Effect of Ionizing Radiation on the TC255P CCD

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Introduction

In January 2000, the Saclay group had in their possession forty BCAM cameras (Boston CCD Angle Monitors) left over from the Saclay DATCHA. They were about to return them to us at Brandeis when Harry van der Graaf came to Saclay to conduct an ionizing radiation test at Saclay's cobalt-60 facility. We asked Harry to irradiate some of the BCAMs along with his own instruments.

On February 2, 2001, Harry placed four BCAMs in the radiation chamber. The BCAMs were not connected to power, which is how they will operate 99% of the time in ATLAS.

Harry describes the experiment as follows:

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On Friday Feb 2, 2001, we have irradiated four of your BCAMs
with 60Co gamma rays.

Serial nrs 13 and 26 were placed at 115 cm from the source
(12000 Ci, 195 Watts) and received, during some 6 h, about 400
Gy. BCAMs nrs 17 and 44 were placed at 200 cm away from the
source, and thus received ((115/200)**2) x 400 Gy.
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Each of the four cameras contains a TC255P image sensor and a TC255P Head (A2007) [1]. The camera itself uses a 150-mm focal length lens and two mirrors to focus and direct the image onto the CCD [5,6]. The TC255P Head consists of one op-amp, several zenar diodes, several resistors, several ceramic capacitors, and two tantalum capacitors. The head connects to the CCD with an eight-way flex cable, and the CCD itself is glued to a post protruding from the camera base.

Results

We received the irradiated BCAMs back from Saclay in May 2001. Figure 1 is a close-up of an image taken with one of the two most severely irradiated BCAMs. The image is a 5-ms exposure of a flat-topped infra-red LED sixteen meters from the camera. It is indistinguishable from images taken with a fresh camera.

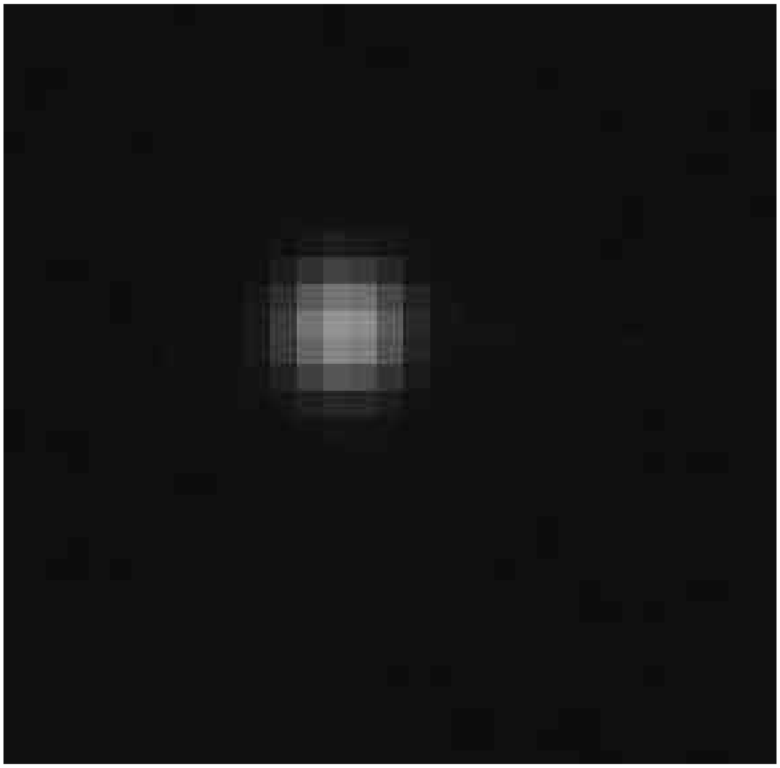

Figure 1: Image of BCAM light source taken with BCAM that had received a dose of 400 Gy ionizing radiation.

No image of a BCAM source taken with any of the irradiated cameras shows any evidence of irradiation. We began to doubt if we were testing the right cameras.

We know from our neutron irradiation experiments [2,3] that the dark current in the CCD tends to increase with damage to the CCD silicon. We can measure the dark current in an irradiated CCD relative to that of a fresh CCD by allowing the CCD to expose for a much longer period, blocking off the camera aperture, and measuring the average intensity of the resulting image. Figure 2 is a 500-ms dark current exposure taken with a fresh camera. The average intensity is 64 8-bit ADC counts. If we take a 0-ms exposure with the same CCD, we get an average intensity of 50 counts. The dark current in a fresh CCD is therefore 14 counts in 500 ms, or 28 counts/s.

