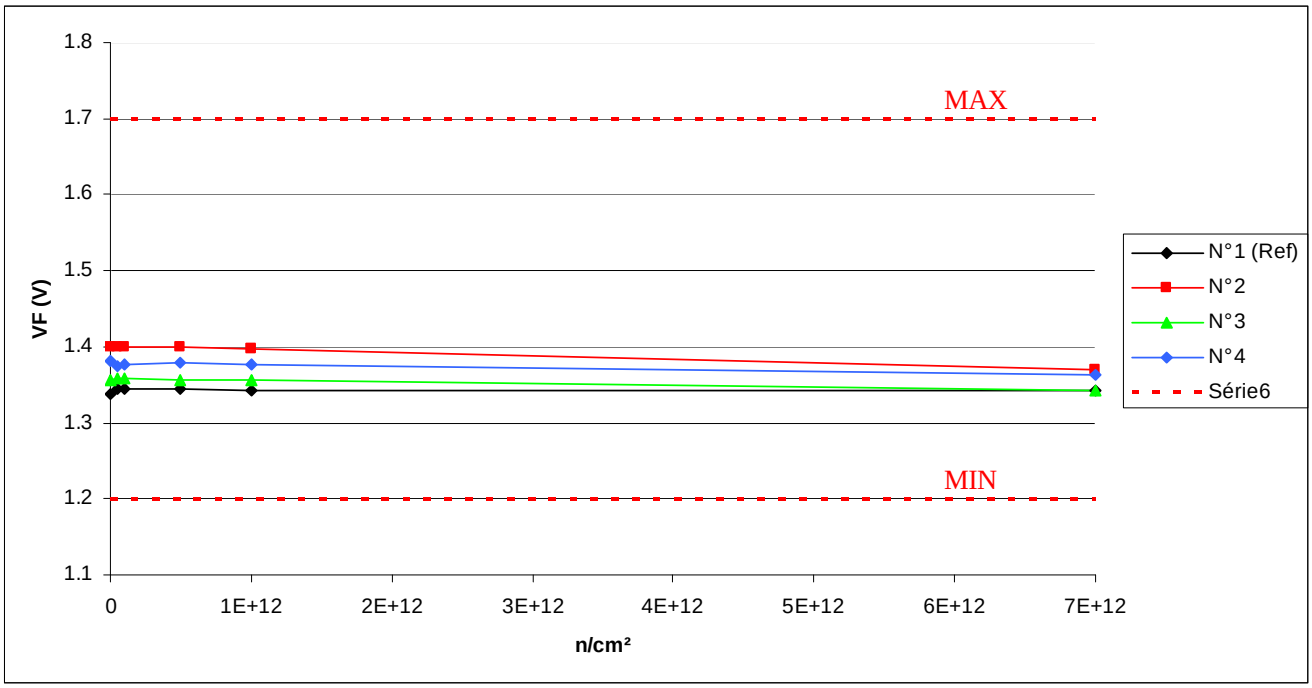
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	16.336	9.135	9.832	10.498	11.130	11.052
N° 2	15.799	18.520	18.901	23.747	24.257	48.135
N° 3	4.632	5.675	8.825	15.276	18.063	31.936
N° 4	16.025	16.417	17.556	19.971	20.511	34.698

Delta [Ice(off)]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-7.201E+0	-6.505E+0	-5.839E+0	-5.207E+0	-5.284E+0
N° 2	---	2.722E+0	3.102E+0	7.948E+0	8.458E+0	3.234E+1
N° 3	---	1.043E+0	4.193E+0	1.064E+1	1.343E+1	2.730E+1
N° 4	---	3.922E-1	1.531E+0	3.946E+0	4.486E+0	1.867E+1
Average	---	1.386E+0	2.942E+0	7.513E+0	8.792E+0	2.610E+1
σ	---	1.202E+0	1.338E+0	3.370E+0	4.482E+0	6.910E+0
Average+3σ	---	4.991E+0	6.956E+0	1.762E+1	2.224E+1	4.683E+1
Average-3σ	---	-2.220E+0	-1.072E+0	-2.597E+0	-4.653E+0	5.374E+0

