TRT Electronics
Gamma Irradiation Test

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Abstract

The radiation tolerance of the TRT 99-version of the read-out electronics, i.e. DTMROC99 and ASDBLR99 chips, was evaluated by characterising a full flex board (12 DTMROC and 24 ASDBLR chips) before and after 3Mrad gamma irradiation.
DTMROC board number 7 with ASDBLR boards number 13, 14 and 15 were irradiated at Saclay. During irradiation power was provided but no clock.
No single channel upsets were observed, all channels working before irradiation were also functional after. Radiation damage is seen on the digital power consumption which increases by 34 %. The cause of which is believed to be fixed in the next version of the DTMROCs.
An increase in offset spread is observed for some thresholds. All other measurements do not indicate any change in performance.

Many thanks to Juan Valls for providing major parts of the analysis software.

1 Introduction

Flex board # 7 with ASDBLR [1] boards 13, 14 and 15 was irradiated with 3 Mrad gammas at Saclay[1]. The integrated dose for ten years of operation of the TRT is expected to be 1.6 Mrad [2], the recommended dose for testing the radiation tolerance is 2.4 Mrad [3].
During irradiation power was provided but no clock.
The number of chips are 12 DTMROCs [4] and 24 ASDBLRs, both the

[1] CEA Saclay, F-91191 Gif-sur-Yvette, France.

99-versions. A schematic diagram of the arrangement of the boards is shown in fig. 1.

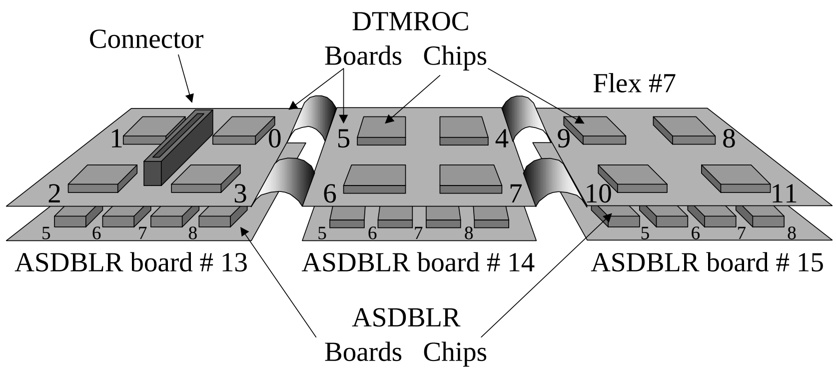

Figure 1: Schematic of the DTMROC flex board and the ASDBLR board arrangement.

The following measurements were performed before and after irradiation:

- Power consumption.
- V_{DD}-voltage scans.
- DAC threshold voltages.
- Current into ASDBLR thresholds.
- Threshold scan of test pulses.

These measurements allow the investigation of single channel upsets and the evaluation of the offset spread.

2 Measurements

2.1 Power consumption

The measured voltages and currents before and after irradiation are given in table 1. Units are in Volts, Ampere and Watts.

The changes on the ASDBLR boards (here given as the sum of the three tested boards #13, 14 and 15) are not significant ($< 2\%$). The DTMROC board shows an increase of about 34 % in power consumption. This problem is believed to be cured in the next generation of

BEFORE			AFTER		
V_{DD}	I_{DD}	P_{DD}	V_{DD}	I_{DD}	P_{DD}
5.05	1.28	6.46	5.04	1.72	8.67
V_{EE}	I_{EE}	P_{EE}	V_{EE}	I_{EE}	P_{EE}
-3.04	1.06	3.22	-3.06	1.03	3.15
V_{CC}	I_{CC}	P_{CC}	V_{CC}	I_{CC}	P_{CC}
3.03	1.37	4.15	3.02	1.40	4.23

Table 1: Measured voltages and currents before and after 3Mrad gamma irradiation. Values are given in SI-units (V, A and W).

the chip.
The voltages are measured on the far end (with respect to the connector) DTMROC board at the capacitors.
The measurement after irradiation was performed less than a week after irradiation (annealing time was less than a week at room temperature).

