GAMMA RAY DAMAGE OF UNBIASED CCD IMAGE SENSORS

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High image quality Charge-coupled device (CCD) image sensors are needed in many applications. Low noise and high dynamic range are critical parameters required in scientific and industrial applications. In many of the applications, however, the CCD image sensor can be irradiated by a ionizing radiation, as alpha, beta, gamma or x-ray. This paper shows behaviour of low noise, high dynamic range, 1 Megapixel Frame-Transfer CCD FTT1010-M [1] image sensor radiated by gamma ray radiation. CCD image sensor driver board with rad-hard components was designed and used during the tests. Results of the investigation will be used in system for protein crystallization study in microgravity.

Keywords: CCD image sensor, gamma ray

1. INTRODUCTION

A 12-bit, 1 Megapixel, high dynamic range CCD camera was designed (see Fig. 1) for application, where an ionizing radiation can be present. Therefore test setup (see Fig. 2) was created to analyze performance of the FTT1010-M CCD image sensor under ionizing radiation. First, prior the irradiation, virgin images were acquired – at dark condition and at bright condition. Than the CCD sensor was irradiated by doze of a radiation and images were acquired to observe the changes in performance. This paper describes results of CCD image sensor exposed unbiased by gamma ray source. The CCD sensor was unbiased in between the periodical measurements.

2. CCD SENSOR DRIVER

Block schematic of the CCD image sensor driver used during the radiation tests is shown on Fig. 3. Radiation hard components are used to eliminate the possibility of parameter degradation by CCD image sensor driver circuitry.

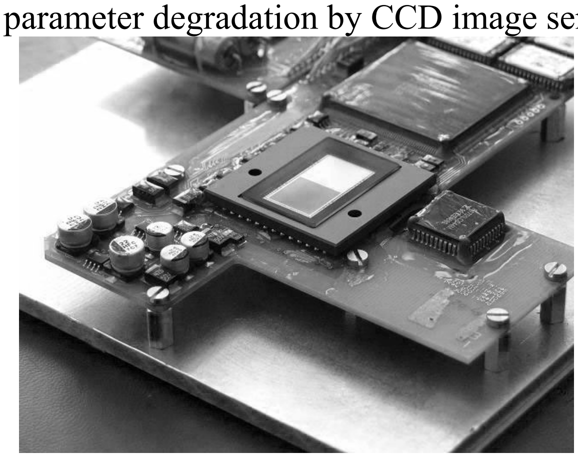

Fig. 1: Camera with FTT1010-M CCD image sensor

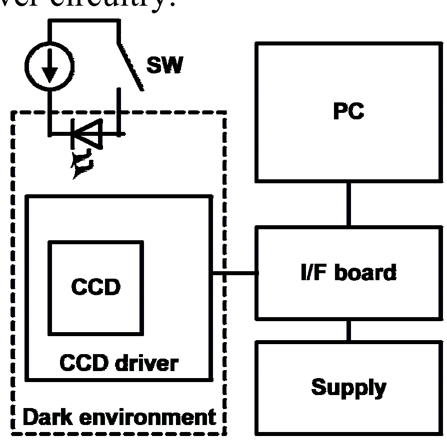

Fig. 2: Test Setup

FTT1010-M Frame Transfer CCD image sensor is build from several blocks – image area, storage area, horizontal output register and output amplifier. Image clock gate driver shifts the image from image area to storage area after image integration period. This shifting must be fast to avoid gradient, caused by difference in integration time of the first and the last line in the image area. The only difference between image and storage area is, that storage area is covered from light. Therefore, the read-out can be relatively slow. During read-out, the storage clock gate driver shifts one line first to horizontal shift register and than horizontal clock driver shifts this line pixel by pixel to the output register of the CCD.

