Single Photon Avalanche Diode radiation tests

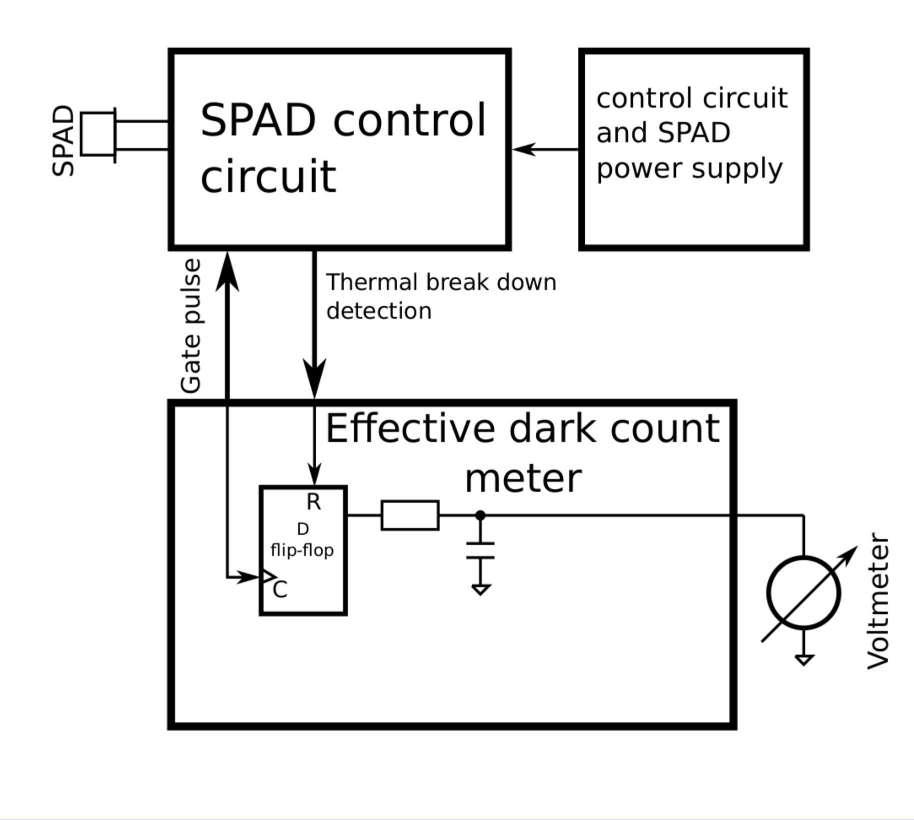
Jan Kodet[a], Ivan Prochazka[a], Josef Blazej[a], Xiaoli Sun[b], John Cavanaugh[b]

prochazk@cesnet.cz

[a] Czech Technical University in Prague, Brehova 7, 115 19 Prague 1, Czech Republic
[b] NASA Goddard Space Flight Center, Code 694, 8800 Greenbelt Rd., Greenbelt, MD, USA

