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TID TEST REPORT FOR COTS LT1521 LDO - DATE CODE: 1738

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1. INTRODUCTION

The current report presents the TID results on the LDO LT1521 (Vout adjustable version), date code: 1738.

The test campaign was performed between the 9th August and 24th August 2021 at the ESTEC 60Co facility.

Additional information on the context is provided in the test plan [AD02].

2. DOCUMENTS

2.1. Applicable documents

AD01 ESCC22900 Total Dose Steady-state irradiation test method, June 2016

AD02 LT1521_TID_test_plan_LDO

2.2. Reference documents

N/A

3. PART & PROCUREMENT INFORMATION

Part number	LT1521IS8#PBF
Manufacturer	Analog Devices
Function	300mA Low Dropout Regulator with Micropower Quiescent Current and Shutdown
Technology	Bipolar
Package	SO-8

	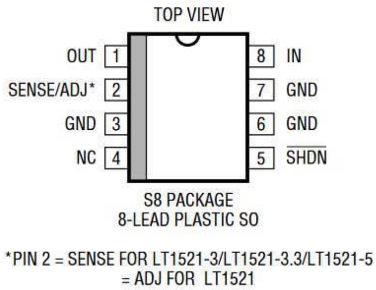
Date Code	1738
Distributor	Mouser Electronics
Part #	5 samples unbiased (n°1 to 5) 5 samples biased (n°6 to 10) 1 reference (REF)

Table 1: Part & procurement information

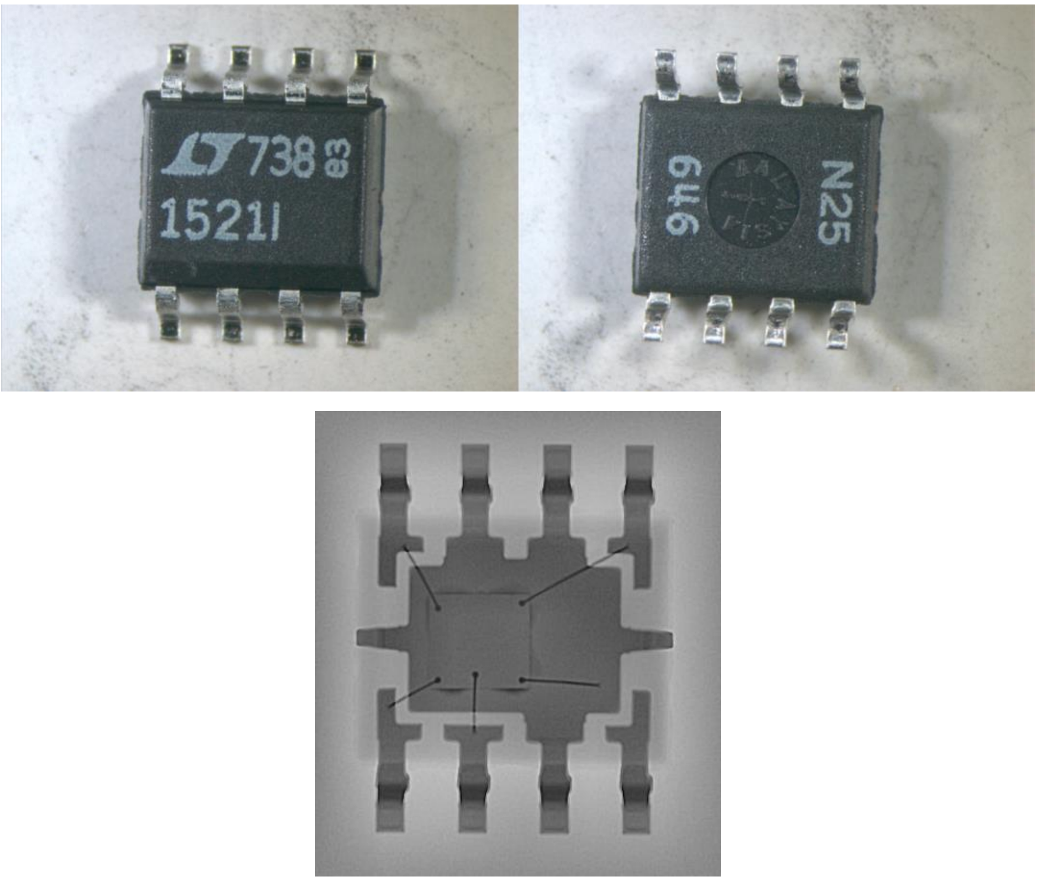

Figure 1: Package marking (top left & right), X-ray of the DUT (bottom). All samples package markings are the same.

4. DOSIMETRY AND IRRADIATION FACILITY

IRRADIATION FACILITY	
Source:	C060
Localization:	ESTEC, Netherlands
Dosimetry:	Electrometer: PTW UNIDOS2 s/n 2127 Ionisation chamber: PTW TW30012-10 s/n 000417

IRRADIATION TIMING	
TID steps (krad)	0, 5, 10, 15, 20, 35
Dose rate (rad(Si)/h)	210

ANNEALING TIMING		Condition during annealing
Annealing 22°C	24 h	ON for those tested ON Unbiased for those tested Unbiased
Ageing 100°C	168h	ON for those tested ON Unbiased for those tested Unbiased

5. TEST SET-UP

5.1. Test set-up overview

The set-up is schematically depicted in the Figure 2. Additionally, The unbiased DUTs were measured at each of the specified TID steps externally from the irradiation chamber.

