PROTONS TEST REPORT

ESA study: “Survey of Critical Components for 150 kRad Power Systems”

ESTEC Contract N° 22831/09/NL/AF refers

Part Type : 2N5154

Package : TO-39

Description : NPN Medium Power Silicon Switching Transistor

Manufacturer: Microsemi Corporation

Date Code: 1023

Alter Technology Group Spain Purchase Order N° ATGSP-TL-09-JC-CO-9 dated 11/27/2009

Alter Technology Group Spain Project Manager: David NUNEZ

Hirex reference :	HRX/TID/0919	Issue : 02	Date :	January 24st, 2012
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CHANGE RECORD

ISSUE	DATE	PAGE	DESCRIPTION OF CHANGES
01	June 01st, 2011	All	Original Issue
02	January 24st, 2012	10 to 23	Update serial numbers on curves and data table

PROTONS TEST REPORT
on
2N5154
NPN Medium Power Silicon Switching Transistor

From Microsemi Corporation

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1 Introduction

In the scope of the ESA study: “Survey of Critical Components for 150 kRad Power Systems”, a protons test of the Microsemi Corporation 2N5154, NPN Medium Power Silicon Switching Transistor has been performed up to a total fluence of about 2E11 p/cm^2, in response to Alter Technology Group Spain purchase order reference ATGSP-TL-09-JC-CO-9 that refers to ESTEC contract N° 22831/09/NL/AF.

Displacement damage effects were investigated using 60 MeV protons energy. Devices were irradiated at UCL in Louvain - Belgium.

The purpose of this test was to characterize degradation due to proton displacement damage so a further mission analysis could determine their suitability for flight use. This test was conducted on samples provided by Alter Technology Group Spain.
Test has been performed in accordance with Hirex Engineering Radiation Test Plan HRX/SPE/0248 issue 1 dated 04/19/2011.

A complete set of electrical measurements together with graphical representation of measured parameters with respect to Equivalent Fluence levels received is also presented.

2 Applicable and Reference Documents

2.1 Applicable Documents

- Hirex Engineering Radiation Test Plan: HRX/SPE/0248 issue 1 dated 04/19/2011
- Alter Technology Group Proposal: ATGSP-OF-648/2009 Issue 1
- Minutes of Meeting: MM-SRP-ATG-0001 dated 29/10/2009
- Hirex specification: Total Ionizing dose test general procedure.
- MIL detail specification: MIL-PRF-19500/544G

2.2 Reference Documents

- Microsemi Corporation datasheet: T4-LDS-0039 Rev. 1 (080797)

3 Test Samples

7 samples of the 2N5154 devices were tested (6 + 1 control sample).
Allocation of samples used for testing is provided in the following table.

Serial Number	Samples Allocation
1	Control sample
23	Biased OFF
24	Biased OFF
25	Biased OFF
26	Biased OFF
27	Biased OFF
28	Biased OFF

Identification of the 2N5154 is given below:

Part Number: 2N5154

Top Marking: MSC E1023 F2N5154

Inspection lot: -

Date Code: 1023

4 Experimental Conditions

4.1 Radiation Source Description

The protons exposures were performed at the UCL facility in Louvain-la-Neuve - Belgium.
The Proton Irradiation facility (Light Ion irradiation Facility or LIF) was used for this experiment. The corresponding experimental set-up is shown in Figure 1.

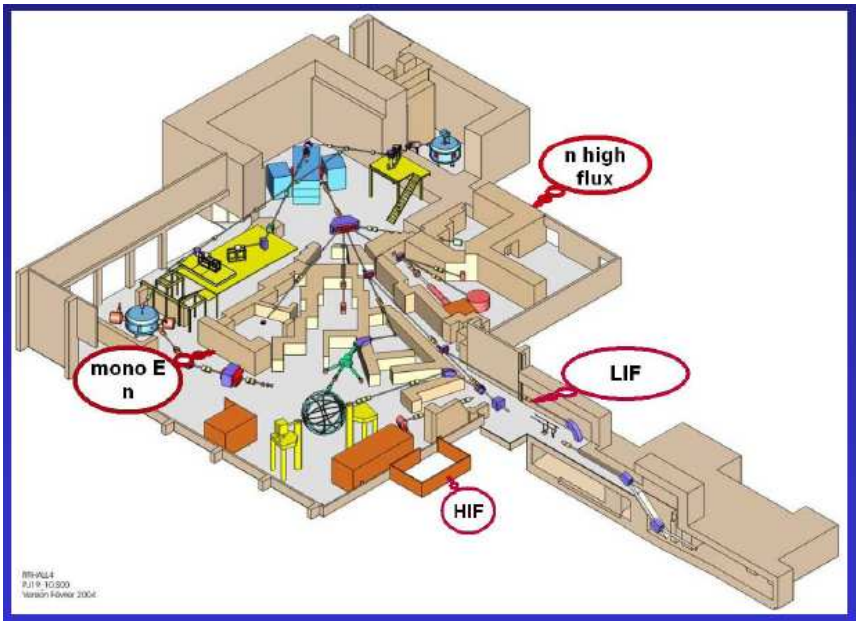


Figure 1 : LIF layout and typical experimental set-up

Light Ion irradiation Facility is characterized by the following beam parameters:
• Initial Proton Energies: 65 MeV;
• Energy Range: 9.3 – 62 MeV using energy degraders (See figure 2)
• Beam Flux at 62 MeV is between 10p/cm2/sec to 5E8 p/cm2/sec
• Irradiation Area: 8 cm diameter maximum