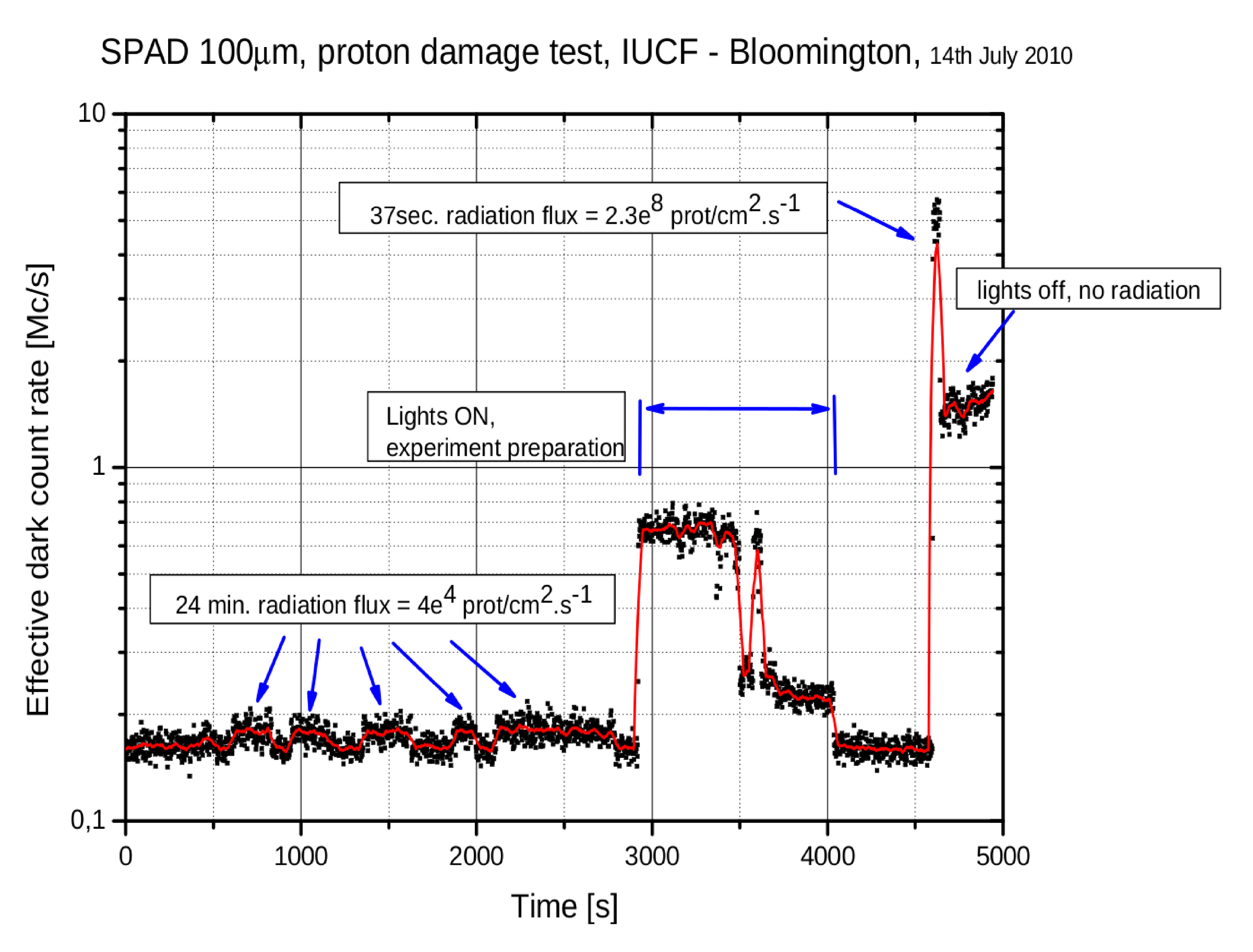
Proton radiation tests

The main characterization of the SPAD[1], which is expected to be changed after the radiation, which is not larger then 10krad, is the effective dark count rate increase. Another parameters such as quantum efficiency, break down voltage, speed were not expected to change[2]. The silicon Single Photon Counting Diodes have been tested with 54 MeV protons at Indiana University Cyclotron Facility (IUCF) at Bloomington, Indiana[3] and with ^{60}Co at Nuclear Research Institute in Rez, Czech Republic. The SPAD diodes have diameter of 100um and were fabricated at Czech Technical University (CTU).