2.2 V_{DD}-range for which systems works

Since it was not feasible to run the system at different frequencies (the read out hardware is not foreseen to do that), the digital supply voltage (V_{DD}) was lowered instead.
The measurement was carried out as follows:
The system was biased up according to specification, i.e. $V_{DD} = 5$ V. The digital voltage supply (V_{DD}) was then systematically lowered and a threshold scan acquired. If the threshold scan could be run without any complaints by the XTRT software [5] (no read out errors) then the system was defined as operational at that voltage[2].

All measurements were carried out on the hot systems, which had

BEFORE		AFTER	
V_{DD} [V]			
works	errors	works	errors
2.71	2.66	3.55	3.45

Table 2: V_{DD} voltages for which system is (not) operational.

been running for hours. This may mean that the boards after irradi-

[2]The XTRT software was written by Juan Valls. Read-out errors are defined by incorrect headers in the data acquisition.

ation could be hotter due to the increase in power consumption. The results are given in table 2. The system is still operational at 3.6 V after irradiation, which is well under the nominal 5.0 V for normal operation.

2.3 Measurement of the threshold voltages of the DACs

All 48 threshold voltages and voltages across the 1 kΩ input resistor (giving the currents into ASDBLR thresholds) were measured before and after irradiation for DAC values of 0, 40, 63 and 255.
The results are presented as averages over all (working) thresholds in table 3.

	BEFORE		AFTER		DIFFERENCE	
Mean Values in mV						
DAC	TH_L	TH_H	TH_L	TH_H	TH_L	TH_H
255	1291	1323	1269	1302	21.3	20.5
63	326	331	320	325	6.0	5.7
40	209	211	206	207	3.5	3.5
0	6.8	2.7	6.8	2.8	0.1	0.1
Standard Deviation in mV						
DAC	TH_L	TH_H	TH_L	TH_H	TH_L	TH_H
255	120.7	106.6	137.2	118.6	28.7	23.3
63	30.2	27.3	35.2	30.3	7.5	5.6
40	19.7	17.2	22.5	19.3	4.8	3.8
0	5.3	0.7	5.8	0.8	2.2	0.4

Table 3: Measured DAC threshold voltages before and after irradiation.

One low threshold value was discarded due to consistently showing values way over average (bad channel). Since the mean and standard deviation are calculated directly from the data and not acquired from a fit (not enough data for histogram), such a bad channel would affect the results significantly.
The differences before and after irradiation show standard deviations which are consistently about the same value as the mean. From this it is concluded that their is a large variation in radiation damage between channels (some channels change a lot, others hardly at all).
These changes are significant as far as the calibration is concerned (system must be re-calibrated), they do not however affect the functionality of the system. The selection of a desired threshold value is

as good as before irradiation and no degradation of the performance is to be expected from radiation damage of the threshold DACs.

2.4 Measurement of the input current into the ASDBLR thresholds

The current into the ASDBLR threshold is determined indirectly by measuring the voltage drop across the 1 kΩ resistor on the ASDBLR boards. These voltages are given in mV, so the values correspond to μA (not taking the tolerance of the resistors into account). The mean values and standard deviations are given in table 4.