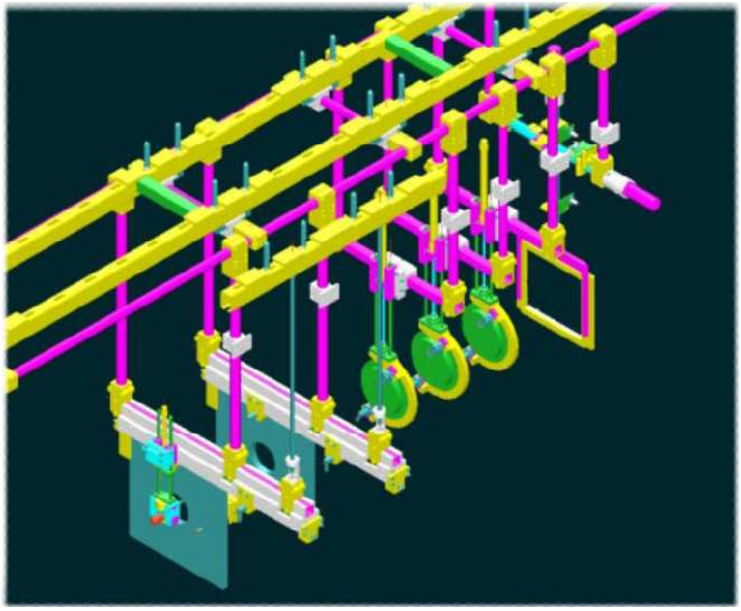


Figure 2: LIF Energy degraders

The irradiation conditions used for this test are provided in the following table:

Fluence Steps	Total Fluence	Flux	Equivalent Total Dose	T
p/cm² @60MeV	p/cm² @60MeV	p/cm²/s	Rad (Si)	°C
0	0		0	
2E+11	2E+11	5.00E+08	27.5E+3	25

4.2 Bias during Dose Exposures and Measurements conditions

4.2.1 Bias conditions

During exposures all samples were biased OFF with all pins connected to ground.

4.2.2 Electrical Measurements

Electrical parameters test program principle for 2N5154 is provided in Figure 3.

A HP4142 DC tester and a network analyzer HP8714ES were used to perform required measurements.

A dedicated test fixture and a test board were designed to ensure proper measurement conditions.

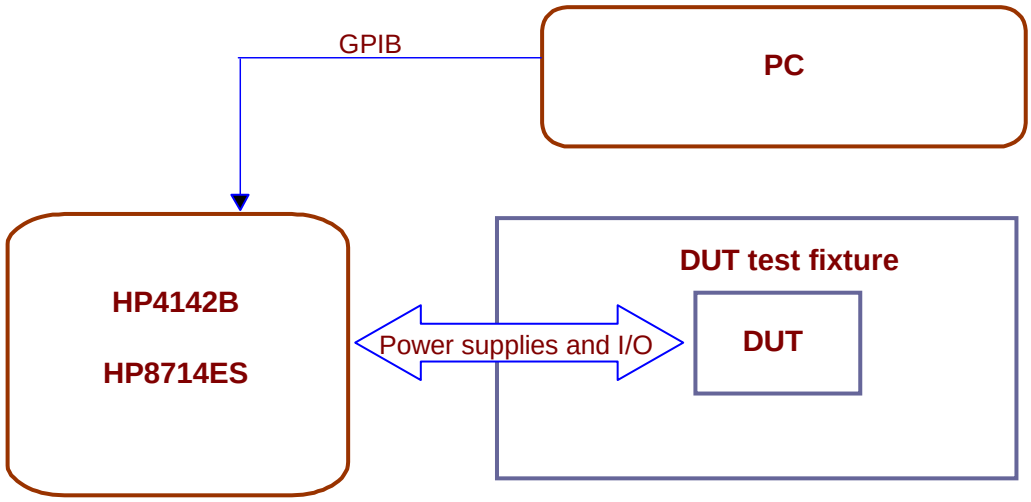


Figure 3 : 2N5154 test program principle

Electrical parameters test conditions and limits used for performing this test are given in Table 1.

Parameter	Description	Conditions	Spec		Unit
			Min	Max	
I_{CES1}	Collector-Emitter cut-off current	V_{CE} = 60V, V_{BE} = 0V	-	1	µA
I_{CES2}	Collector-Emitter cut-off current	V_{CE} = 100V, V_{BE} = 0V	-	1	mA
I_{CEO}	Collector-Emitter cut-off current	V_{CE} = 40V, I_B = 0A	-	50	µA
I_{EBO1}	Emitter-Base cut-off current	V_{EB} = 4V, I_C = 0A	-	1	µA
I_{EBO2}	Emitter-Base cut-off current	V_{EB} = 5.5V, I_C = 0A	-	1	mA
$V_{(BR)CEO}$	Collector-Emitter breakdown voltage	I_C = 100mA, Note 1	80	-	V
$V_{CE(SAT)1}$	Collector-Emitter saturation voltage	I_C = 2.5A I_B = 250mA, Note 1	-	0.75	V
$V_{CE(SAT)2}$	Collector-Emitter saturation voltage	I_C = 5A I_B = 500mA, Note 1	-	1.5	V
$V_{BE(SAT)1}$	Base-Emitter saturation voltage	I_C = 2.5A I_B = 250mA, Note 1	-	1.45	V
$V_{BE(SAT)2}$	Base-Emitter saturation voltage	I_C = 5A I_B = 500mA, Note 1	-	2.2	V
H_{FE1}	Forward-current transfer ratio	I_C = 50mA, V_{CE} = 5V, Note 1	50	-	-
H_{FE2}	Forward-current transfer ratio	I_C = 2.5A, V_{CE} = 5V, Note 1	70	200	-
H_{FE3}	Forward-current transfer ratio	I_C = 5A, V_{CE} = 5V, Note 1	40	-	-
F_T	Gain Bandwidth Product	V_{CE} = 5V, I_C = 0.5A	70	-	MHz

Note 1 - Pulse measurement: Pulse Width ≤ 300µs, duty cycle 1%.

Table 1 : Measured electrical parameters

5 Conclusion

A proton displacement damage test was carried out by Hirex Engineering under Alter Technology Group Spain contract on the Microsemi Corporation 2N5154 NPN Medium Power Silicon Switching Transistor in TO-39 package.