A single in-house breadboard allowed to accommodate both biased and unbiased components in a 10*16 cm² breadboard, which limits the TID variation across board to less than 10% (cf. Figure 5). Set-up pictures are provided in Annex B.

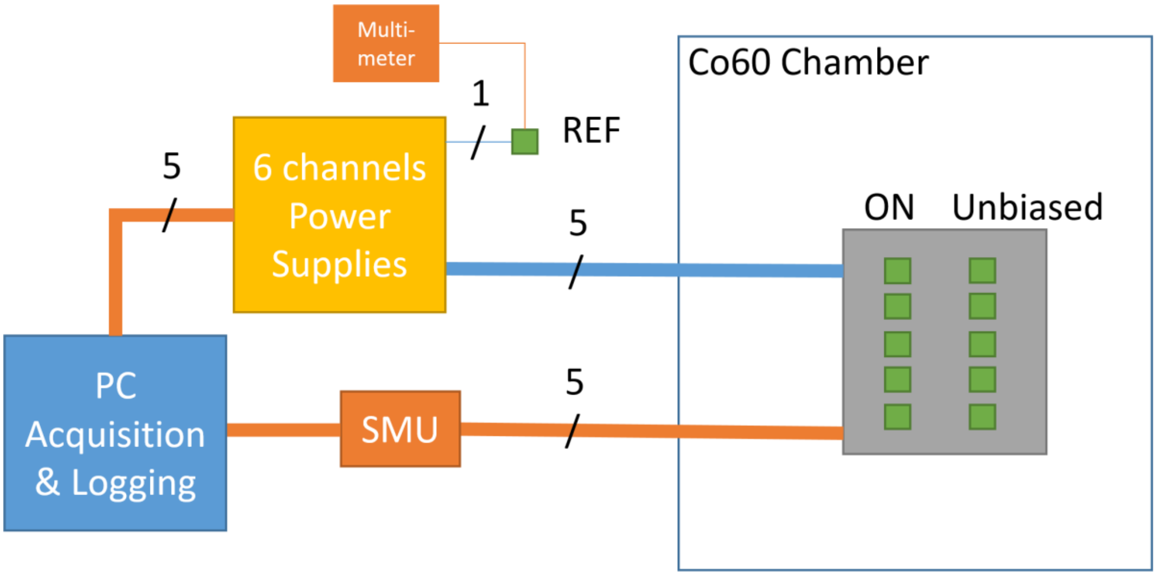

Figure 2: Simplified schematic of the overall test set-up

Each power input cable is a 4-wire cable allowing to compensate for any voltage drop. At the breadboard, the input voltage remains less than 10% of the input voltage (5.5V). The load resistor is on the board close to the DUT (i.e. no voltage drop seen on the output voltage lines to the SMU).

All unbiased sample pins were shorted during irradiation.

The PC laptop allowed to acquire and log the output voltage (V_{out}) as well as the input current (I_{in}) of each of the 5 biased samples. The sampling rate was set to 1 sample per hour (much higher than needed). The laptop time is synchronised to the time used for controlling the Co60 facility.

During each defined TID steps, V_{out} and I_{in} of each unbiased sample are measured and logged using the breadboard of the reference sample.

An overnight dry-run (> 15h) was done to validate the set-up.

5.2. Test equipment

TEST EQUIPMENT	PARAMETER MEASURED
3 x Keithley 2412A System SourceMeter (2 channels per equipment)	Providing V_{in} = 5.5V for each of the 5 biased components. I_{max} = 200 mA.
1 x Keithley 2410 1100V SourceMeter	Providing V_{in} = 5.5V & measuring V_{out} for the reference & the 5 unbiased components. I_{max} = 200 mA.
1 x Hewlett Packard 34970A Data Acquisition	Measuring V_{out} for each of the 5 biased components.
1 x Fluke 115 True RMS Multimeter	Measuring V_{out} for the reference & the 5 unbiased components.
1 x Laptop with LabView	Logging and saving the V_{out} measurements using an in-house VI.

6. TEST PARAMETERS

The following two parameters are measured:

PARAMETERS	SYMBOLS
Output Voltage	V_{out}
Input current	I_{in}

7. BIASING CONDITIONS

The same biasing conditions of the ON devices is used for the measurements of the unbiased components. Table 2 summarised the main biasing conditions, V_{out} is adjusted by 2 resistors (for more info see Annex C):

	Value	Unit
V_{in}	5.5	V
V_{out}	3.8	V
I_{load} R_{load}	140 27	mA Ω

Table 2: Biasing conditions during irradiation & for measurements.

At 35 krad and during annealing measurements, for additional preliminary investigations, V_{out} was measured at:

	Value	Unit	Referred as
I_{load}	0	mA	No load
I_{load} R_{load}	140 27	mA Ω	High load
I_{load} R_{load}	~1 3.6	mA kΩ	Low load

Table 3: Biasing conditions during irradiation & for measurements.

8. SUCCESS CRITERIA

SUCCESS CRITERIA	V_{out} shall remain within [4.5V-3V] up to 15 krad in both ON and unbiased conditions when measured in application conditions (load of 140 mA).