6. VF

Ta = 20°C ; VF = 10mA



VF . (V) **Min = 1.2 Max = 1.7**

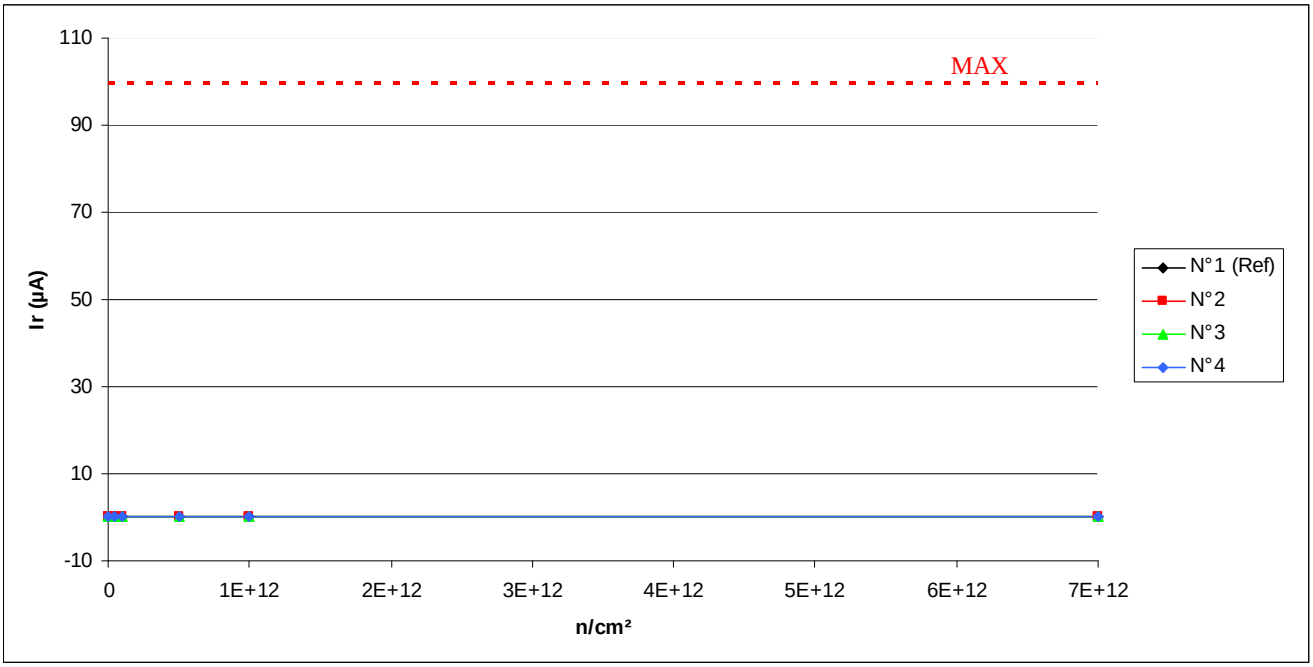
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1.339	1.345	1.345	1.344	1.343	1.342
N° 2	1.399	1.400	1.401	1.400	1.398	1.369
N° 3	1.357	1.358	1.358	1.357	1.355	1.343
N° 4	1.381	1.375	1.377	1.379	1.377	1.364

Delta [VF]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	6.009E-3	5.931E-3	5.361E-3	4.264E-3	3.813E-3
N° 2	---	6.110E-4	1.404E-3	4.430E-4	-1.628E-3	-2.994E-2
N° 3	---	1.597E-3	1.027E-3	3.940E-4	-1.308E-3	-1.357E-2
N° 4	---	-6.531E-3	-3.944E-3	-2.670E-3	-4.342E-3	-1.765E-2
Average	---	-1.441E-3	-5.043E-4	-6.110E-4	-2.426E-3	-2.039E-2
σ	---	4.436E-3	2.985E-3	1.783E-3	1.667E-3	8.519E-3
Average+3σ	---	1.187E-2	8.450E-3	4.739E-3	2.575E-3	5.170E-3
Average-3σ	---	-1.475E-2	-9.459E-3	-5.961E-3	-7.427E-3	-4.595E-2

7. Ir

Ta = 20°C ; Vr = 2V



Ir . (µA) **Max = 100.0**

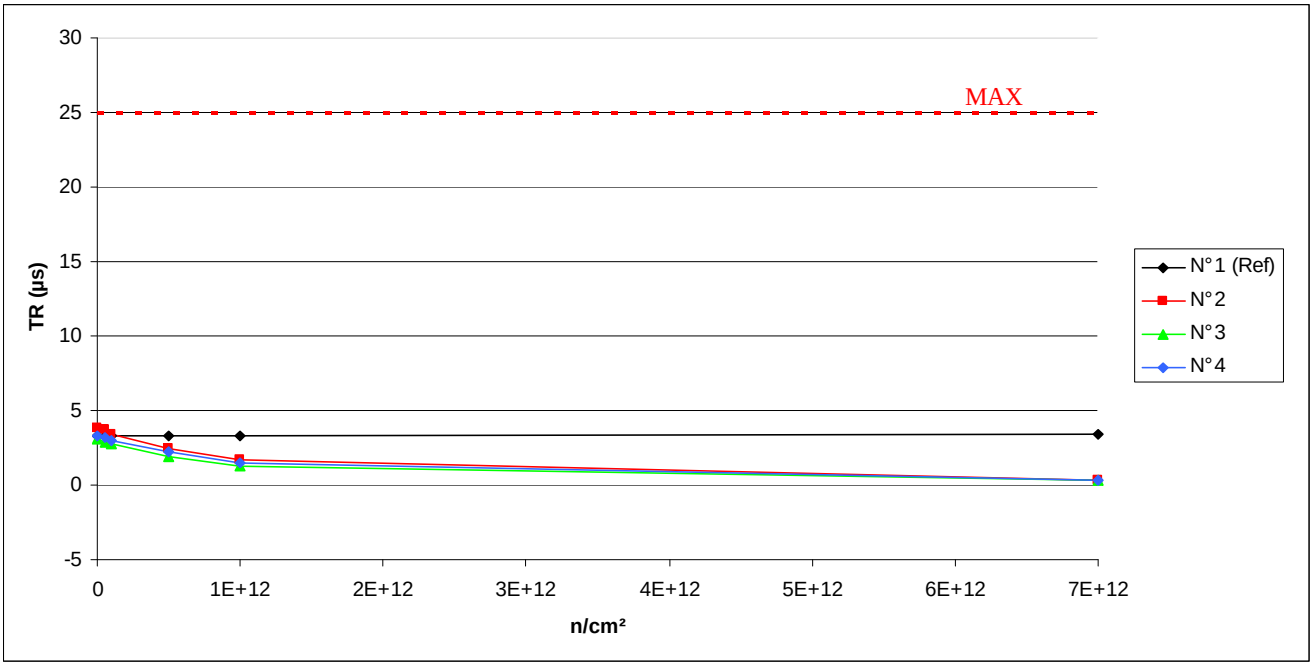
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	5.209E-6	1.343E-5	8.952E-6	1.822E-5	2.760E-5	6.259E-6
N° 2	4.304E-6	9.575E-6	3.883E-5	1.453E-5	2.626E-5	2.362E-5
N° 3	4.226E-5	9.994E-6	4.391E-5	2.941E-5	2.978E-5	2.299E-5
N° 4	7.196E-6	1.016E-5	4.018E-5	3.427E-5	3.142E-5	8.703E-6

