Analysis of the effect of the interline CCD-sensor dark signal increasing during gamma-irradiation

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Abstract. This paper discusses results of the study of a dark signal degradation of visible range interline transfer CCD during gamma-irradiation.

1. Introduction
A spacecraft requires precise information about its location. On board Focal Plane Arrays (FPA), based on CCD-sensors are used for capturing current position relative to the preset star map. Star trackers have to operate in severe radiation environments of protons and electrons that can lead to Total Ionizing Dose (TID) effects [1-12].

2. Device under test
The operation of charge-coupled devices (CCD) is based on the formation, storage and transfer of charge packets in the potential wells formed in the surface layer of the semiconductor by application of external voltage to the electrodes.

The device under test (DUT) was a high-performance multimegapixel image sensor KAI-2093. The key features of this sensor, such as 7.4 µm square pixels with microlenses and the large full well capacity, result in high dynamic range. The split horizontal register offers a choice of single or dual output allowing either 15 or 30 frame per second (fps). The architecture allows either progressive scan or interlaced readout (fig.1).
3. DUT parameters and characteristics
The frame capture was carried out between irradiation cycles. Dark current, dark signal non-uniformity, fixed pattern noise were calculated from the received frames. Supply currents were monitored within the test process.

4. Experimental technique
CCD-sensor irradiations were carried out at the gamma irradiation facility Panorama- MEPhI with Co$^{60}$ source (NRNU MEPhI-SPELS) [13].

The device was biased during irradiation.

5. Results and discussion
One of the effects of gamma-irradiation is the increase of the dark signal of the CCD. The main contributor to the resulting dark signal is the surface dark current caused by electron generation at the Si/SiO$_2$ interface [14]. Figure 2 shows dark images obtained before and after irradiation.

Due to the thermal generation in the depletion region, photosensitive pixel parts produce electron-hole pairs. Electrons and holes are separated and moved by the space charge region (SCR) field in the p and n region, respectively (Fig. 2).

When exposed to radiation, surface states are formed at the Si/SiO$_2$ interface, leading to increase of thermal generation due to additional levels in the SCR (Shockley-Read-Hall process). As a result, even in the absence of light, additional "dark" electrons are thermally generated and the resulting increase of the average dark signal is observed.
At the 40 krad[Si] TID level nonuniform degradation of a corner columns was observed. Dark signal averaged over all rows is presented in Fig.4. Region with dark reference pixels degraded more than photosensitive area. This effect can be explained by the influence of hydrogen incorporated into surface layers during processing of light shielded area [15].

After 100 krad[Si], dark signal of light sensitive area constitutes one-sixth of the ADC range. Also sequence of columns with different dark signal level was observed (Fig.5). Presumably, this effect is concerned with redistribution of radiation induced charge during transfer of signal charge.
6. Conclusion
The paper discusses TID degradation of interline transfer CCD image sensor. The main reason of degradation is the formation of surface states at the Si/SiO$_2$ interface leading to increase of thermal generation. That, in turn, results in the increase of the dark current of CCD image sensor. Nonuniform degradation of corner regions was observed. It is therefore recommended not to use light shielded area as a dark level reference during image processing.

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