Each device was exposed at room temperature to a protons flux of 60 MeV incident energy up to a total fluence of 2E+11p/cm².

Gain Bandwidth Product parameter F_T was found below minimum specification limit at initial measurements step. No significant drift was observed on this parameter after exposure.

A summary of failed parameters is provided in the following table.
Parameters not listed remained within specification limits all along testing.
Detail test results are presented in the following section.

Parameters	Failure Level between :	Comments
HFE1	0 & 2 E+11p p/cm²	
HFE2	0 & 2 E+11p p/cm²	

Table 2 : Summary of failed parameters

6 Test Results

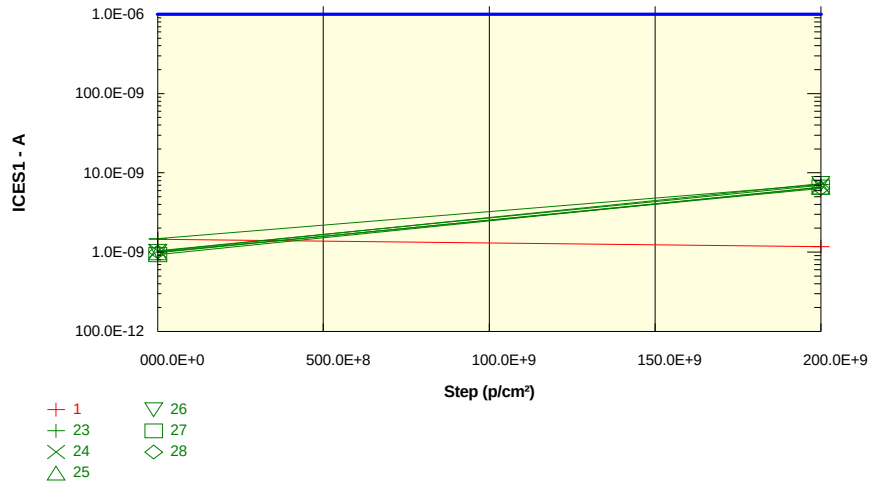
Test results including tables and graphics are provided in this section for each measured parameter.

Parameter measurements values are plotted versus Equivalent Fluence levels for 60 MeV incident energy protons. Fluences are expressed in protons/cm^2 in Silicon.

For each parameter, a drift calculation table is provided computing the drift between a given exposure step with respect to initial readings:

$$\Delta\text{(Parameter value)}=\text{(Parameter value}_{POSTRAD}\text{)} - \text{(Parameter value}_{PRERAD}\text{)}$$

Parameter : Collector-Emitter Cut-Off Current : ICES1
Test conditions : VCE=60V. VBE=0V
Unit : A
Spec Limit Max : 1.0E-06
Spec limits are represented in bold lines on the graphic.



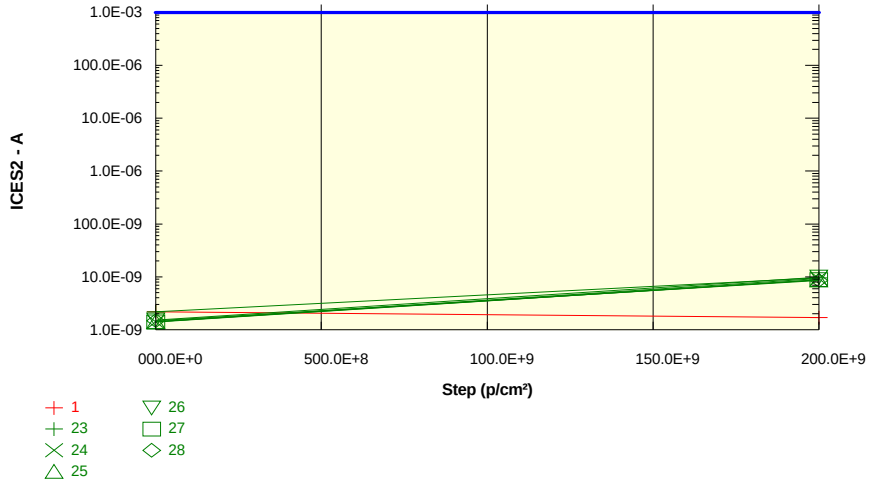
Measurements

ICES1	0 p/cm²	2E+11 p/cm²
1_REF	1.4E-09	1.2E-09
OFF samples		
23	1.5E-09	7.1E-09
24	1.0E-09	7.0E-09
26	1.0E-09	7.3E-09
25	986.0E-12	6.6E-09
27	932.6E-12	6.6E-09
28	1.0E-09	6.4E-09
Statistics		
Min	932.6E-12	6.4E-09
Max	1.5E-09	7.3E-09
Average	1.1E-09	6.8E-09
Sigma	183.9E-12	342.0E-12

Drift Calculation

ICES1	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	5.6E-09
24	-	6.0E-09
26	-	6.3E-09
25	-	5.6E-09
27	-	5.7E-09
28	-	5.4E-09
Average	-	5.8E-09
Sigma	-	307.4E-12

Parameter : Collector-Emitter Cut-Off Current : ICES2
Test conditions : VCE=100V. VBE=0V
Unit : A
Spec Limit Max : 1.0E-03
Spec limits are represented in bold lines on the graphic.