Delta [Ir]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	8.220E-6	3.743E-6	1.301E-5	2.239E-5	1.050E-6
N° 2	---	5.271E-6	3.453E-5	1.022E-5	2.196E-5	1.932E-5
N° 3	---	-3.226E-5	1.649E-6	-1.285E-5	-1.247E-5	-1.926E-5
N° 4	---	2.966E-6	3.298E-5	2.707E-5	2.422E-5	1.507E-6
Average	---	-8.008E-6	2.305E-5	8.148E-6	1.124E-5	5.213E-7
σ	---	2.104E-5	1.855E-5	2.004E-5	2.056E-5	1.931E-5
Average+3σ	---	5.510E-5	7.871E-5	6.827E-5	7.292E-5	5.845E-5
Average-3σ	---	-7.112E-5	-3.260E-5	-5.198E-5	-5.045E-5	-5.741E-5

8. TR

Ta = 20°C ; Vcc = 10V ; RL = 100 Ohms ; IF = 5mA



TR . (µs) **Max = 25.0**

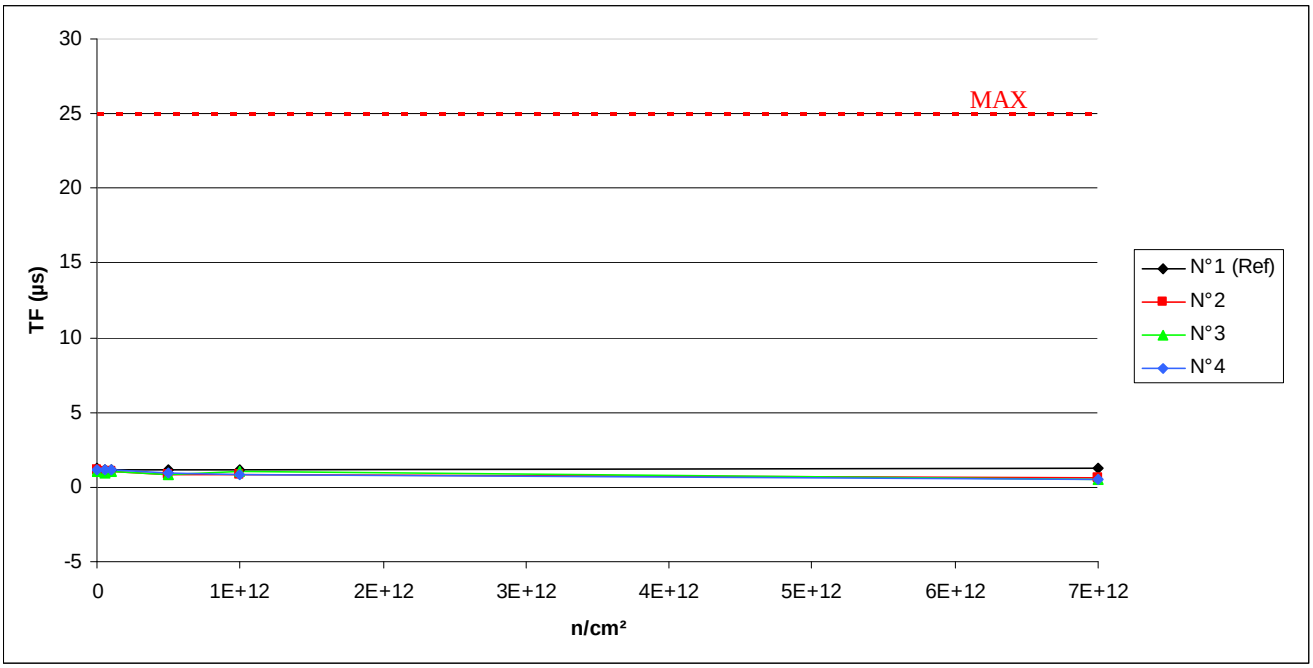
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	3.30	3.30	3.30	3.30	3.30	3.40
N° 2	3.80	3.70	3.40	2.50	1.70	0.35
N° 3	3.10	2.90	2.80	1.90	1.30	0.31
N° 4	3.30	3.20	3.00	2.20	1.50	0.30

Delta [TR]