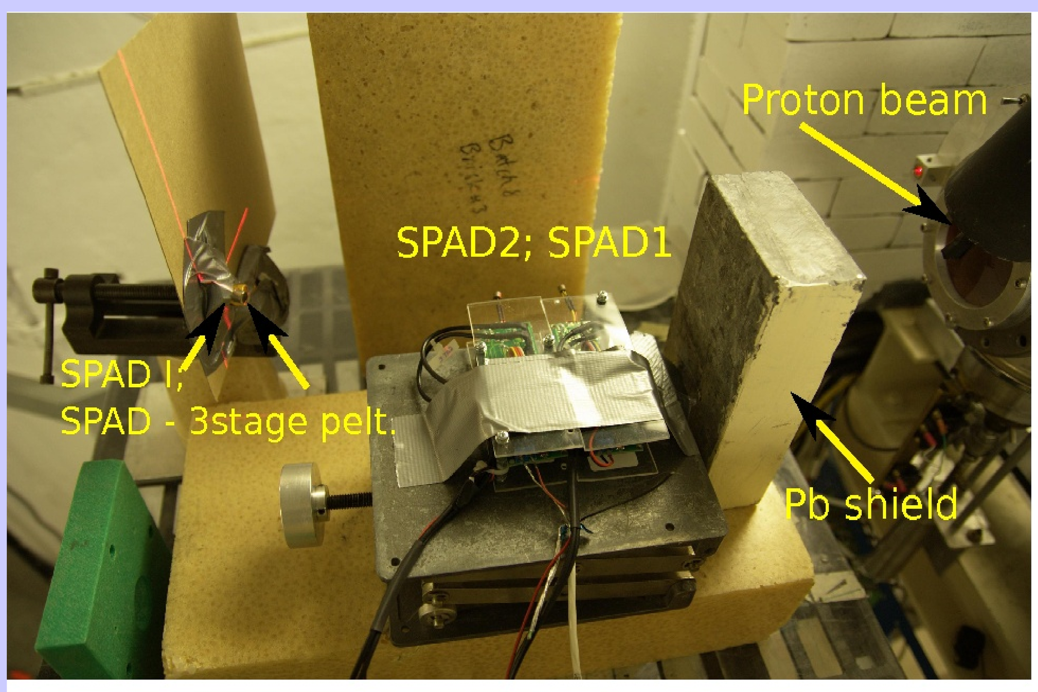
Effective dark count rate measurement - repetition rate was set to 100 Hz. The leading edge of a gate window sets the D flip-flop and the output pulse from SPAD control circuit resets the D flip-flop. The output of the D flip-flop are pulses with 100 Hz repetition rate and with pulse width modulation corresponding to the time interval between opening the gate and thermal noise occurrence - effective dark count. The pulse sequence is simply integrated with integration constant 200 ms and the resulting voltage is measured.