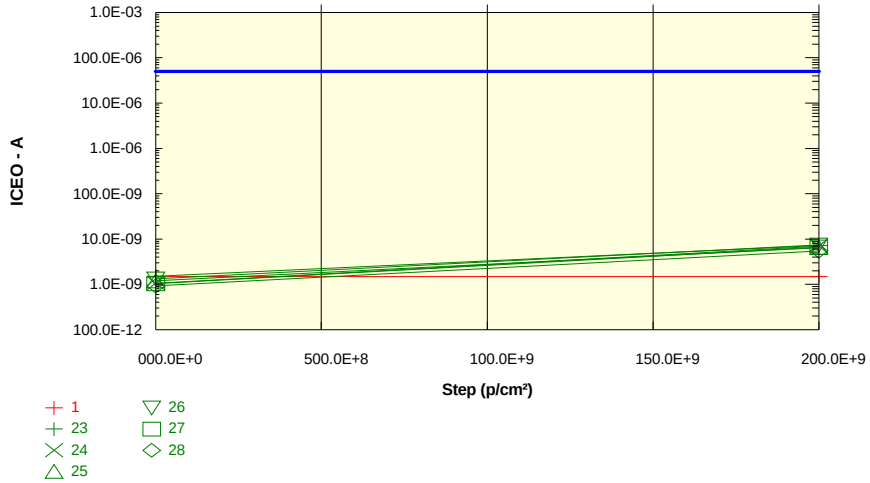
Measurements

ICES2	0 p/cm²	2E+11 p/cm²
1_REF	2.2E-09	1.7E-09
OFF samples		
23	2.2E-09	9.6E-09
24	1.4E-09	9.4E-09
26	1.5E-09	9.8E-09
25	1.4E-09	8.8E-09
27	1.4E-09	8.9E-09
28	1.5E-09	8.6E-09
Statistics		
Min	1.4E-09	8.6E-09
Max	2.2E-09	9.8E-09
Average	1.6E-09	9.2E-09
Sigma	278.0E-12	450.5E-12

Drift Calculation

ICES2	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	7.4E-09
24	-	8.0E-09
26	-	8.3E-09
25	-	7.4E-09
27	-	7.5E-09
28	-	7.1E-09
Average	-	7.6E-09
Sigma	-	399.8E-12

Parameter : Collector-Emitter Cut-Off Current : ICEO
Test conditions : VCE=40V. IB=0A
Unit : A
Spec Limit Max : 50.0E-06
Spec limits are represented in bold lines on the graphic.



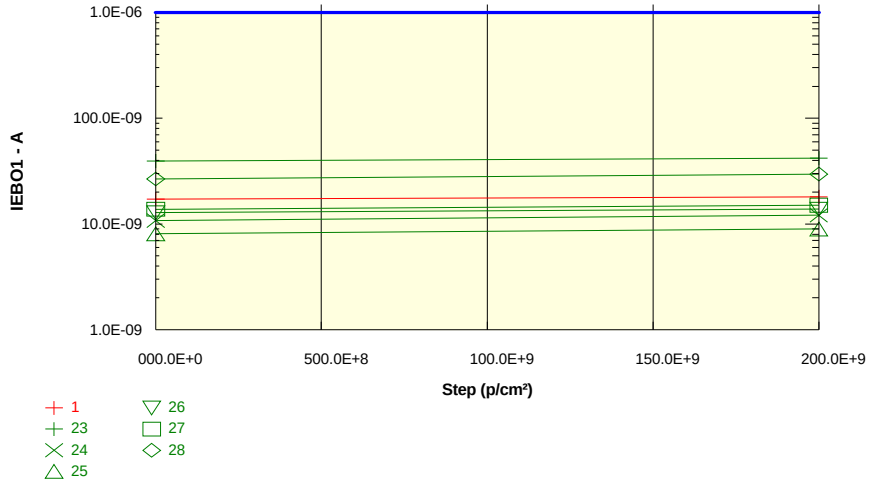
Measurements

ICEO	0 p/cm²	2E+11 p/cm²
1_REF	1.5E-09	1.5E-09
OFF samples		
23	1.5E-09	7.1E-09
24	1.1E-09	7.0E-09
26	1.3E-09	7.4E-09
25	1.2E-09	6.5E-09
27	1.0E-09	6.6E-09
28	926.8E-12	5.4E-09
Statistics		
Min	926.8E-12	5.4E-09
Max	1.5E-09	7.4E-09
Average	1.2E-09	6.7E-09
Sigma	195.0E-12	634.8E-12

Drift Calculation

ICEO	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	5.6E-09
24	-	6.0E-09
26	-	6.1E-09
25	-	5.3E-09
27	-	5.6E-09
28	-	4.5E-09
Average	-	5.5E-09
Sigma	-	514.9E-12

Parameter : Emitter-Base Cut-Off Current : IEBO1
Test conditions : VEB=4V. IC=0A
Unit : A
Spec Limit Max : 1.0E-06
Spec limits are represented in bold lines on the graphic.



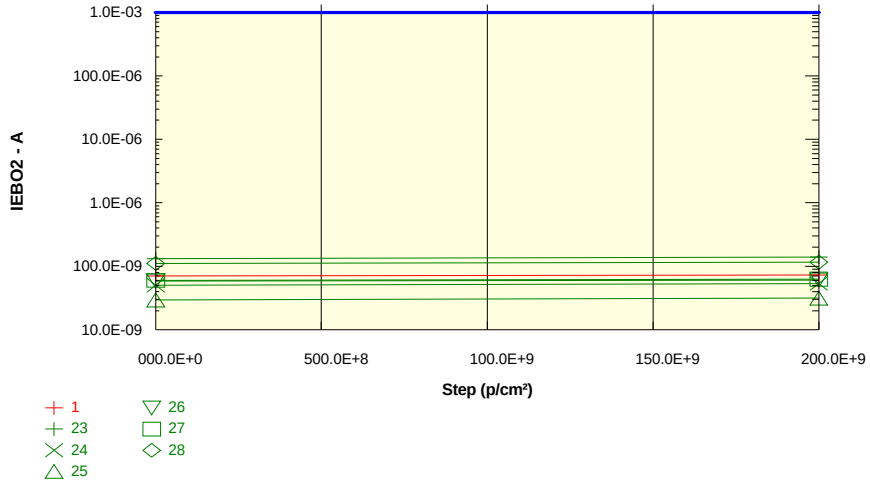
Measurements

IEBO1	0 p/cm²	2E+11 p/cm²
1_REF	17.3E-09	18.0E-09
OFF samples		
23	39.3E-09	42.0E-09
24	10.8E-09	12.1E-09
26	12.8E-09	13.8E-09
25	8.1E-09	9.0E-09
27	13.8E-09	15.0E-09
28	26.6E-09	29.6E-09
Statistics		
Min	8.1E-09	9.0E-09
Max	39.3E-09	42.0E-09
Average	18.6E-09	20.3E-09
Sigma	11.0E-09	11.7E-09

Drift Calculation

IEBO1	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	2.7E-09
24	-	1.3E-09
26	-	1.0E-09
25	-	904.0E-12
27	-	1.2E-09
28	-	3.0E-09
Average	-	1.7E-09
Sigma	-	824.5E-12

Parameter : Emitter-Base Cut-Off Current : IEBO2
Test conditions : VEB=5.5V. IC=0A
Unit : A
Spec Limit Max : 1.0E-03
Spec limits are represented in bold lines on the graphic.