	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	1.000E-1
N° 2	---	-1.000E-1	-4.000E-1	-1.300E+0	-2.100E+0	-3.450E+0
N° 3	---	-2.000E-1	-3.000E-1	-1.200E+0	-1.800E+0	-2.790E+0
N° 4	---	-1.000E-1	-3.000E-1	-1.100E+0	-1.800E+0	-3.000E+0
Average	---	-1.333E-1	-3.333E-1	-1.200E+0	-1.900E+0	-3.080E+0
σ	---	5.774E-2	5.774E-2	1.000E-1	1.732E-1	3.372E-1
Average+3σ	---	3.987E-2	-1.601E-1	-9.000E-1	-1.380E+0	-2.068E+0
Average-3σ	---	-3.065E-1	-5.065E-1	-1.500E+0	-2.420E+0	-4.092E+0

9. TF

Ta = 20°C ; Vcc = 10V ; RL = 100 Ohms ; IF = 5mA



TF . (µs) **Max = 25.0**

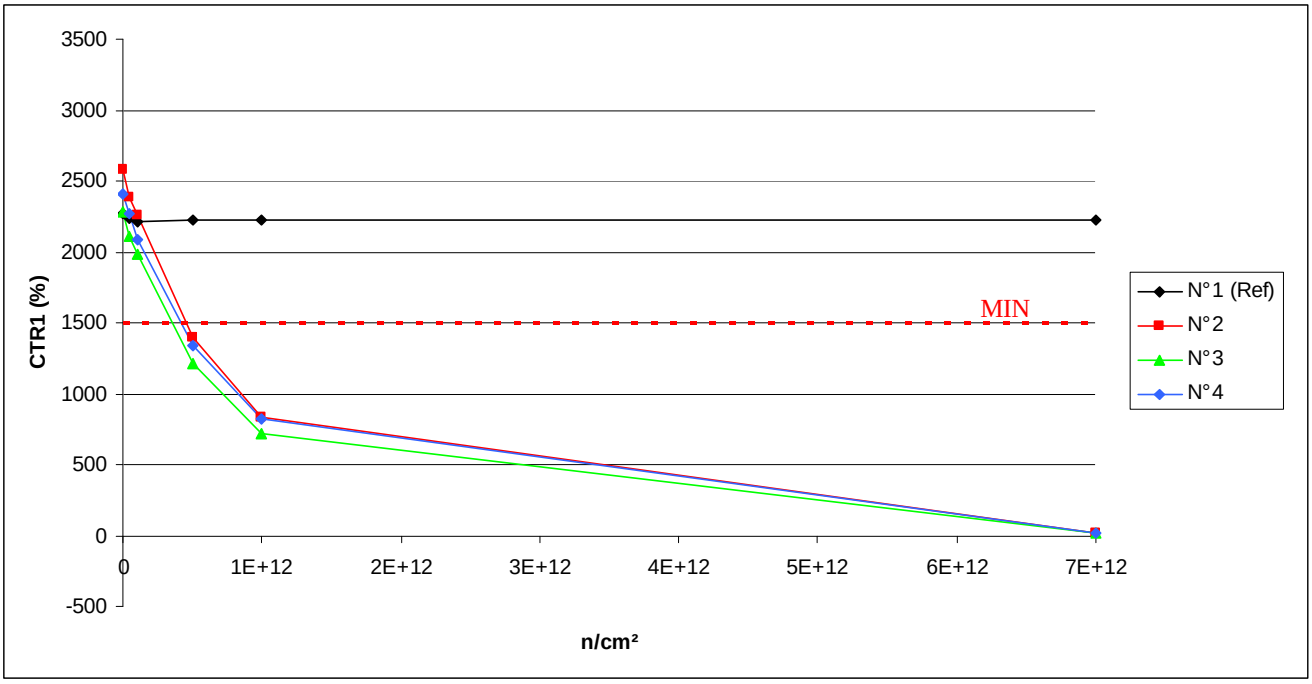
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1.30	1.20	1.20	1.20	1.20	1.30
N° 2	1.10	1.00	1.00	0.80	0.80	0.62
N° 3	1.00	0.90	1.00	0.80	1.00	0.47
N° 4	1.20	1.10	1.10	0.90	0.80	0.55

Delta [TF]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-1.000E-1	-1.000E-1	-1.000E-1	-1.000E-1	0.000E+0
N° 2	---	-1.000E-1	-1.000E-1	-3.000E-1	-3.000E-1	-4.800E-1
N° 3	---	-1.000E-1	0.000E+0	-2.000E-1	0.000E+0	-5.300E-1
N° 4	---	-1.000E-1	-1.000E-1	-3.000E-1	-4.000E-1	-6.500E-1
Average	---	-1.000E-1	-6.667E-2	-2.667E-1	-2.333E-1	-5.533E-1
σ	---	1.110E-16	5.774E-2	5.774E-2	2.082E-1	8.737E-2
Average+3σ	---	-1.000E-1	1.065E-1	-9.346E-2	3.912E-1	-2.912E-1
Average-3σ	---	-1.000E-1	-2.399E-1	-4.399E-1	-8.578E-1	-8.154E-1