9. TID RESULTS

9.1. Pre-irradiation measurements

Table 4 provides the measured parameters prior to irradiation. Each measurement was done after waiting 5 min (to ensure stabilisation of the parameters):

	V_{out} (V) @ high load	I_{in} @ 5.5V (mA)
Part # REF	3.833	145
Part # 1 (biased)	3.807	143
Part # 2 (biased)	3.822	144
Part # 3 (biased)	3.830	145
Part # 4 (biased)	3.760	142
Part # 5 (biased)	3.821	145
Part # 6 (unbiased)	3.770	142
Part # 7 (unbiased)	3.766	142
Part # 8 (unbiased)	3.825	144
Part # 9 (unbiased)	3.827	145
Part # 10 (unbiased)	3.767	142

Table 4:Pre-irradiation values for all biased/unbiased samples. The min/max V_{out} values are underlined.

9.2. Irradiation results

In Figure 3, values are provided in TID(H_20), the conversion to TID(Si) is done using the conversion factor of: 0.898.

```
Dosimetry chain: E
Electrometer: PTW UNIDOS2 s/n 2127
Ionisation chamber: PTW TW30012-10 s/n 000417              Environmental  data  summary
Correction factor  set: 1.0000
Dose unit set: Gy                                                    min      max   avg(t)
Rate unit set:  min                                      T [°C]     22.80    23.00    22.91
Measurement set:  Dose                                p [mbar] 1007.30 1021.50 1016.26
Measurement range: Low                                R.H. [%]    50.80    53.40    51.90

Run    Irradiation Start          Irradiation Stop            Total Dose        Dose rate       Irr.time

  1    09 Aug 2021  10:10:12      10 Aug 2021  09:59:52        55.710  Gy     2.338  Gy/h      23:49:40
  2    10 Aug 2021  10:27:57      11 Aug 2021  10:11:09        55.910  Gy     2.357  Gy/h      23:43:12
  3    11 Aug 2021  10:40:47      12 Aug 2021  10:13:17        55.450  Gy     2.355  Gy/h      23:32:30
  4    12 Aug 2021  10:56:12      13 Aug 2021  10:35:49        55.680  Gy     2.354  Gy/h      23:39:37
  5    13 Aug 2021  11:17:27      16 Aug 2021  10:19:55       167.200  Gy     2.353  Gy/h      71:02:28

                                                  Total    389.900  Gy     2.352  Gy/h     165:47:27

(Averages for the dose rate data and the environmental parameters are time-weighted.)
```

Figure 3: ESTEC Co60 Facility log summary

Measurements of the unbiased components: all measurements have been done under 30 min at room temperature for each irradiation steps.

9.2.1. Unbiased samples

Measurements of the unbiased samples are provided in Table 5. Figure 4 and Figure 5 plot respectively the V_{out} and I_{in} of all unbiased samples.

All unbiased samples did not provide any V_{out} after a TID of 35 krad. It is not clear whether the thermal shutdown function degradation could explain such a behaviour. Changing the load did not results in any improvements.

Although before irradiation, V_{out} and I_{in} were immediately stabilised values (values not variating in time), all measurements of irradiated parts required a certain time to stabilise (varying sample-to-sample), which increased with TID, and with an increasing difference between the initially read value and the value reached after a certain time given for stabilisation:

- At 5 krad, very small increase (few mV for V_{out}, few mA for I_{in}) occurred;
- At 10 krad, it took about 2 minutes for the measured parameters to stabilise. All samples were noted to be become sensitive to temperature fluctuations;

- At 15 krad & 20 krad, after 5 minutes, parameters were not yet fully stabilised. Sensitivity to temperature of all samples appeared very high;
- At 35 krad, no reponse from any samples.

The statistical spread increase which can be noted during the 15 krad and the 20 krad measurements is likely polluted by the above effect, as values may not have reached full saturation.

After 35 krad, an attempt was made on Part # 6 to revive the sample by increasing V_{in} at 19.5V (absolute max V_{in} = 20V) as shown in Table 6. Although a very small voltage reading appears, when no load is applied, the component was clearly not able to recover.