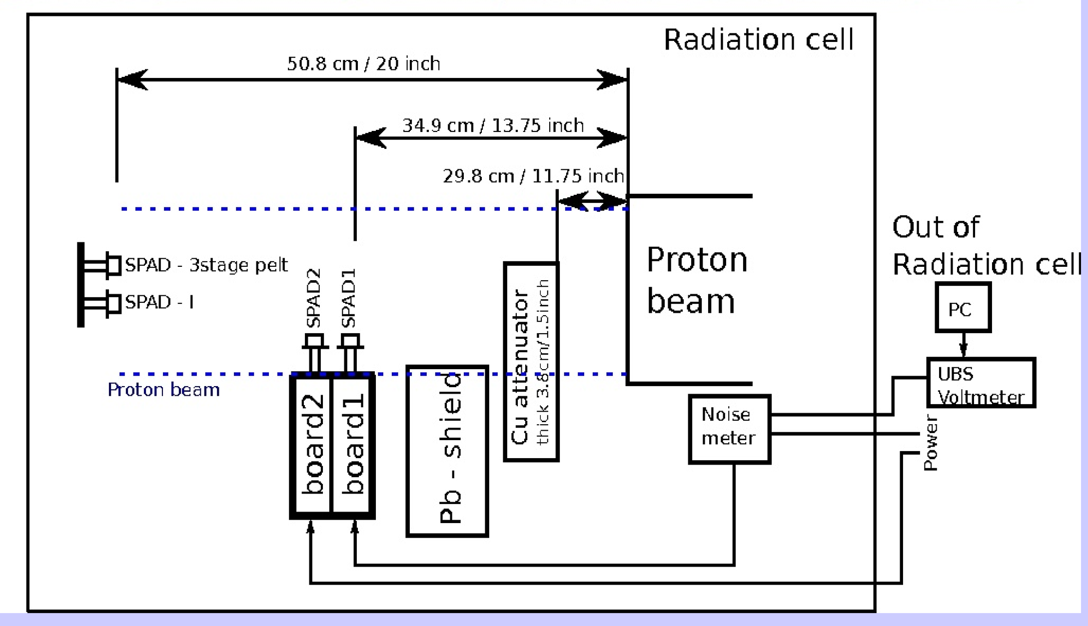
Proton radiation tests results

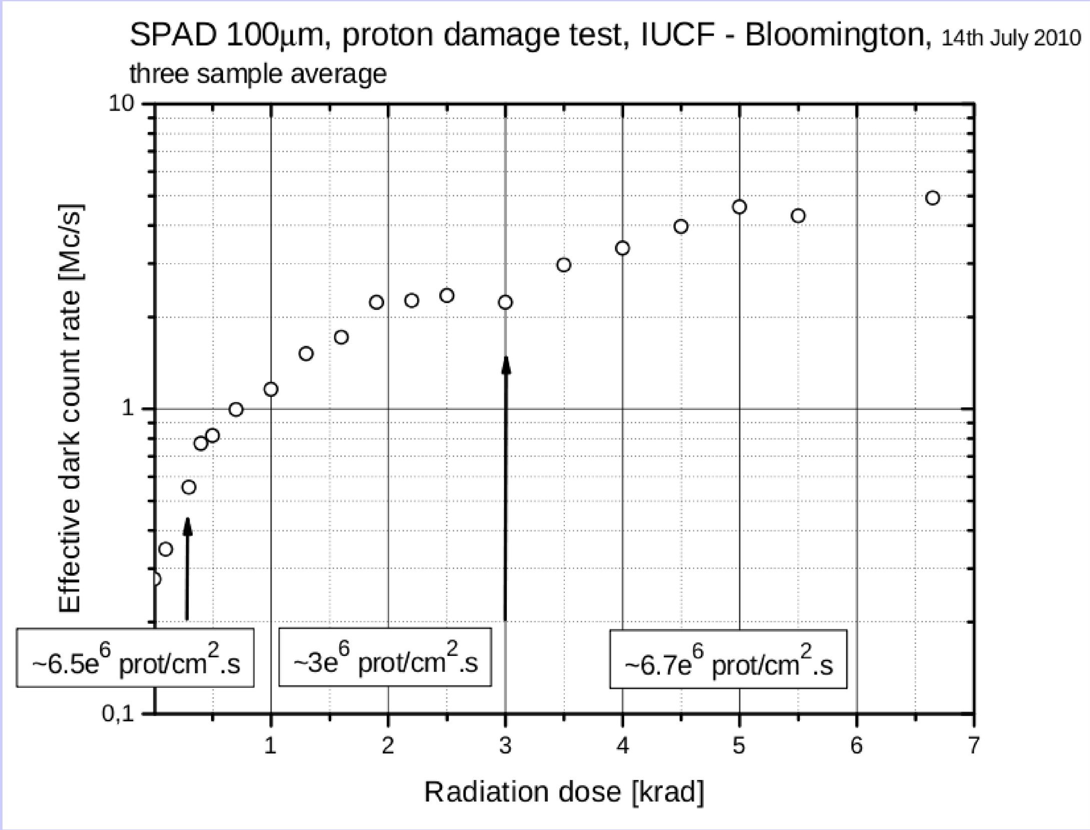


Effective dark count rate of SPAD#1 irradiated with 53 MeV protons, pulsed biased 1.3 V above the break down voltage and the effective dark count rate was measured during the radiation.

The first radiation test set up - the diodes with control circuits were set to the radiation cell and the voltmeter with PC were set out of the radiation cell. SPAD#1 was operated in actively quenching and gating mode and the effective dark count was monitored, SPAD#2 was biased bellow its break down voltage and the third diode was unbiased (SPAD#I). The proton flux was first set to 4×10^4 protons.cm^{-2}.s^{-1} - expected peak proton flux of spacecrafts in Earth orbit. The achieved dose was 0.008 krad and fluence 5.8×10^7 protons.cm^{-2}. Then the proton flux was set to 1.99×10^8 protons.cm^{-2}.s^{-1}, exactly for 37 seconds; the dose was 1.28 krad hence the overall fluence = 8.3×10^9 protons.cm^{-2}.







The effective dark count rate dependence on radiation dose three diodes average.