10.CTR1

Ta = 25°C ; IF = 1mA ; Vce = 5V



CTR1 . (%) **Min = 1500.0**

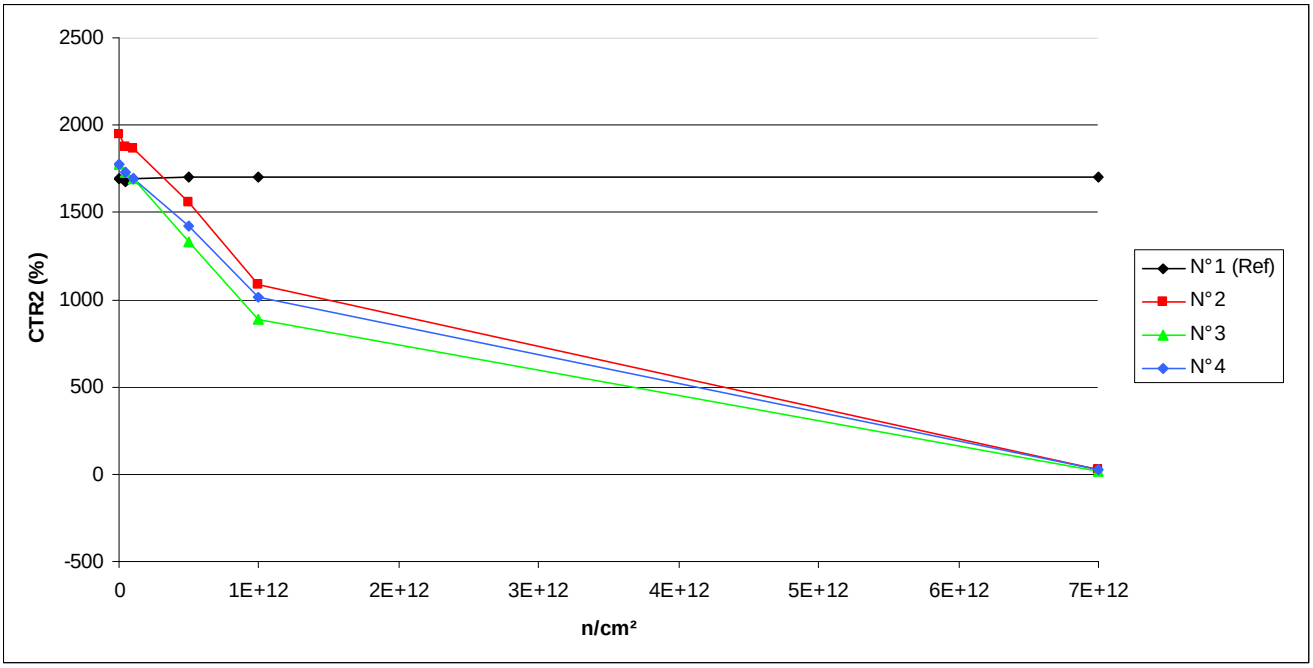
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	2275.35	2236.90	2217.82	2227.15	2228.32	2223.84
N° 2	2581.84	2382.09	2253.14	1400.63	836.86	14.75
N° 3	2278.33	2109.25	1981.96	1210.89	720.66	11.59
N° 4	2404.58	2264.56	2088.49	1336.27	818.98	15.27

1/Delta [CTR1]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	7.555E-6	1.140E-5	9.511E-6	9.277E-6	1.018E-5
N° 2	---	3.248E-5	5.650E-5	3.266E-4	8.076E-4	6.742E-2
N° 3	---	3.518E-5	6.563E-5	3.870E-4	9.487E-4	8.584E-2
N° 4	---	2.571E-5	6.294E-5	3.325E-4	8.052E-4	6.508E-2
Average	---	3.113E-5	6.169E-5	3.487E-4	8.538E-4	7.278E-2
σ	---	4.877E-6	4.690E-6	3.327E-5	8.217E-5	1.137E-2
Average+3σ	---	4.576E-5	7.576E-5	4.485E-4	1.100E-3	1.069E-1
Average-3σ	---	1.649E-5	4.762E-5	2.489E-4	6.073E-4	3.867E-2

11.CTR2

Ta = 20°C ; IF = 2mA ; Vce = 5V



CTR2 . (%)

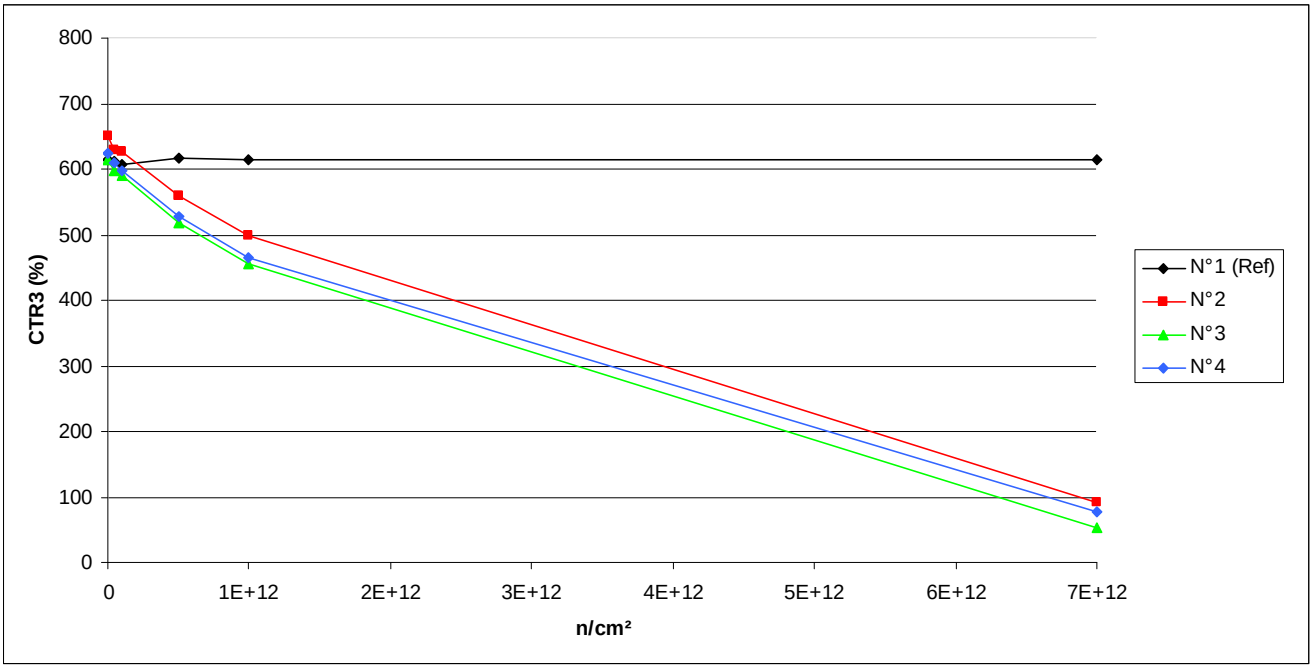
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	1697.49	1675.63	1689.73	1703.46	1705.93	1704.08
N° 2	1947.39	1874.03	1868.80	1555.38	1085.59	26.64
N° 3	1776.78	1725.22	1692.60	1330.94	882.83	19.75
N° 4	1774.94	1726.27	1691.86	1424.99	1014.95	27.30