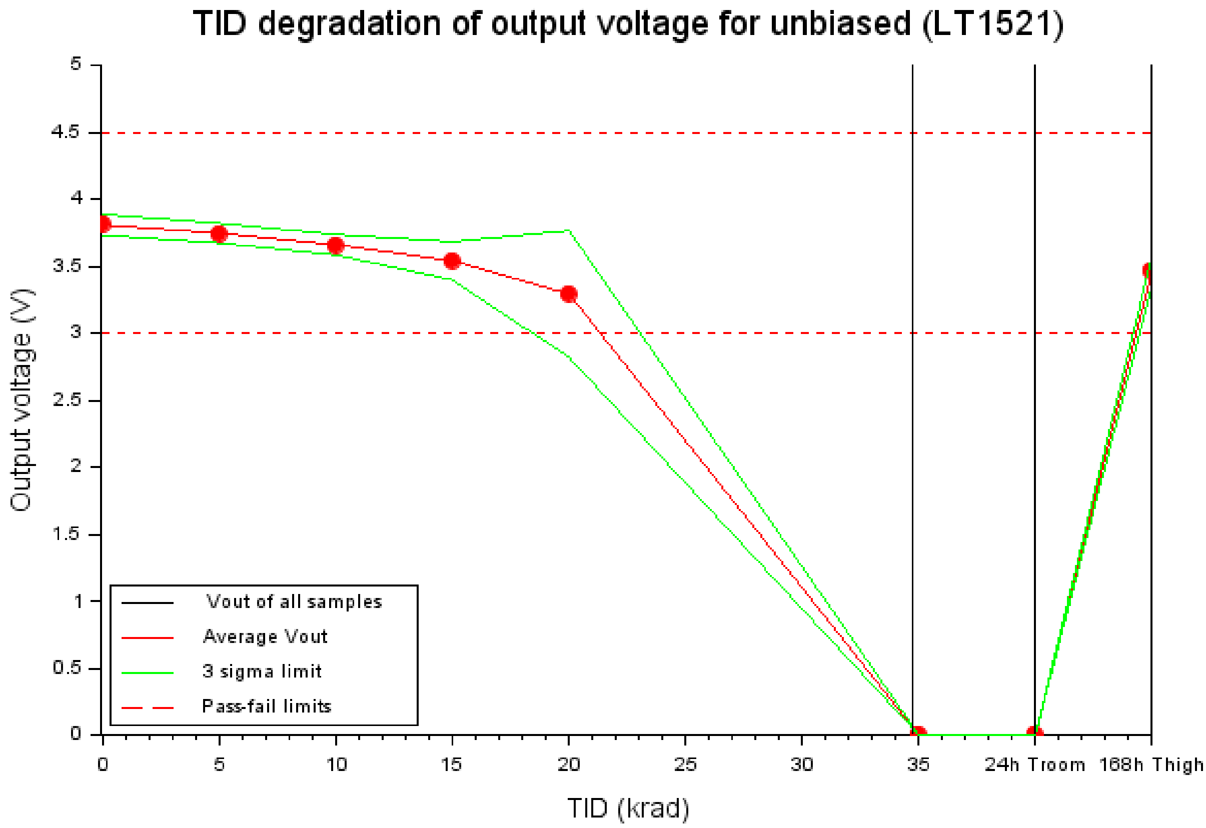

Figure 4: Average V_{out} and statistical spread for the unbiased samples (+/- 3 σ)