Figure 2: The image captured by an undamaged CCD after a 500-ms exposure with the camera aperture blocked off. The average intensity is 64 8-bit ADC counts.

Figure 3 is a 500-ms dark-current exposure taken with a camera placed 200 cm from the cobalt source. The camera received a dose of roughly 130 Gy. The image is obviously brighter than that of a fresh CCD, so we conclude that we are seeing evidence of radiation damage.

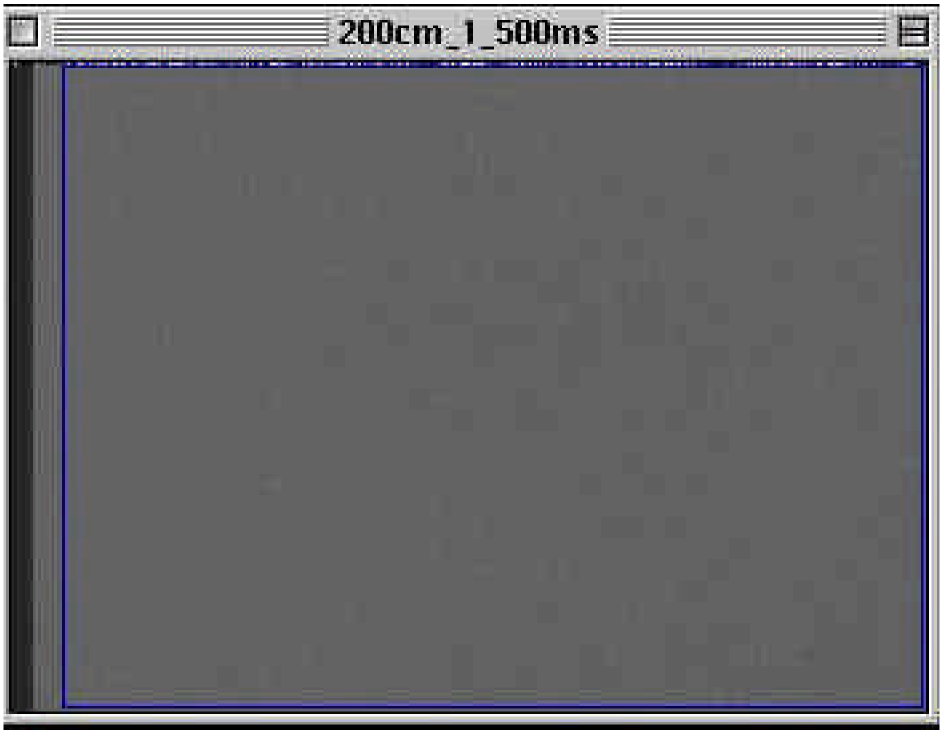

Figure 3: The image captured after 500 ms in the dark by a CCD that had been exposed to 130 Gy. The average intensity is 102 8-bit ADC counts.

Figure 4 is a 500-ms dark exposure taken with one of the cameras placed 115 cm from the cobalt source, which received about 400 Gy.