The same channel as before shows an abnormal behaviour and is not

	BEFORE		AFTER		DIFFERENCE	
Mean Values in mV						
DAC	TH_L	TH_H	TH_L	TH_H	TH_L	TH_H
255	3.01	3.11	3.33	3.45	0.327	0.335
63	1.57	1.60	1.81	1.84	0.237	0.241
40	1.40	1.42	1.62	1.65	0.227	0.229
0	1.10	1.11	1.30	1.31	0.198	0.198
Standard Deviation in mV						
DAC	TH_L	TH_H	TH_L	TH_H	TH_L	TH_H
255	0.285	0.310	0.323	0.336	0.077	0.061
63	0.113	0.133	0.125	0.141	0.036	0.032
40	0.096	0.115	0.103	0.118	0.025	0.025
0	0.068	0.080	0.070	0.083	0.022	0.021

Table 4: Measured voltage across the 1 kΩ resistor, before and after irradiation (ASDBLR threshold).

taken into account. The changes in the current are much more uniform than the changes in the threshold DAC voltage, i.e. the standard deviation is several times smaller than the mean shift. All channels seem to experience a similar change in contrary to the change in the threshold voltage.

The average current (over all low thresholds) for the four measured DAC values is shown before and after irradiation in fig. 2.

The error bars are the standard deviation calculated from the low threshold values. These are used for the calculation of the χ^2 in the fitting procedure. The natural spread of the different threshold values is not an adequate measure of the uncertainty of each mean value and therefore the reduced χ^2 values are rather small (approximately three

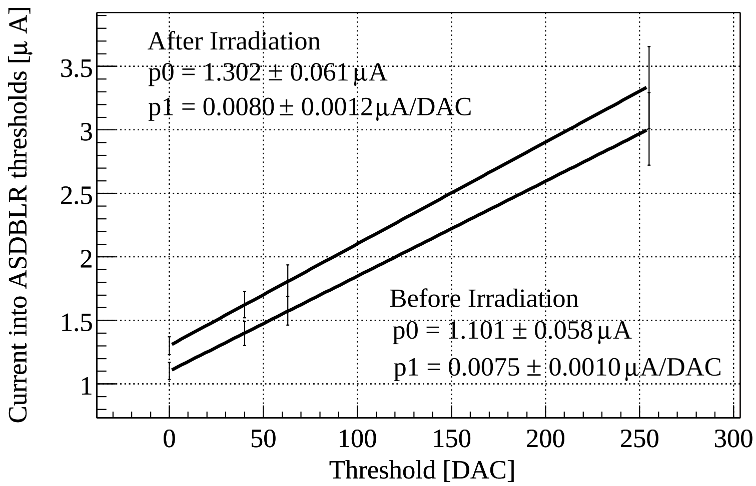

Figure 2: Current into the ASDBLR thresholds before and after irradiation with 3 Mrad gammas. (p0 is the offset, p1 the gradient of the line fit.)

orders of magnitude too low)[3].
From fig. 2 it is concluded that the spread of the current into the ASDBLR thresholds does not increase significantly (error bars in fig. 2 are of the same order before and after irradiation) and that in average the current increases by about 0.2 μA after irradiation.
This is in accordance to an increase in the base-emitter current of the input transistor which leads to a lower β value [7].

2.5 Threshold scans with test pulses

These measurements were performed by injecting pulses simultaneously into all inputs. The threshold scans are evaluated by fitting an error function to each channel[4]. The 50 % values and the noise are histogrammed and shown in fig. 3 and fig. 4 for the data before and after irradiation, respectively. The conversion of the input amplitude to equivalent deposited energy is approximately 8.5 mV for 400 eV[5].

The notation “mean” and “average” is used to refer to the values

[3]The analysis is done in ROOT [6], which defines $\mathrm{RMS}^2 = \Sigma_i^n \frac{(\overline{x}-x_i)^2}{n}$

[4]The software for this analysis was written by Juan Valls and was only slightly modified to suit the specific requirements of this analysis.

[5]The measurements were performed with injector boards that used similar electronics as the injector calibrated by Anatoli Romaniouk.