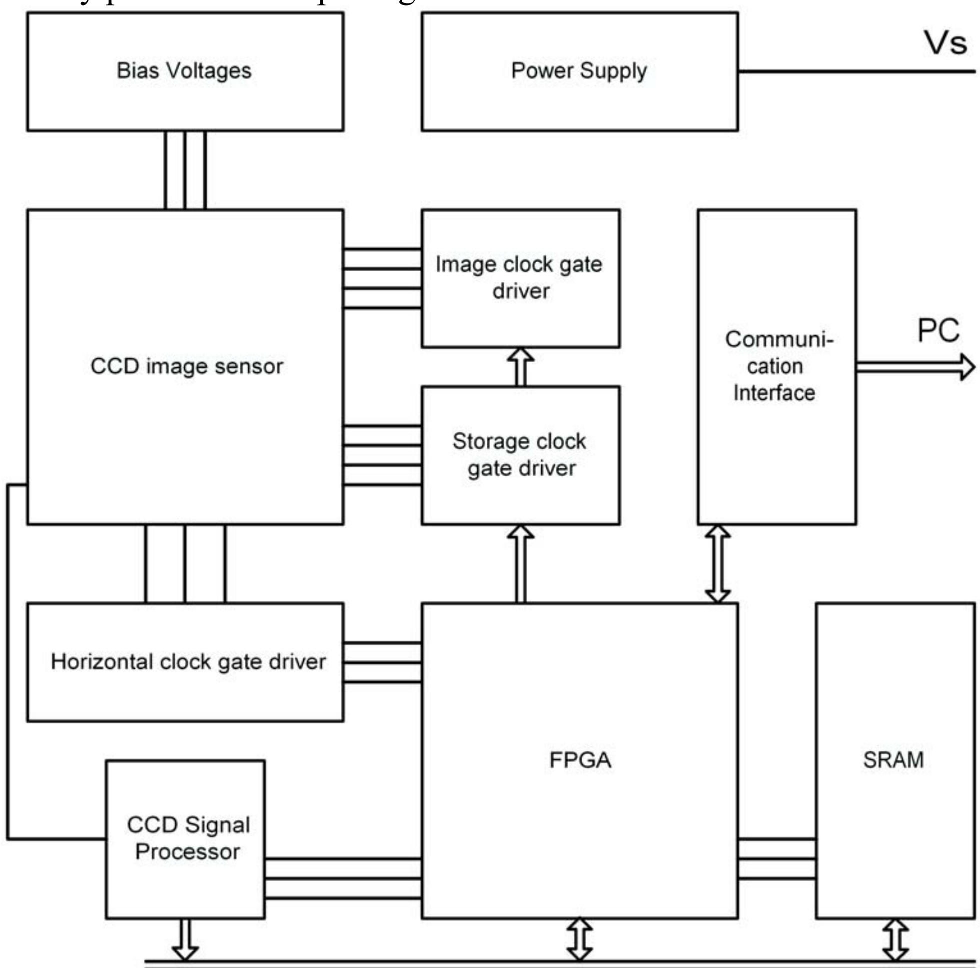

Fig. 3: Block Schematic of Camera with FTT1010-M CCD image sensor

Each pixel is processed by CCD signal processor using Correlated Double Sampling. Its output 12-bit digital value is stored in SRAM memory. Electrical Dynamic range of the camera, measured with virgin non radiated CCD image sensor, is approx. 65 dB. Black pixel clamping technique was not applied during the image processing. During normal processing, the CCD signal is referenced to a well established "black level". This black level is provided by the CCD black lines on bottom of the CCD and black columns on sides of the CCD. However, in our case are the black pixels also influenced by the ionizing radiation and the black pixel clamping would distort the results.

3. MEASUREMENT RESULTS

There were always two images taken to characterize the camera performance – the first image was taken at bright condition (the camera board is placed at dark environment and the light source is switched on, the camera setting is such, that the CCD is just below saturation) and the second image is taken at dark condition (the camera board is placed at dark environment and the light source is switched off, the camera setting is similar as at the bright condition).

Histogram of the bright image before exposure is on Fig. 4. Integration time and gain of the camera were adjusted such, that the CCD image sensor is just below saturation and value of most of the pixels is below 4095 DN.

In next step the CCD sensor was irradiated by dose of 30 rad total dose. Remaining circuitry was covered during the exposure. Fig. 5 shows histogram 7 days after this exposure.