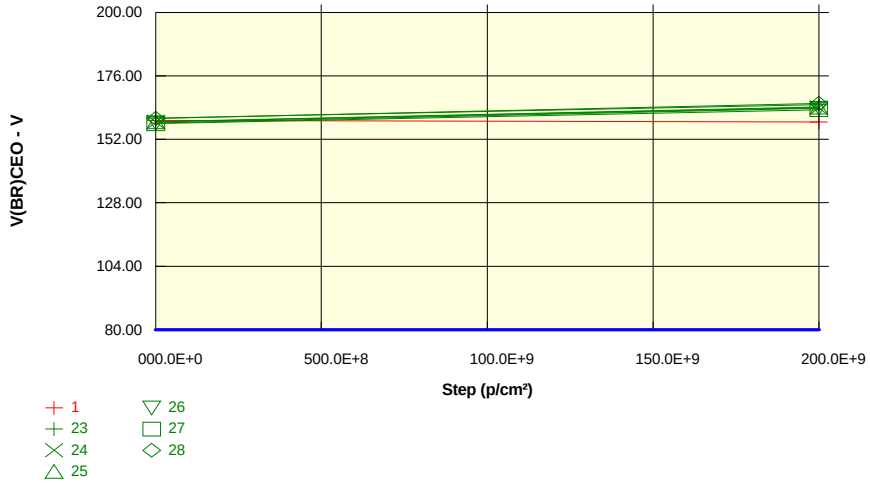
Measurements

IEBO2	0 p/cm²	2E+11 p/cm²
1_REF	70.5E-09	73.1E-09
OFF samples		
23	130.7E-09	138.6E-09
24	50.4E-09	53.5E-09
26	58.2E-09	60.8E-09
25	29.4E-09	31.4E-09
27	59.8E-09	62.5E-09
28	111.1E-09	115.3E-09
Statistics		
Min	29.4E-09	31.4E-09
Max	130.7E-09	138.6E-09
Average	73.3E-09	77.0E-09
Sigma	35.6E-09	37.3E-09

Drift Calculation

IEBO2	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	7.8E-09
24	-	3.1E-09
26	-	2.6E-09
25	-	2.0E-09
27	-	2.7E-09
28	-	4.2E-09
Average	-	3.7E-09
Sigma	-	1.9E-09

Parameter : Collector-Emitter Breakdown Volatge : V(BR)CEO
Test conditions : IC=100mA
Unit : V
Spec Limit Min : 80.00
Spec limits are represented in bold lines on the graphic.



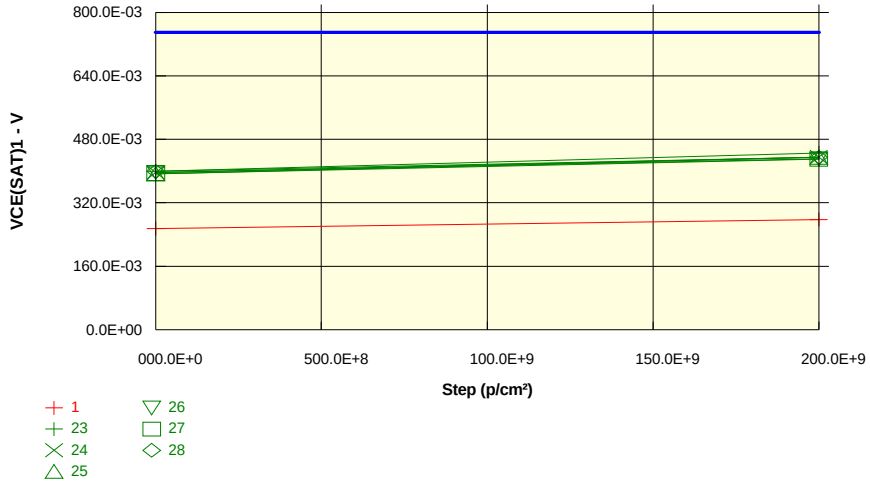
Measurements

V(BR)CEO	0 p/cm²	2E+11 p/cm²
1_REF	159.20	158.58
OFF samples		
23	160.03	165.02
24	158.54	164.05
26	158.22	163.78
25	158.65	164.22
27	157.97	163.22
28	159.91	165.59
Statistics		
Min	157.97	163.22
Max	160.03	165.59
Average	158.89	164.31
Sigma	0.80	0.78

Drift Calculation

V(BR)CEO	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	5.0E+00
24	-	5.5E+00
26	-	5.6E+00
25	-	5.6E+00
27	-	5.3E+00
28	-	5.7E+00
Average	-	5.4E+00
Sigma	-	235.0E-03

Parameter : Collecor-Emitter Saturation Voltage : VCE(SAT)1
Test conditions : IC=2.5A. IB=250mA
Unit : V
Spec Limit Max : 750.0E-03
Spec limits are represented in bold lines on the graphic.