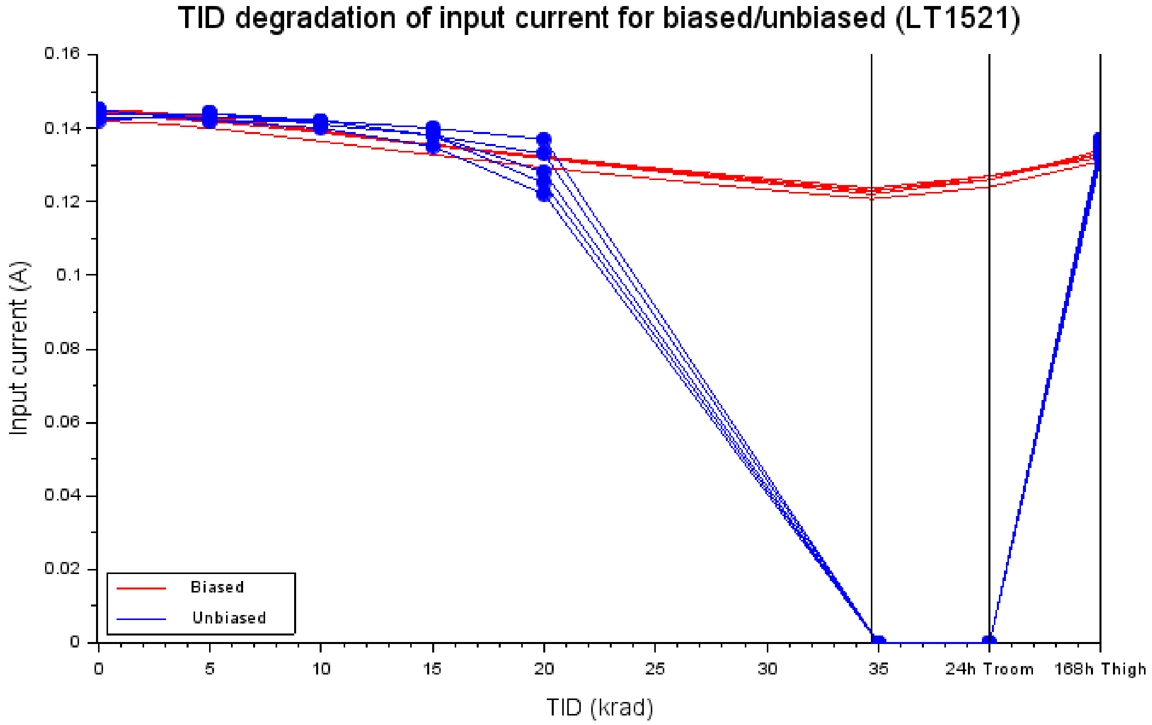

Figure 5: Current inputs for the unbiased samples

	0 krad		5 krad		10 krad		15 krad		20 krad		35 krad		35 krad	
	Vout (V) @ high load	I_{in} (mA) @ high load	Vout (V) @ high load	I_{in} (mA) @ high load	Vout (V) @ high load	I_{in} (mA) @ high load	Vout (V) @ high load	I_{in} (mA) @ high load	Vout (V) @ high load	I_{in} (mA) @ high load	Vout (V) @ low load	I_{in} (mA) @ low load	Vout (V) @ high load	I_{in} (mA) @ high load
Part # REF	3.833	145	3.830	145	3.829	145	(3.829) 3.829	(145) 145	3.828	145	3.842	1	3.829	145
Part # 6	3.807	143	3.745	143	(?) 3.688	(?) 142	(3.5xx) 3.616	(139) 140	(?) 3.527	(?) 137	0	0	0	0
Part # 7	3.822	144	3.726	142	(3.627) 3.650	(140) 141	(3.4xx) 3.540	(136) 138	(1.7xx) 3.400	(current ramping up from few 10mA) 133	0	0	0	0
Part # 8	3.830	145	3.774	144	(3.616) 3.675	(140) 142	(3.3xx) 3.545	(135) 138	(1.5xx) 3.261	(current ramping up from few 10mA) 128	0	0	0	0
Part # 9	3.760	142	3.772	144	(3.590) 3.668	(139) 142	(3.1xx) 3.526	(136) 138	(1.3xx) 3.171	(current ramping up from few 10mA) 125	0	0	0	0
Part # 10	3.821	145	3.714	142	(3.543) 3.616	(138) 140	(3.2xx) 3.470	(133) 135	(0.9xx) 3.101	(current ramping up from few 10mA) 122	0	0	0	0

Table 5: Summary of all unbiased sample measurements. Value in brackets are values read as first measurements, value not in bracket are values measured after several minutes. This was done starting at 10 krad.

Part # 6	Vout (V) @ no load	Vout (V) @ low load	Vout (V) @ high load
V_{in} = 5.5 V	0 mV	0 mV	0 mV
V_{in} = 10.5 V	12 mV	1 mV	0 mV
V_{in} = 15.5 V	41 mV	3 mV	0 mV
V_{in} = 19.5 V	59 mV	4 mV	0 mV
V_{in} = 5.5 V (again)	**13 mV**	1 mV	0 mV

Table 6: Input voltage changes and impact on the measured parameters for Part # 6 only.

9.2.2. Biased samples

Biased samples were always kept ON during irradiation,

Figure 6, shows the results. The biased devices show an homogeneous degradation of the V_{out} and I_{in}.

All parts survived at 35 krad under “high load” conditions, contrary to the unbiased parts.

After the end of the irradiation, after reaching 35 krad, additional measurements with different loads were done on the biased samples after performing a power cycle, and are summarised in Table 7.

During the final “high load” measurement, a similar ramp-up of the V_{out} and I_{in} was seen, as for the unbiased parts, requiring here about 10 min for the value to stabilise. A higher spread of the initial value (values in bracket in Table 7) can be seem during this measurement with input voltage being close to 1.7 V for the lowest starting value.

Interestingly, stabilisation at “no load” or “low load” took only few seconds, whereas stabilisation at “high load” took between 5 to 10 minutes even if the reached V_{out} values were lower. Performing a power cycle did not result is a large improvement of V_{out}.

Finally, similarly to the unbiased samples, all biased samples showed a high sensitivity to temperature (although not fully characterised as beyond the scope of this work).

	35 krad *@ last measurement before beam OFF (for information)*		35 krad *After power cycle*		35 krad *After power cycle*		35 krad *After power cycle* (after waiting >10 min in biased)	
	Vout *(V)* *@ high load*	I_{in} *(mA)* *@ high load*	Vout (V) @ no load	I_{in} (mA) @ no load	Vout (V) @ low load	I_{in} (mA) @ low load	Vout (V) @ high load	I_{in} (mA) @ high load
Part # REF	-	-	3.845	0	3.843	1	3.829	145
Part # 1	*3.189*	*123*	3.307	0	3.296	1	(2.9xx) 3.210	(?) 124
Part # 2	*3.206*	*123*	3.330	0	3.322	1	(2.9xx) 3.225	(117) 124
Part # 3	*3.160*	*122*	3.180	0	3.308	1	(1.7xx) 3.156	(72) 122
Part # 4	*3.135*	*121*	3.267	0	3.255	1	(1.8xx) 3.152	(75) 121
Part # 5	*3.179*	*123*	3.307	0	3.297	1	(2.9xx) 3.196	(107) 123

Table 7: Summary of the biased measurements after irradiation. Value in brackets are read as first measurements, value not in bracket are measured after several minutes