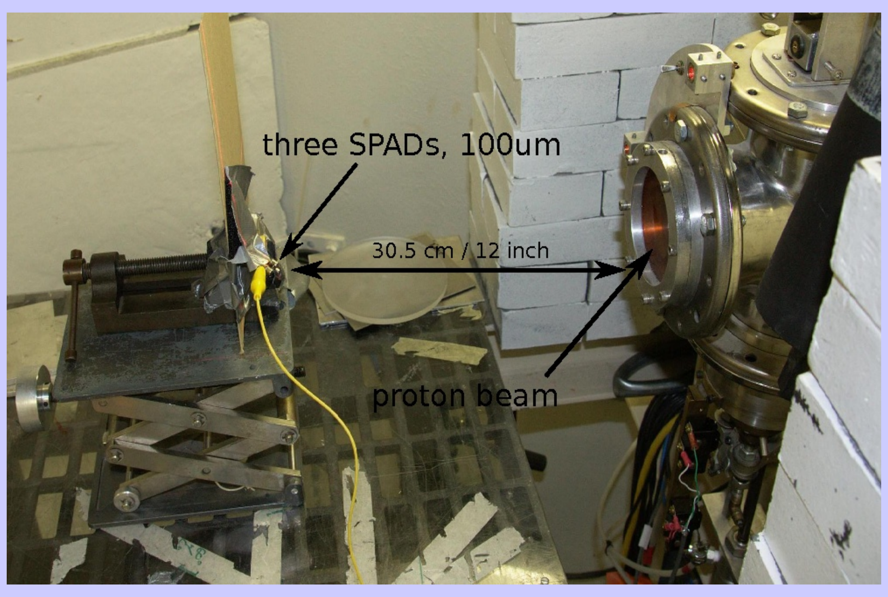
The second radiation test set up - SPADs#3, #4, #5 pins were shorted and connected to the ground. The samples were irradiated with proton energy 54 MeV. The radiation proton flux was set:

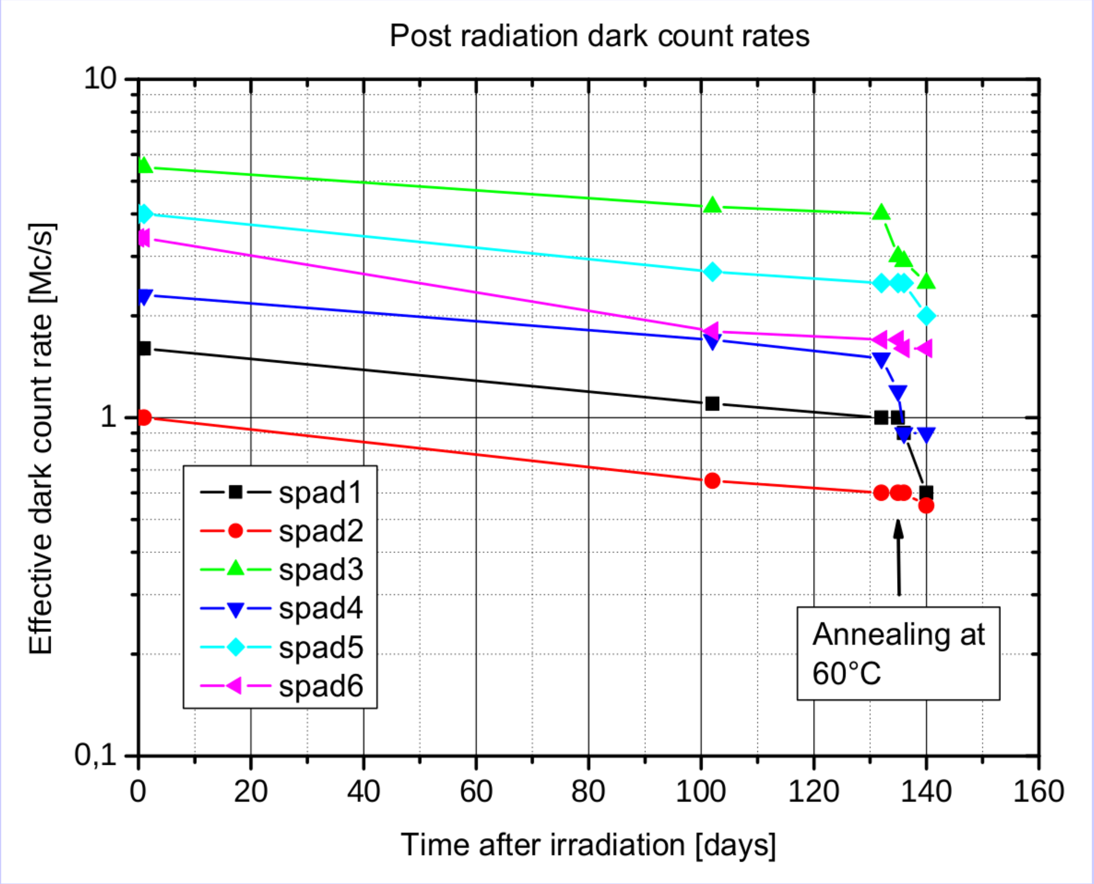
6.5×10^6 protons.cm^{-2}.s^{-1} - radiation dose reached 0.3 krad and fluence = 1.87×10^9 protons.cm^{-2}.