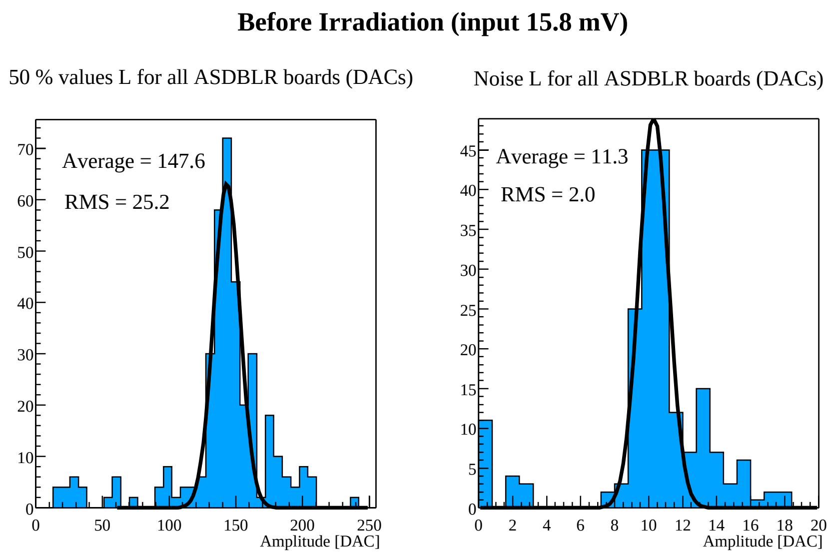

Figure 3: Histograms of the 50 % values and the noise of the fit of the error function to the S-curves before irradiation.

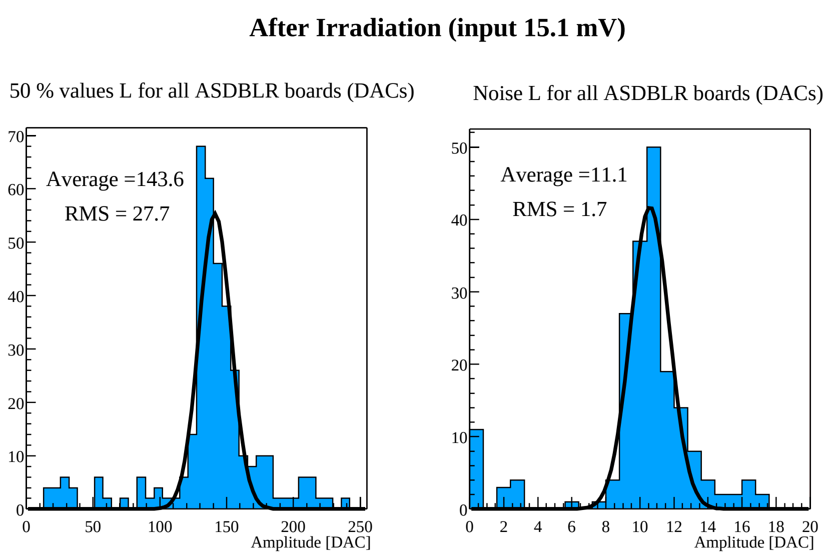

Figure 4: Histograms of the 50 % values and the noise of the fit of the error function to the S-curves after irradiation.

	BEFORE		AFTER	
	before 15.8 mV		after 15.1 mV	
Parameter	50 % value	Noise	50 % value	Noise
Mean	143.25 ± 0.97	10.312 ± 0.081	141.3 ± 1.2	10.61 ± 0.12
StDev	9.74 ± 0.88	0.864 ± 0.070	11.9 ± 1.2	1.17 ± 0.13
Ave	147.59	11.25	143.6	11.05
RMS	25.22	1.99	27.7	1.73
	before 20.0 mV		after 20.0 mV	
Parameter	50 % value	Noise	50 % value	Noise
Mean	174.2 ± 1.4	8.97 ± 0.10	174.3 ± 1.2	8.97 ± 0.11
StDev	12.7 ± 1.3	0.997 ± 0.093	12.90 ± 0.98	1.013 ± 0.077
Ave	175.38	9.52	173.5	9.25
RMS	30.25	1.75	29.32	1.55

Table 5: Parameters of the histograms of the 50 % values and the Noise of the fit parameters. The mean and standard deviation are extracted from a Gaussian fit to the histograms; the average and RMS are directly calculated from the data.

from the fit and the direct calculation, respectively. Similarly "standard deviation" and "RMS" refer to the fitted and directly calculated values.