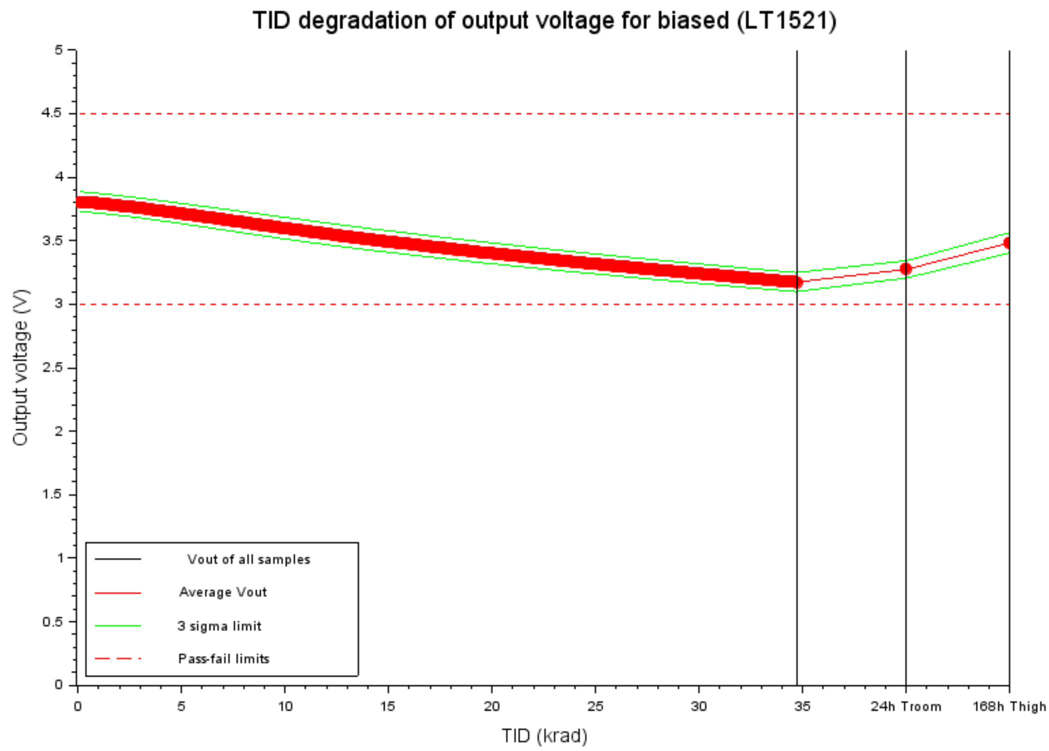

Figure 6: Average Vout and statistical spread for the biased samples (+/- 3 σ) @ high load

9.2.3. Annealing of biased/unbiased samples

Annealing was performed in 2 steps:

- 24h at room temperature
- 168h at high temperature (T=100°C)

Results are plotted in Figure 4 and Figure 5 for unbiased samples and
Figure 6 for biased samples. Table 8 and Table 9 display the measured values for both the annealing steps.

As during the high temperature annealing V_{out} of the biased samples was fluctuating, the load was removed which was not originally planned for (Cf. Annex D for the log of events during annealing).

The room temperature annealing did not improve the behaviour of the unbiased samples but slightly improved the V_{out} and I_{in} values of the biased samples.

However after high temperature annealing, all unbiased parts show a drastic increase of their V_{out} and I_{in}. All parts (biased and unbiased) showed an partial recovery of those parameters to very similar values, although lower to the pre-irradiation state for all samples.

Interesting to note is that for biased samples, the stabilised (approx. 10 min) V_{out} resulted in a loss of few tens of mV whereas for the unbiased samples, the stabilised output (approx. 10 min) voltage resulted in an increase of a few tens of mV.

Finally, all irradiated samples showed a fluctuation of their V_{out} with temperature which was not further characterised in this work.

	Vout (V) @ no load	I_{in} (mA) @ no load	Vout (V) @ low load	I_{in} (mA) @ low load	Vout (V) @ high load	I_{in} (mA) @ high load
Part # REF	3.846	0 [86 uA]	3.844	1	3.831	145
Part # 1 (biased)	3.359	0 [70 uA]	3.352	1	3.288	127
Part # 2 (biased)	3.382	0 [71 uA]	3.378	1	3.301	127
Part # 3 (biased)	3.378	0 [70 uA]	3.374	1	3.275	126
Part # 4 (biased)	3.321	0 [70 uA]	3.317	1	3.235	124
Part # 5 (biased)	3.356	0 [70 uA]	3.351	1	3.272	126
Part # 6 (unbiased)	0.016*	0 [1.45 uA]	0.001	0 [1.45 uA]	0	0 [1.45 uA]
Part # 7 (unbiased)	0.005	0 [1.49 uA]	0	0 [1.49 uA]	0	0 [1.49 uA]
Part # 8 (unbiased)	0.003	0 [1.32 uA]	0	0 [1.32 uA]	0	0 [1.32 uA]
Part # 9 (unbiased)	0.002	0 [1.18 uA]	0	0 [1.18 uA]	0	0 [1.18 uA]
Part # 10 (unbiased)	0.002	0 [1.18 uA]	0	0 [1.18 uA]	0	0 [1.18 uA]

Table 8:Summary of the measurements after 24h room temperature annealing. For all values, saturation was achieved (approx.. 5 min for each). (*) Sample 6 condition was changed after putting a higher input voltage to attempt to revive it. Measurements in brackets were done at higher current resolution.

	Vout (V) @ no load	I_{in} (mA) @ no load	Vout (V) @ low load	I_{in} (mA) @ low load	Vout (V) @ high load	I_{in} (mA) @ high load
Part # REF	3.849	85µA	3.845	1.20mA	3.829	144.8
Part # 1 (biased)	3.530	75µA	3.525	1.10mA	(3.491) 3.466	131.8
Part # 2 (biased)	3.558	75µA	3.552	1.11mA	(3.520) 3.491	132.6
Part # 3 (biased)	3.587	75µA	3.583	1.12mA	(3.550) 3.519	133.7
Part # 4 (biased)	3.516	74µA	3.513	1.10mA	(3.480) 3.444	130.9
Part # 5 (biased)	3.564	75µA	3.562	1.11mA	(3.530) 3.499	132.9
Part # 6 (unbiased)	3.554	85µA	3.550	1.18mA	(3.497) 3.524	136.9
Part # 7 (unbiased)	3.487	85µA	3.485	1.17mA	(3.385) 3.447	134.3
Part # 8 (unbiased)	3.513	87µA	3.508	1.18mA	(3.350) 3.467	135.6
Part # 9 (unbiased)	3.521	87µA	3.517	1.19mA	(3.410) 3.462	135.3
Part # 10 (unbiased)	3.468	87µA	3.465	1.17mA	(3.280) 3.411	132.5

Table 9:Summary of the measurements after high temperature 168h annealing. For all values, saturation was achieved (approx. 10 min for each), values in bracket are initial measured values.