1/Delta [CTR2]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	7.685E-6	2.705E-6	-2.064E-6	-2.913E-6	-2.278E-6
N° 2	---	2.010E-5	2.159E-5	1.294E-4	4.077E-4	3.703E-2
N° 3	---	1.682E-5	2.799E-5	1.885E-4	5.699E-4	5.008E-2
N° 4	---	1.588E-5	2.767E-5	1.384E-4	4.219E-4	3.607E-2
Average	---	1.760E-5	2.575E-5	1.521E-4	4.665E-4	4.106E-2
σ	---	2.214E-6	3.603E-6	3.186E-5	8.985E-5	7.827E-3
Average+3σ	---	2.424E-5	3.656E-5	2.477E-4	7.360E-4	6.454E-2
Average-3σ	---	1.096E-5	1.494E-5	5.652E-5	1.969E-4	1.758E-2

12.CTR3

Ta = 20°C ; IF = 10mA ; Vce = 5V



CTR3 . (%)

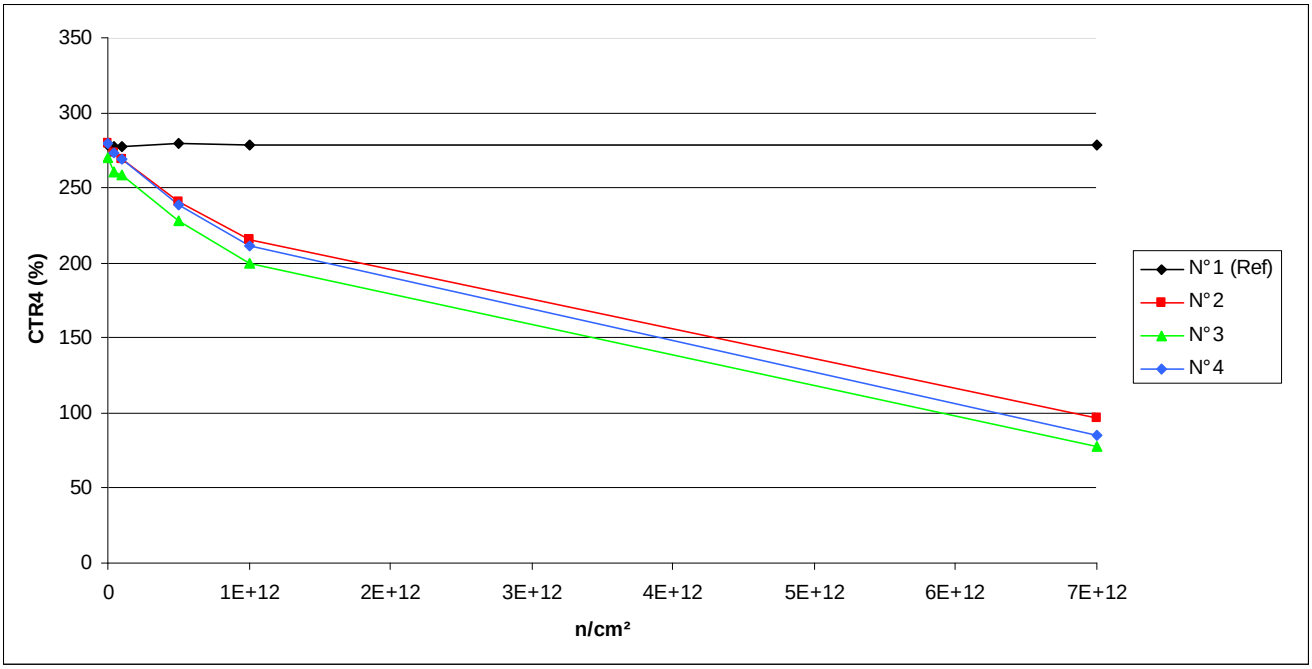
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	614.12	611.14	608.21	617.57	615.32	614.05
N° 2	649.73	629.28	625.54	558.35	499.86	90.51
N° 3	613.94	597.70	589.23	517.32	454.55	53.98
N° 4	625.20	609.72	598.42	527.13	464.08	77.66