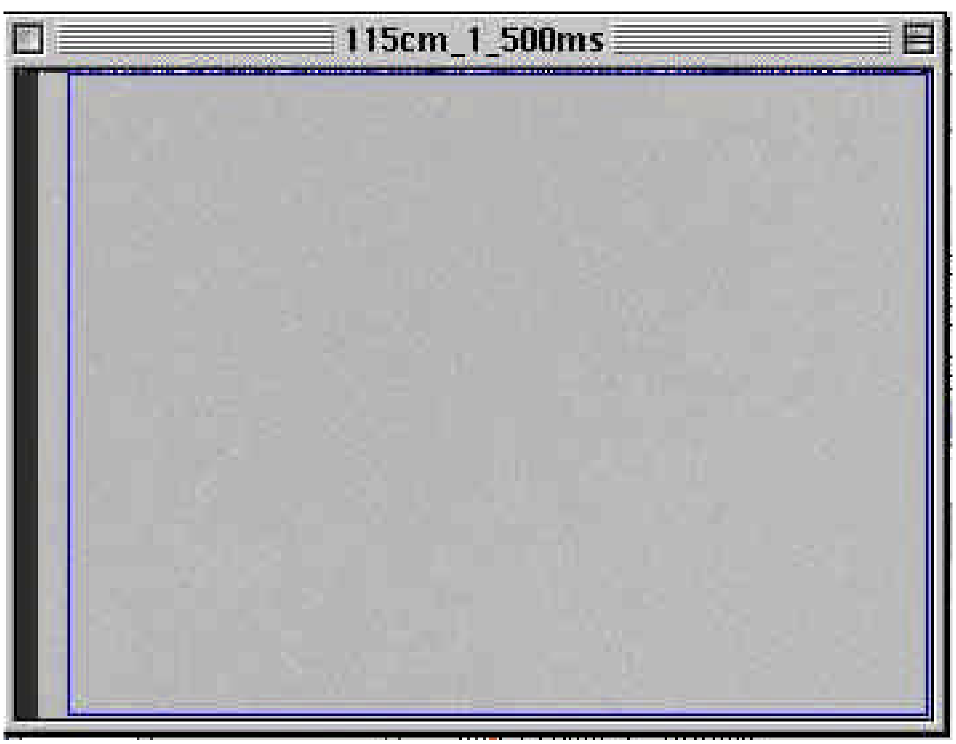

Figure 4: The image captured after 500 ms in the dark by a CCD that had been exposed to 400 Gy. The average intensity is 202 8-bit ADC counts.

Table 1 gives the dark currents in all four irradiated CCDs, and calculates the dark current increase per Gray over that of a fresh CCD.

Dose (Gy)	Image Intensity (counts)	Dark Current (counts/s)	Damage Rate (counts/s/Gy)
0	64	28	NA
130	102	104	0.58
130	112	126	0.74
400	202	304	0.69
400	210	320	0.73

Table 1: Dark currents in irradiated CCDs, and damage rate. The dark current is the 0-ms dark-current image intensity (50 counts) subtracted from the 500-ms dark current image intensity, dividing by the exposure time (500 ms). The damage rate is the dark current minus the fresh camera dark current, divided by the dose.

With neutron irradiation, we observed that the increase in dark current was linear with accumulated neutron dose [2]. Table 1 suggests that the damage rate is constant with ionizing radiation as well, with a rate of roughly 0.7 counts/s/Gy.

Conclusion

The images we take from our irradiated BCAMs are consistent with a linear increase in TC255P dark current at 0.7 counts/s/Gy. We observed just such a linear increase in dark current with neutron irradiation [2,3]. According to the ATLAS Radiation Tolerance Criteria [4], the simulated worst-case ionizing radiation dose in the end-cap muon detector is 6.4 Gy. At 0.7 counts/s/Gy, our dark current would be 4.5 counts/s after 6.4 Gy. We recall from our previous work [2] that our end-cap data acquisition system can tolerate a dark current of up to 11,000 counts/s.

The four BCAMs were not powered up during the irradiation, but in normal operation, the cameras will be powered up for less than 1% of the time. We conclude, therefore, that any change in the damage rate caused by the device being powered up will be insignificant. Using the ATLAS Radiation Tolerance Criteria [4] for ionizing radiation in the end-cap, the most pessimistic safety factor possible is 100. We appear to have a safety factor of 2,400. We conclude that the components used in our original BCAMs will survive the end-cap ionizing radiation.

It remains to be seen if the additional components in the next generation of BCAMs will survive the ATLAS ionizing radiation dose. The new circuits have 74VHC series logic chips, and a LDO (low drop-out) regulator in addition to the components of the original circuits. We hope to test these parts this year in ionizing, neutron, and single-event radiation.

Acknowledgments

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References

[1] http://www.hep.brandeis.edu/ddb/alignment/daq/a2007.pdf

[2] *Irradiation of the TC255P CCD by Fast Neutrons*, Hashemi et al, MUON-98-253.

[3] *Irradiation of the TC255P CCD by Fast Neutrons Part 2*, Hashemi et al, MUON-2000-011.

[4] *ATLAS Radiation Tolerance Criteria for Electronic Components*, Appendix 1 of ATLAS doc. ATC-TE-QA-0001, 21 July 00.

[5] http://www.hep.brandeis.edu/ddb/alignment/bcam.

[6] *The BCAM Camera*, Hashemi et al, MUON-2000-024.