10. CONCLUSION

Based on the success criteria mentioned in section 8, this test is considered as passed for this particular procurement lot. A small deviation from the planned annealing (no load instead of high load) of the ON samples had to be performed.

A degradation of V_{out} & I_{in} can be expected, similar between the biased & unbiased parts and within the pass/fail criteria. The most extreme values (considering all samples and results after irradiation only) being:

- V_{out} (@15 krad) = 3.39 V (-3σ) / 3.68 V (+3σ)

- I_{in} (@15 krad) = 132 mA (-3σ) / 143 mA (+3σ)

Above 15 krad, the unbiased samples show a higher degradation than the biased samples.

Annealing did not degrade the response of any parts. On the contrary, annealing was able to restore to an extend V_{out} of all parts, especially high temperature annealing of the unbiased parts.

During irradiation measurements of the unbiased parts, it was noted that:

- V_{out} required some time before being able to be stabilised (this time increasing with TID level) with initial values still staying within the pass-fail criteria up to 15 krad.
- V_{out} appeared to be affected by temperature and this should be further investigated.

It is highly suspected that besides the part degradation (leading to a degradation of I_{in} and V_{out}), the thermal shutdown/protection system degradation is adding to the overall effects observed. Effect of the load was only briefly analysed. These topics should be further investigated.

ANNEX A – DATASHEET

LINK:

https://www.analog.com/media/en/technical-documentation/data-sheets/lt1521-1521-3-1521-3-3-1521-5.pdf

ANNEX B – SET-UP

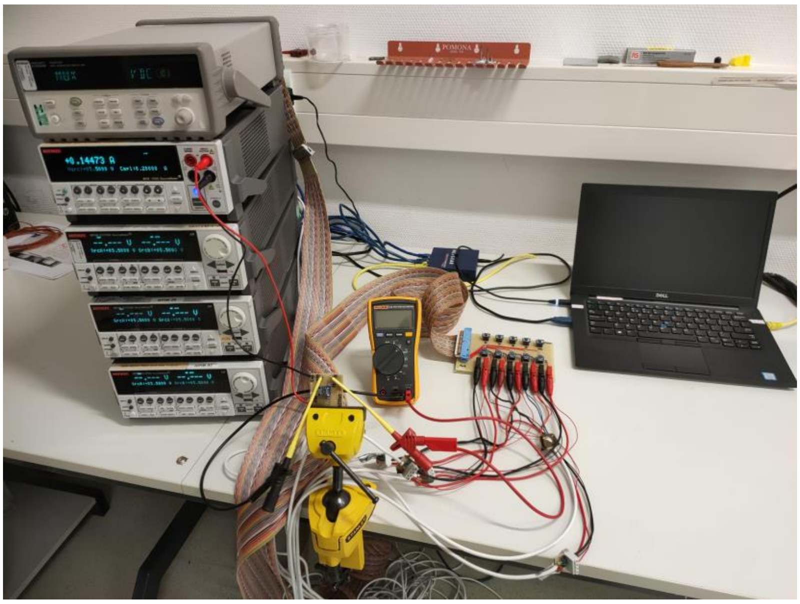

Figure 7: Set-up during dry-run.

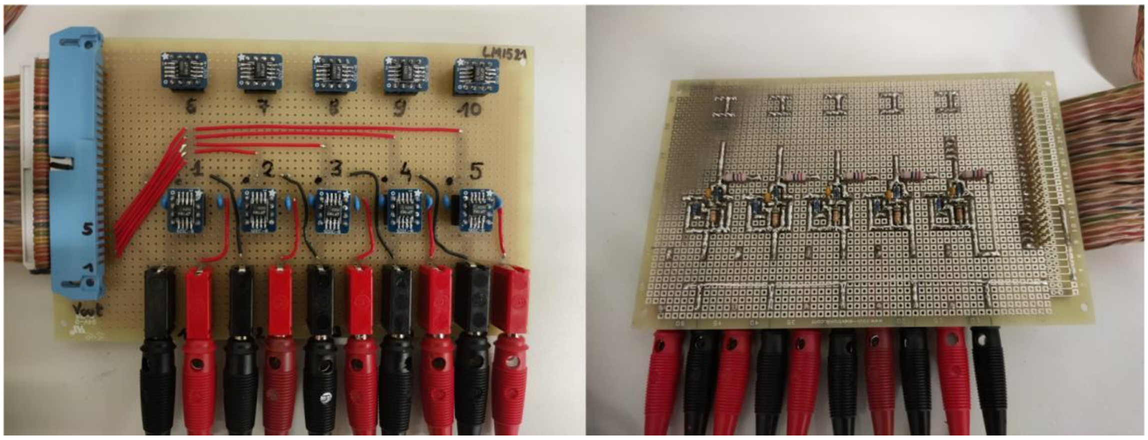

Figure 8: Breadboard to be installed in the 60Co chamber with the 10 samples.