3.1×10^6 protons.cm^{-2}.s^{-1} - dose reached 3 krad and fluence = 2.15×10^{10} protons.cm^{-2}.

6.7×10^6 protons.cm^{-2}.s^{-1} - radiation dose was 6.647 krad and fluence = 4.26×10^{10} protons.cm^{-2}.

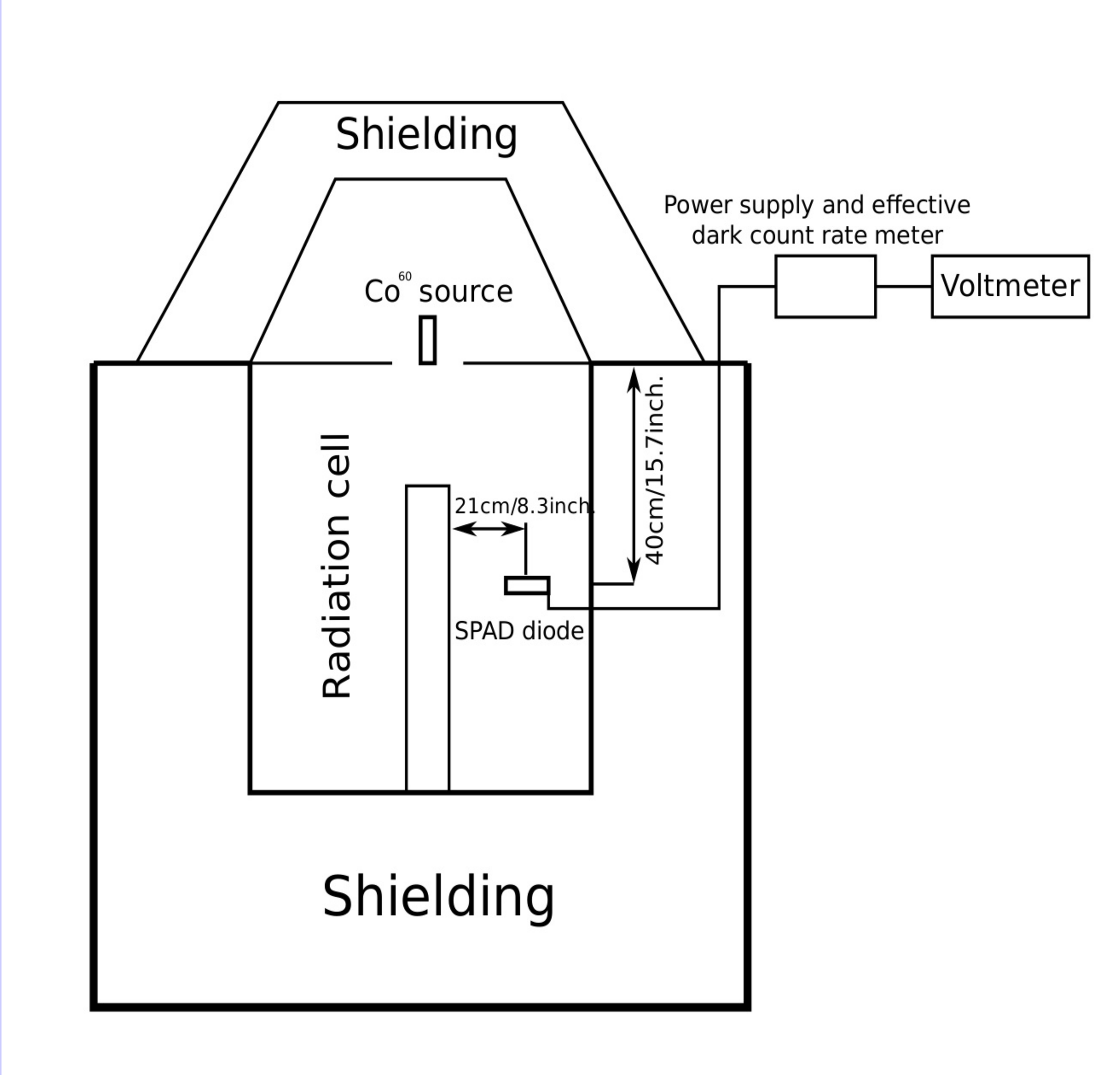
After each step the diodes break down voltages were measured, however no changes were observed.