Defining the channels that lie within the Gaussian as "normal", allows to evaluate the irradiation effects on average over "normal" channels. The direct calculation takes all channels into account and weights those which lie outside the Gaussian equally. If single channels were effected by irradiation (single channel upsets) these would be detected in the direct calculation of the RMS. The number of channels for which the fitting procedure was successful (defined as good channels) is the same before and after irradiation (this is only important to make sure that no single channels have been knocked out completely.). From the Gaussian fits it is concluded that there is no significant change (difference is less than 1 σ) for all parameters.

The above results do not indicate any severe radiation damage (no significant measurable effect in the threshold scans).

2.6 Threshold spread

Each ASDBLR chips receives 4 threshold levels, 2 high and 2 low. Of the 16 channels on an ASDBLR 8 are associated with one low and one high threshold level. Therefore the accuracy at which the threshold can be set depends on the spread in gain and offset between the 8 channels which share the same threshold.

The RMS (normalised) is calculated for every 8 channels sharing the same low threshold value before and after irradiation. Fig. 5 shows the RMS values for all 24 low thresholds of the flex board.

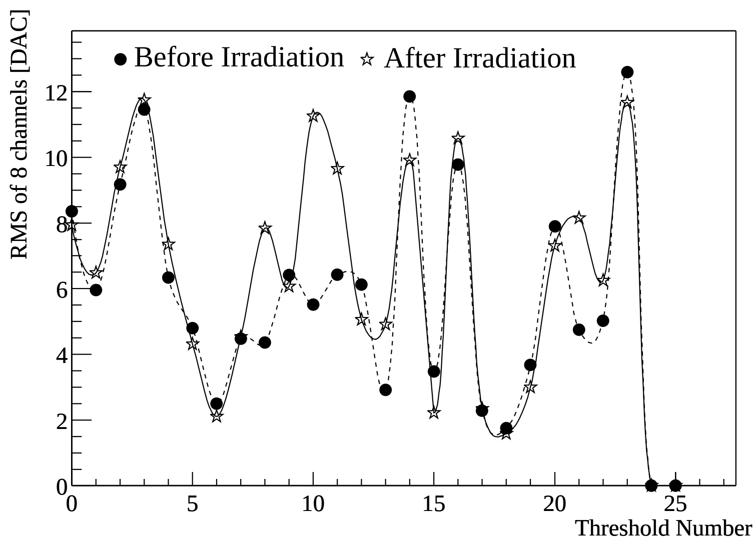

Figure 5: RMS values before and after irradiation for all 24 low thresholds of the flex board.

Threshold number 0 corresponds to ROC 0 threshold low 0; threshold number 23 to ROC 12 threshold low 1 and the intermediate values are logically incremented.
The sum of the differences between the RMS before and after irradiation is 14.02 DACs. This indicates an increase in threshold spread. As seen in fig. 5 this is mainly due to an increase of the RMS of the threshold numbers around 10. The input signal from which the data was extracted is 20 mV, the behaviour is the same however for the 15 mV test pulse. Dead channels and possible fitting problems have been taken into account (a cut is applied to the 50 % values). The RMS is therefore not always calculated from 8 channels but in some cases from less.

2.7 Conclusions

The irradiation of a full flex board (12 DTMROCs and 24 ASDBLRs) indicates the following behaviour:

1. 34 % increase in digital power consumption. (This problem is believed to be well understood and a revision of the pipeline design has been implemented in the new version of the DTMROC.)
2. An increase in offset spread is observed for some threshold.
3. All other measurements indicate no change in performance.

References

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