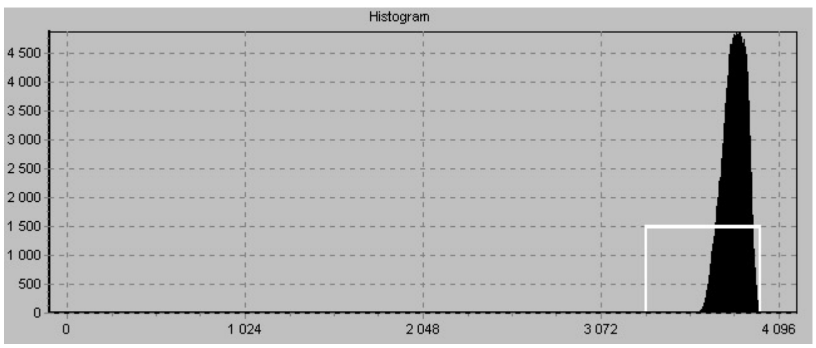

Fig. 4: Histogram of bright image taken prior to gamma ray exposure

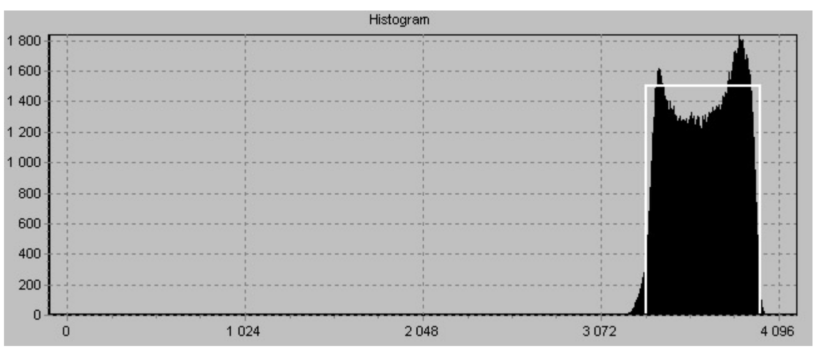

Fig. 5: Histogram of bright image taken 7 days after 30 rad total dose gamma ray exposure

Images were taken immediately and also periodically after exposure to observe a healing or reverse healing effect. The CCD image sensor was unbiased in between the measurements. Histogram on Fig. 6 shows pixel distribution during bright condition 21 days after irradiation of 30 rad total dose gamma ray exposure.

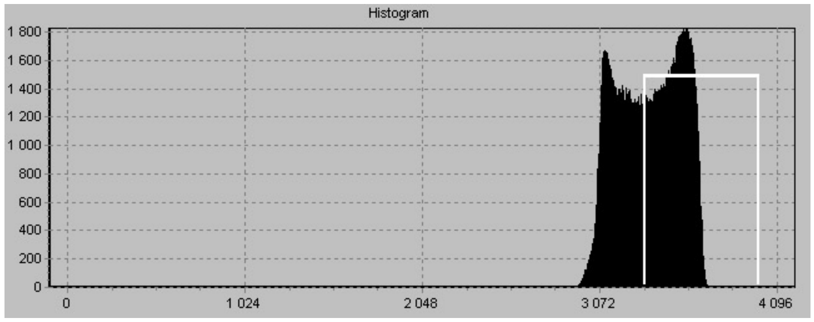

Fig. 6: Histogram of bright image taken 21 days after 30 rad total dose gamma ray exposure

Fig. 7 shows histogram 400 days after exposure. For better comparison of the histograms, window of the same absolute values is drawn on the histograms.