1/Delta [CTR3]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	7.937E-6	1.583E-5	-9.079E-6	-3.162E-6	2.045E-7
N° 2	---	5.001E-5	5.952E-5	2.519E-4	4.614E-4	9.509E-3
N° 3	---	4.425E-5	6.831E-5	3.042E-4	5.712E-4	1.690E-2
N° 4	---	4.059E-5	7.156E-5	2.976E-4	5.553E-4	1.128E-2
Average	---	4.495E-5	6.647E-5	2.846E-4	5.293E-4	1.256E-2
σ	---	4.750E-6	6.228E-6	2.848E-5	5.931E-5	3.858E-3
Average+3σ	---	5.920E-5	8.515E-5	3.700E-4	7.072E-4	2.414E-2
Average-3σ	---	3.070E-5	4.778E-5	1.991E-4	3.514E-4	9.871E-4

13.CTR4

Ta = 20°C ; IF = 40mA ; Vce = 5V



CTR4 . (%)

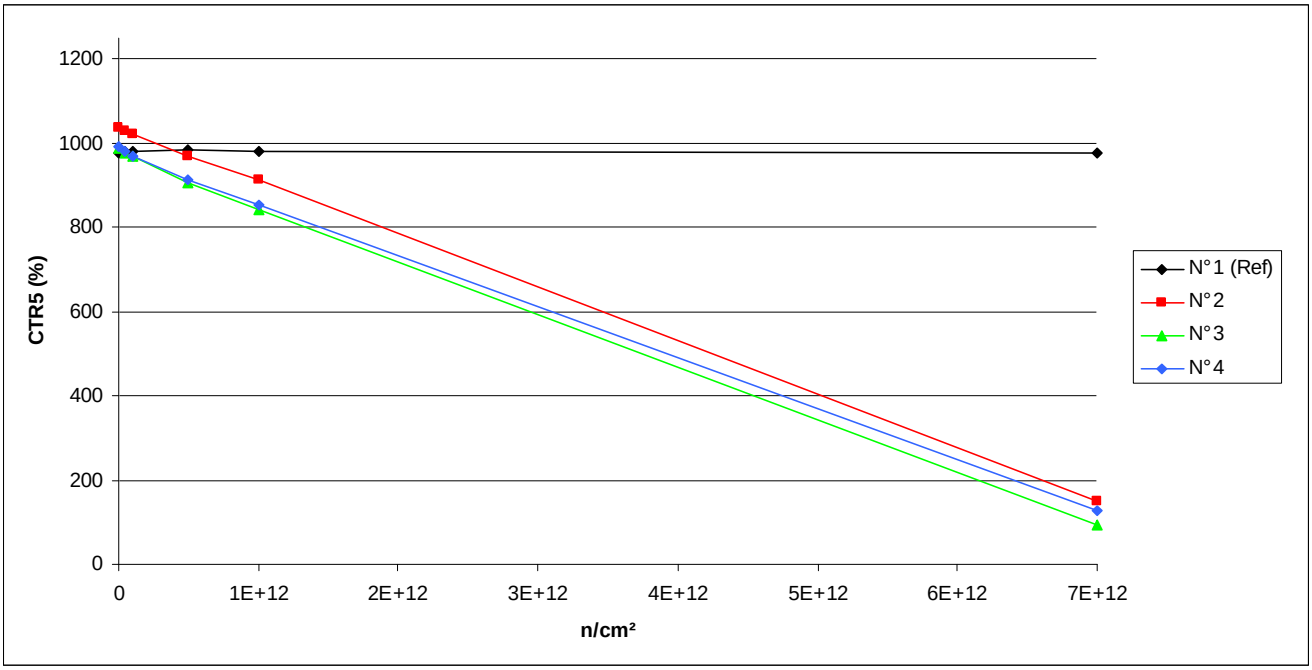
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	278.65	277.56	277.61	279.62	278.75	278.15
N° 2	279.66	272.86	269.08	240.48	215.26	96.71
N° 3	269.72	260.70	258.22	227.55	199.65	78.13
N° 4	279.99	273.56	268.68	238.16	210.76	85.36

1/Delta [CTR4]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.415E-5	1.344E-5	-1.242E-5	-1.281E-6	6.393E-6
N° 2	---	8.914E-5	1.407E-4	5.826E-4	1.070E-3	6.764E-3
N° 3	---	1.283E-4	1.650E-4	6.870E-4	1.301E-3	9.091E-3
N° 4	---	8.401E-5	1.504E-4	6.274E-4	1.173E-3	8.144E-3
Average	---	1.005E-4	1.520E-4	6.323E-4	1.181E-3	8.000E-3
σ	---	2.422E-5	1.223E-5	5.236E-5	1.159E-4	1.170E-3
Average+3σ	---	1.731E-4	1.887E-4	7.894E-4	1.529E-3	1.151E-2
Average-3σ	---	2.783E-5	1.153E-4	4.752E-4	8.337E-4	4.490E-3

14.CTR5

Ta = 20°C ; IF = 10mA ; Vce = 32V



CTR5 . (%)