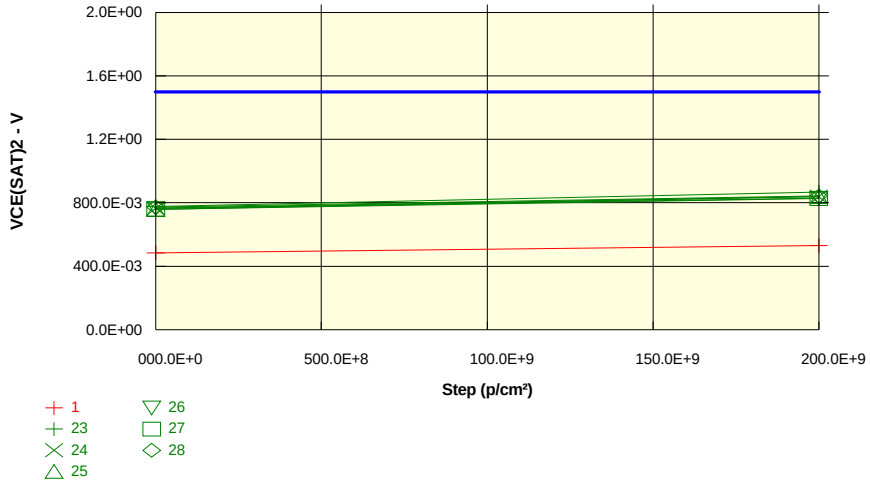
Measurements

VCE(SAT)1	0 p/cm²	2E+11 p/cm²
1_REF	254.8E-03	278.0E-03
OFF samples		
23	399.2E-03	445.6E-03
24	396.4E-03	435.6E-03
26	396.4E-03	430.4E-03
25	393.2E-03	434.8E-03
27	393.6E-03	430.0E-03
28	399.2E-03	435.2E-03
Statistics		
Min	393.2E-03	430.0E-03
Max	399.2E-03	445.6E-03
Average	396.3E-03	435.3E-03
Sigma	2.4E-03	5.1E-03

Drift Calculation

VCE(SAT)1	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	46.4E-03
24	-	39.2E-03
26	-	34.0E-03
25	-	41.6E-03
27	-	36.4E-03
28	-	36.0E-03
Average	-	38.9E-03
Sigma	-	4.1E-03

Parameter : Collecor-Emitter Saturation Voltage : VCE(SAT)2
Test conditions : IC=5A. IB=500mA
Unit : V
Spec Limit Max : 1.5E+00
Spec limits are represented in bold lines on the graphic.



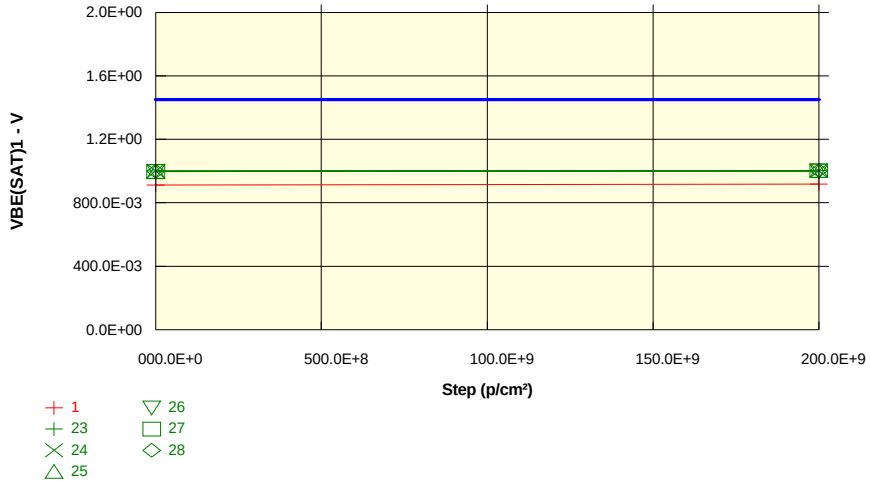
Measurements

VCE(SAT)2	0 p/cm²	2E+11 p/cm²
1_REF	484.8E-03	530.0E-03
OFF samples		
23	776.4E-03	868.8E-03
24	765.6E-03	838.4E-03
26	764.0E-03	828.4E-03
25	759.6E-03	838.8E-03
27	758.0E-03	827.2E-03
28	773.2E-03	842.8E-03
Statistics		
Min	758.0E-03	827.2E-03
Max	776.4E-03	868.8E-03
Average	766.1E-03	840.7E-03
Sigma	6.7E-03	13.8E-03

Drift Calculation

VCE(SAT)2	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	92.4E-03
24	-	72.8E-03
26	-	64.4E-03
25	-	79.2E-03
27	-	69.2E-03
28	-	69.6E-03
Average	-	74.6E-03
Sigma	-	9.1E-03

Parameter : Base-Emitter Saturation Voltage : VBE(SAT)1
Test conditions : IC=2.5A. IB=250mA
Unit : V
Spec Limit Max : 1.5E+00
Spec limits are represented in bold lines on the graphic.