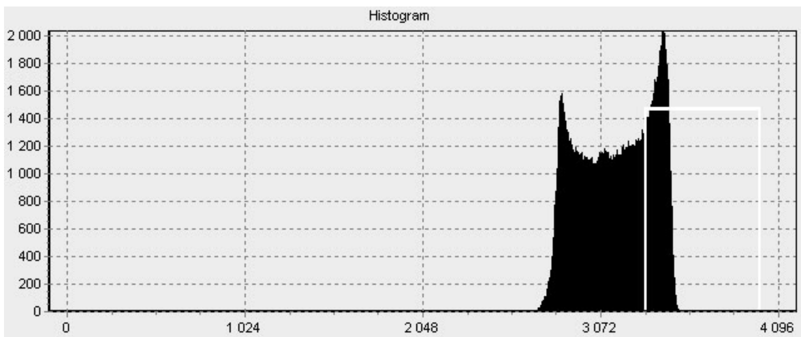

Fig. 7: Histogram of bright image taken 448 days after 30 rad total dose gamma ray exposure

The degradation of parameters during bright conditions is obvious. In the image itself, the degradation results in areas, where the pixel values can not be increased, even if light intensity or integration time would be increased. In our case, the brightest part was in the center on the bottom of the image, the darkest was the right top corner.

Potential in Volts on CCD gates versus depth in the substrate is shown on Fig. 8 [3]. When the gate is biased by positive voltage, a well is created underneath the gate. Electrons, which are generated in the upper part of the silicon, will be collected in this potential well. When a gate is biased to 0 V or lower, there will not be any potential well in the silicon and no electrons can be stored. During our experiment we modified bias voltages of the CCD and observed the results. Modification of the p-well bias voltage has significant impact to the CCD image sensor performance. Fig. 9 shows histogram of an image taken with decreased p-well voltage.

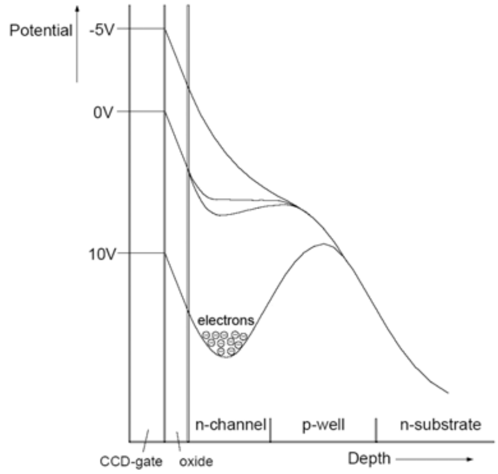

Fig. 8: Potential well diagram

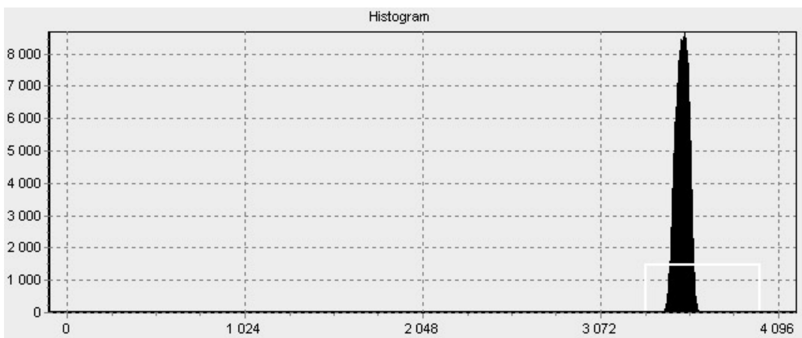

Fig. 9: Histogram of bright image taken 448 days after 30 rad total dose gamma ray exposure with modified p-well bias voltage

4. SUMMARY

It was possible to decrease the impacts of gamma ray ionizing radiation to the FTT1010-M CCD image sensor by adjustment of the bias voltage. This adjustment improved significantly the operation during bright condition. The performance during dark condition is not remarkably influenced by this modification.

Results of the investigation will be used in system for protein crystallization study in microgravity.

5. REFERENCES

[1] http://www.dalsa.com/pi/products/productdetails.asp?ProductID=FTT1010M

[2] James R. Janesick, *Scientific Charge-Coupled Devices*, 1^{d} Ed, vol 2, SPIE, Washington, 2001

[3] http://www.dalsa.com/pi/documents/Application_Note_Camera_Electronics_an01-r3.pdf