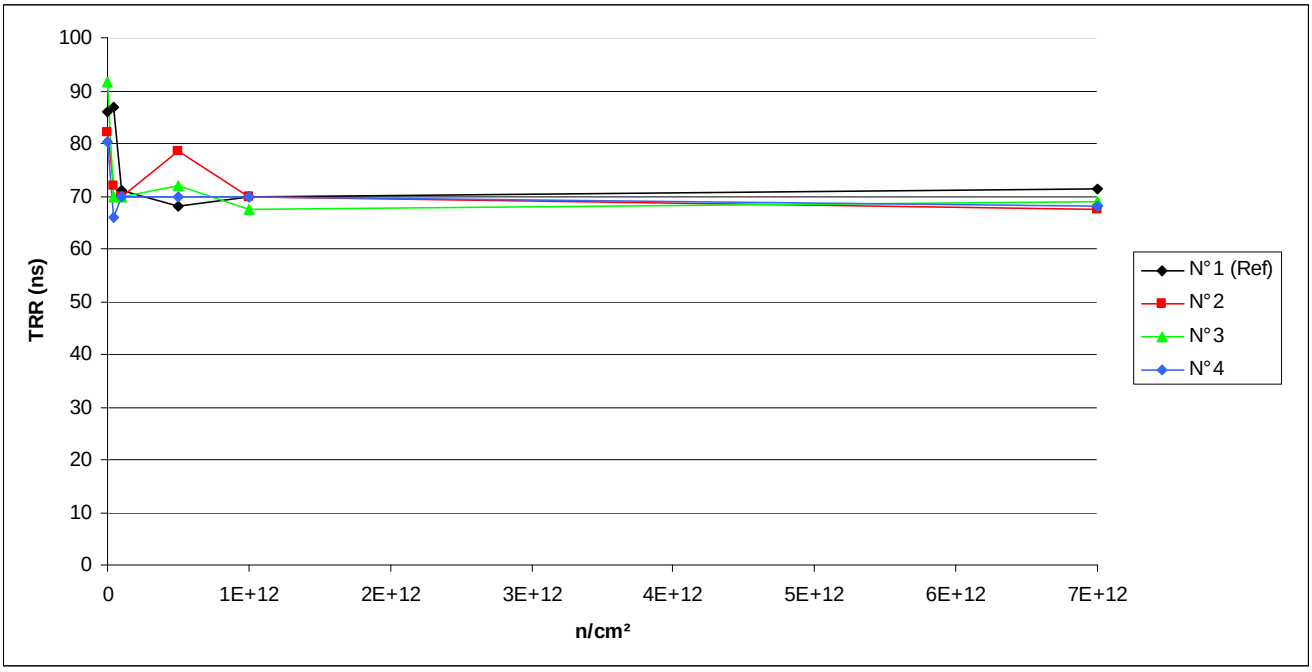
	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	976.35	980.71	980.21	985.09	979.57	976.06
N° 2	1038.01	1029.98	1022.88	968.69	914.02	148.48
N° 3	986.709	977.74	967.73	906.55	841.59	92.99
N° 4	991.45	979.54	970.96	913.33	853.97	126.18

1/Delta [CTR5]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	-4.546E-6	-4.033E-6	-9.087E-6	-3.366E-6	3.120E-7
N° 2	---	7.505E-6	1.425E-5	6.894E-5	1.307E-4	5.771E-3
N° 3	---	9.299E-6	1.987E-5	8.961E-5	1.748E-4	9.739E-3
N° 4	---	1.226E-5	2.128E-5	8.627E-5	1.624E-4	6.916E-3
Average	---	9.689E-6	1.847E-5	8.161E-5	1.559E-4	7.476E-3
σ	---	2.403E-6	3.724E-6	1.109E-5	2.273E-5	2.042E-3
Average+3σ	---	1.690E-5	2.964E-5	1.149E-4	2.241E-4	1.360E-2
Average-3σ	---	2.480E-6	7.296E-6	4.832E-5	8.774E-5	1.349E-3

15.TRR

Ta = 20°C ; IF = 2mA ; RL = 100 Ohms ; 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)	86	87	71	68	70	71
N° 2	82	72	70	78	70	67
N° 3	92	70	70	72	68	69
N° 4	80	66	70	70	70	68

Delta [TRR]

	0.n/cm²	5E10.n/cm²	1E11.n/cm²	5E11.n/cm²	1E12.n/cm²	7E12.n/cm²
N° 1 (Ref)	---	1.010E+0	-1.493E+1	-1.800E+1	-1.600E+1	-1.471E+1
N° 2	---	-1.000E+1	-1.200E+1	-3.569E+0	-1.200E+1	-1.467E+1
N° 3	---	-2.167E+1	-2.167E+1	-1.967E+1	-2.417E+1	-2.281E+1
N° 4	---	-1.433E+1	-1.033E+1	-1.033E+1	-1.033E+1	-1.233E+1
Average	---	-1.533E+1	-1.466E+1	-1.119E+1	-1.550E+1	-1.661E+1
σ	---	5.898E+0	6.121E+0	8.083E+0	7.554E+0	5.504E+0
Average+3σ	---	2.362E+0	3.699E+0	1.306E+1	7.162E+0	-9.425E-2
Average-3σ	---	-3.302E+1	-3.303E+1	-3.544E+1	-3.816E+1	-3.312E+1