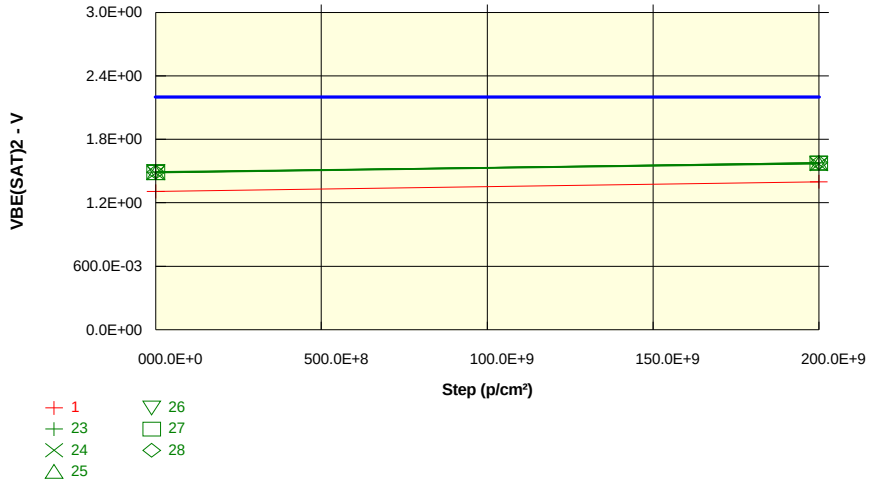
Measurements

VBE(SAT)1	0 p/cm²	2E+11 p/cm²
1_REF	912.0E-03	918.0E-03
OFF samples		
23	1.0E+00	1.0E+00
24	1.0E+00	1.0E+00
26	998.0E-03	998.8E-03
25	996.8E-03	1.0E+00
27	997.6E-03	1.0E+00
28	999.2E-03	1.0E+00
Statistics		
Min	996.8E-03	998.8E-03
Max	1.0E+00	1.0E+00
Average	998.8E-03	1.0E+00
Sigma	1.5E-03	1.8E-03

Drift Calculation

VBE(SAT)1	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	3.2E-03
24	-	2.4E-03
26	-	800.0E-06
25	-	6.4E-03
27	-	5.2E-03
28	-	4.4E-03
Average	-	3.7E-03
Sigma	-	1.8E-03

Parameter : Base-Emitter Saturation Voltage : VBE(SAT)2
Test conditions : IC=5A. IB=500mA
Unit : V
Spec Limit Max : 2.2E+00
Spec limits are represented in bold lines on the graphic.



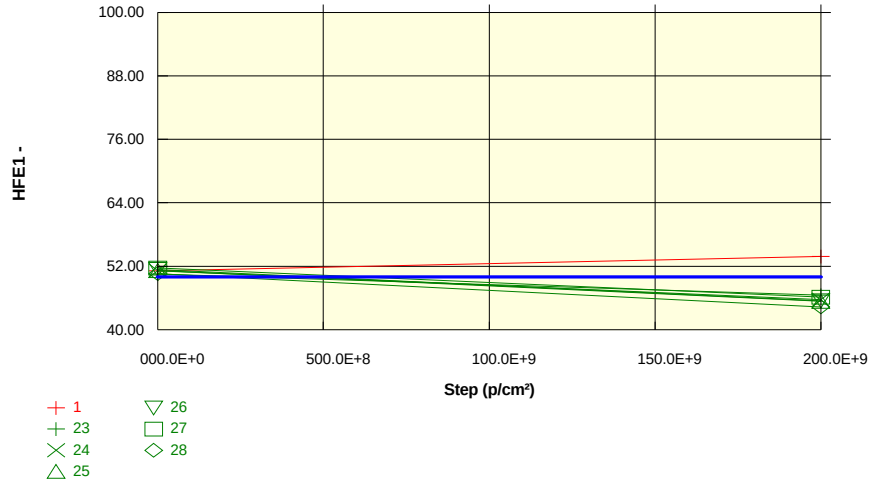
Measurements

VBE(SAT)2	0 p/cm²	2E+11 p/cm²
1_REF	1.3E+00	1.4E+00
OFF samples		
23	1.5E+00	1.6E+00
24	1.5E+00	1.6E+00
26	1.5E+00	1.6E+00
25	1.5E+00	1.6E+00
27	1.5E+00	1.6E+00
28	1.5E+00	1.6E+00
Statistics		
Min	1.5E+00	1.6E+00
Max	1.5E+00	1.6E+00
Average	1.5E+00	1.6E+00
Sigma	4.8E-03	4.3E-03

Drift Calculation

VBE(SAT)2	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	85.2E-03
24	-	84.8E-03
26	-	76.8E-03
25	-	87.6E-03
27	-	94.0E-03
28	-	87.6E-03
Average	-	86.0E-03
Sigma	-	5.1E-03

Parameter : Forward-Current Transfert Ratio : HFE1
Test conditions : IC==50mA. VCE=5V
Unit :
Spec Limit Min : 50.00
Spec limits are represented in bold lines on the graphic.



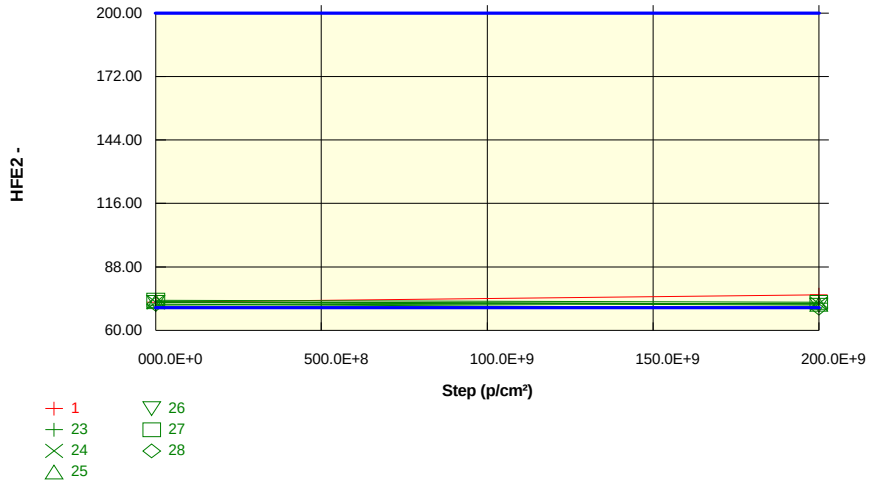
Measurements

HFE1	0 p/cm²	2E+11 p/cm²
1_REF	51.11	53.86
OFF samples		
23	50.51	46.53
24	51.15	45.67
26	51.38	45.43
25	51.19	45.36
27	51.67	46.16
28	50.64	44.33
Statistics		
Min	50.51	44.33
Max	51.67	46.53
Average	51.09	45.58
Sigma	0.40	0.69

Drift Calculation

HFE1	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	1.7E-03
24	-	2.3E-03
26	-	2.5E-03
25	-	2.5E-03
27	-	2.3E-03
28	-	2.8E-03
Average	-	2.4E-03
Sigma	-	342.9E-06

Parameter : Forward-Current Transfert Ratio : HFE2
Test conditions : IC=2.5A. VCE=5V
Unit :
Spec Limit Min : 70.00
Spec Limit Max : 200.00
Spec limits are represented in bold lines on the graphic.