The effective dark count rates were measured 1, 102, 132 days after the proton irradiation. The test samples were stored at room temperature except short time, when the diodes where shipped from USA to the Czech republic. After 132 days the samples were stored in an oven at 60±1°C for 3 days and the effective dark count rates where measured 1, 3, 8 days after being stored in the oven. The slow annealing effects were observed within the first 132 days. The slope can be roughly estimated to be 0.8 Mc/s in 100days depending on the total radiation dose. The annealing effect was increased when the temperature raised up to 60°C.

Gamma rays radiation tests



The another group of three SPADs were gamma irradiated in the Czech Republic at Nuclear Research Institute in Rez using ^{60}Co radiation source. The radiation speed was set to 2.5 rad/s. The effective dark count rate was monitored during the irradiation. The samples were irradiated for 3.75 hours and the total reached dose was 34 krad. The effective dark count rate before irradiation was 0.2 Mc/s. During the irradiation it increased to 1.5 Mc/s, because there were additional breaks down caused by gamma radiation. After the irradiation the effective dark count rate was again 0.2 Mc/s. The diode break down voltage and detection timing jitter were tested before and after the irradiation, however the gamma ray radiation did not caused any observable changes in diodes performance.

References

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[2] Xiaoli Sun; Dautet, H.; , "Proton radiation damage of Si APD single photon counters," Radiation Effects Data Workshop, 2001 IEEE , vol., no., pp.146-150, 2001 doi: 10.1109/REDW.2001.960462
[3] von Przewoski, B.; Rinckel, T.; Manwaring, W.; Broxton, G.; Chipara, M.; Ellis, T.; Hall, E.R.; Kinser, A.; Foster, C.C.; , "Beam properties of the new radiation effects research stations at Indiana University Cyclotron Facility," Radiation Effects Data Workshop, 2004 IEEE , vol., no., pp.145-150, 22-22 July 2004 y-VCH, 2005, ISBN: 3527402306

Conclusion

This study examines the silicon Single Photon Avalanche Diodes 100 μm of diameter of active area. The six diodes were irradiated with 53 MeV protons and the effective dark count rate radiation dependence can be roughly estimated as 0.95 Mc/s/krad for all tested diode. It can be concluded, that the effective dark count rate radiation dependence is strictly dependent on the radiation flux. The first three diodes were irradiated with approximately 150 times higher proton flux than the second three diodes. The average effective dark count rate radiation dependence for first three diode is 1.31 Mc/s/krad and for the second three diodes is 0.59 Mc/s/krad, which is 2.2 times less. The diodes annealing rates were monitored at room temperature and at 60°C. The effective dark count rate was monitored during the radiation, however the effective dark count rate was the same before and after the radiation. Comparison of the proton and gamma ray tests indicate that the increase of the effective dark count rate is due primarily to displacement damage in the depletion region.

This work has been carried out at the Czech Technical University in Prague, Czech Republic. The research and development of solid states detectors and their applications is supported MSM6840770015.

Presented at 6th International Conference on New Development in Photodetection (NDIP2011), July 4-8, 2011, Lyon, France.