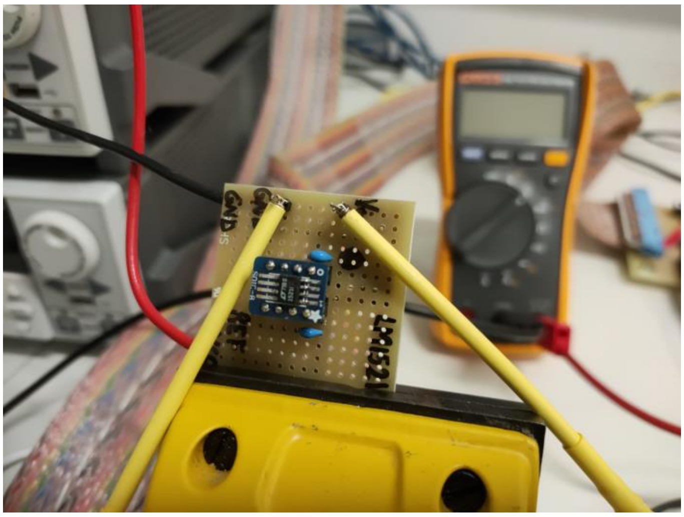

Figure 9: Reference board also used for the measurements of the unbiased samples.

ANNEX C – ADDITIONAL INFORMATION ABOUT BIASING

The same biaising condition of the ON devices is used for the measurements of the unbiased components. Table 2 summarised the main biasing conditions.

Considering R7 = 56 (+/- 5%) kΩ and R8 = 1 (+/- 5%) kΩ, and assuming Iadj = 50 nA @ 25°C (cf. Annex 10 - datasheet):

$$V_{out} = 3.75V \times (1+R8/R7) + (Iadj \times R8) \approx [3.81 – 3.82]\ V$$

Additionally, a load is added in series to the output in order to simulate the load foreseen in the application: R_{load} = 27 (+/- 1%) Ω which results in a current load of 140 mA. The application current load is 150 mA.

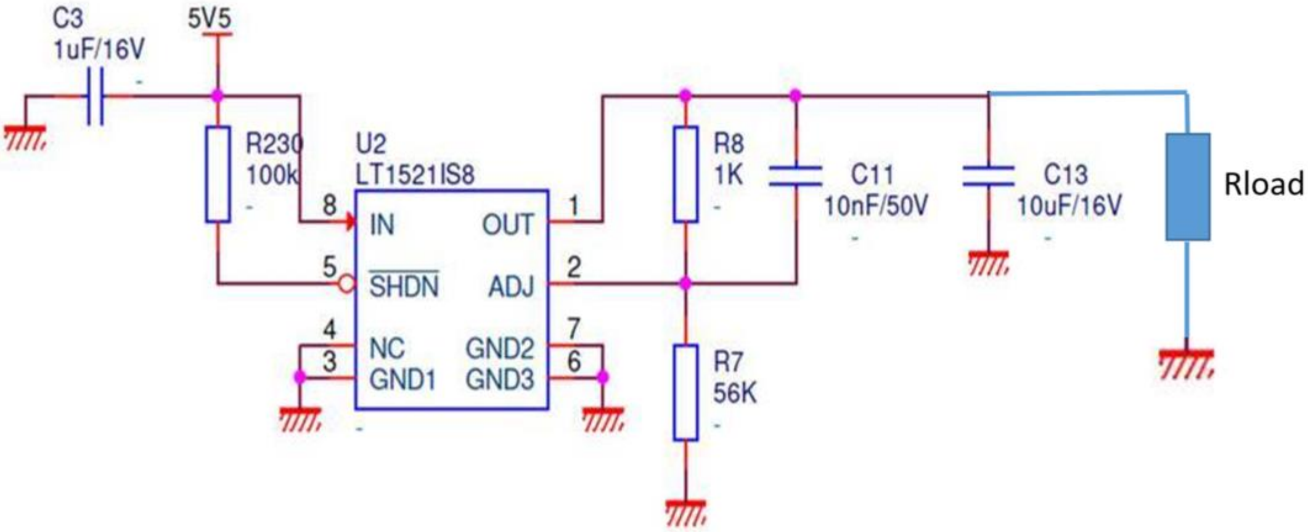

Figure 10: Schematic of the biasing conditions for the ON LT1521 samples, with the resistive load.

ANNEX D – ANNEALING LOG FILES

Timestamps	Description
16/08/2021 14:15	Annealing started (room temperature)
17/08/2021 15:36	Annealing ended (room temperature)
17/08/2021 17:40	Annealing started (high temperature), include ramping up in temperature.
17/08/2021 18:20	Chamber opened to check that everything was fine as parameters were behaving weird.
17/08/2021 18:37	Chamber closed again after fixing again the set-up. High measurement rate kept.
18/08/2021 10:42	Chamber opened to remove load as the thermal shutdown is probably kicking in. Besides this fluctuation, Vout Improved from 3.1 to 3.3 overnight. High measurement kept
18/08/2021 10:50	Chamber closed back again slight overshoot in temperature 110 deg. Vout increasing as no load. Few minutes later (11:00) sampling frequency reduced to 1 every hour…
24/08/2021 17:20	Resart of Keithley VIs because they stopped logging (60s logging time)
24/08/2021 17:40	Shutdown and open chamber (loging interval 60s)
24/08/2021 18:00	Set logging interval to 1h
25/08/2021 9:50	Stop logging
25/08/2021 10:00 – 11:00	Measure all components Annealing ended (high temperature)

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