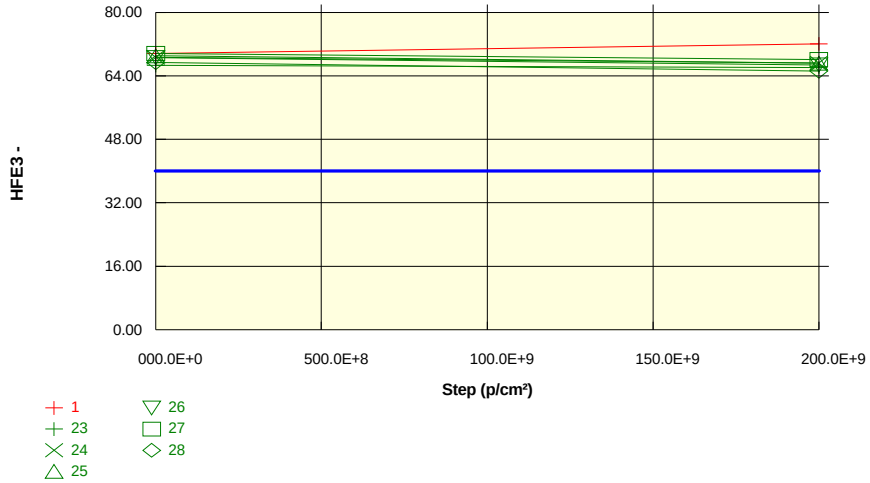
Measurements

HFE2	0 p/cm²	2E+11 p/cm²
1_REF	72.44	75.69
OFF samples		
23	71.09	71.92
24	72.46	71.77
26	72.35	71.07
25	72.69	71.55
27	73.28	72.39
28	71.61	69.80
Statistics		
Min	71.09	69.80
Max	73.28	72.39
Average	72.25	71.41
Sigma	0.72	0.83

Drift Calculation

HFE2	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	-163.0E-06
24	-	133.2E-06
26	-	250.1E-06
25	-	220.2E-06
27	-	169.0E-06
28	-	362.0E-06
Average	-	161.9E-06
Sigma	-	162.1E-06

Parameter : Forward-Current Transfert Ratio : HFE3
Test conditions : IC=5A. VCE=5V
Unit :
Spec Limit Min : 40.00
Spec limits are represented in bold lines on the graphic.



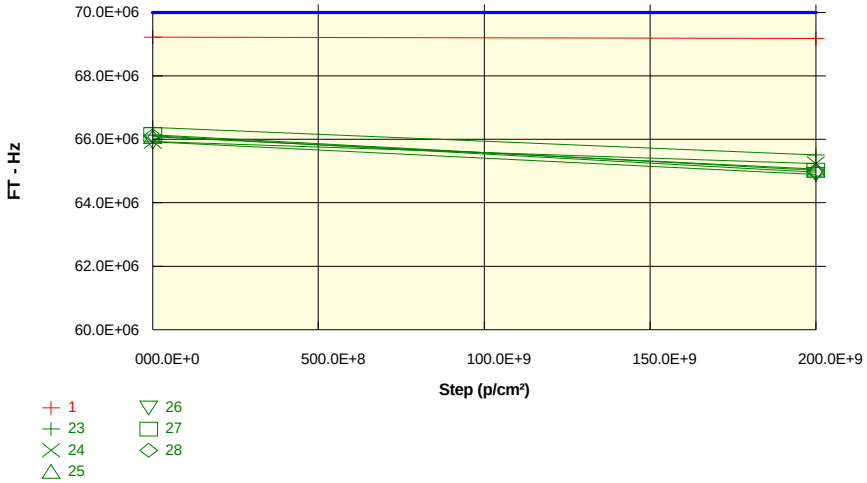
Measurements

HFE3	0 p/cm²	2E+11 p/cm²
1_REF	69.70	72.10
OFF samples		
23	66.66	66.10
24	68.74	67.22
26	68.58	66.76
25	69.07	67.20
27	69.69	68.13
28	67.33	65.21
Statistics		
Min	66.66	65.21
Max	69.69	68.13
Average	68.34	66.77
Sigma	1.03	0.92

Drift Calculation

HFE3	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	126.8E-06
24	-	327.2E-06
26	-	396.6E-06
25	-	401.4E-06
27	-	328.9E-06
28	-	482.9E-06
Average	-	344.0E-06
Sigma	-	110.3E-06

Parameter : Gain Bandwidth Product : FT
Test conditions : VCE=5V. IC=0.5A
Unit : Hz
Spec Limit Min : 70.0E+06
Spec limits are represented in bold lines on the graphic.



Measurements

FT	0 p/cm²	2E+11 p/cm²
1_REF	69.2E+06	69.2E+06
OFF samples		
23	66.4E+06	65.5E+06
24	65.9E+06	65.2E+06
26	65.9E+06	64.9E+06
25	66.1E+06	65.1E+06
27	66.1E+06	65.0E+06
28	66.1E+06	65.0E+06
Statistics		
Min	65.9E+06	64.9E+06
Max	66.4E+06	65.5E+06
Average	66.1E+06	65.1E+06
Sigma	152.2E+03	204.9E+03

Drift Calculation

FT	0 p/cm²	2E+11 p/cm²
OFF samples		
23	-	-865.5E+03
24	-	-694.7E+03
26	-	-1.0E+06
25	-	-1.0E+06
27	-	-1.1E+06
28	-	-1.1E+06
Average	-	-979.2E+03
Sigma	-	155.7E+03