Test of charge injection into CCD sensors

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1 Introduction

For the recovery of the charge transfer efficiency (CTE) of CCD sensors damaged by irradiation, injection of fat-zero charge is known to be one of the effective methods. The injected charge packet which exists in every pixel fills up the trap centers created by the radiation damage, hence the signal charge can escape from trapping to some extent.

The CCD sensors type S5466 manufactured by Hamamatsu Photonics have external pins for the charge injection. We have tested how the charge injection works, particularly on the amount of the kCT noise which is inevitably introduced in the charge injection.

2 Experiment

The principle of the charge injection is schematically illustrated in Fig. 1. This injection method is called the potential equilibration method. By pulsing the input diode (ID) a certain amount of charge determined by the potential difference between the potential wells under two gates IG1 and IG2 is injected. The CCD sample and the readout electronics (CCD board) are put inside the refrigerator in the same manner as in the beam tests. The readout frequency of 250 kHz and the readout cycle of 3 sec are adopted. At each setting, we took three runs of data; the dark run, the source run, and the source run with the shtter closed.

2.1 Charge injection into horizontal register

The output spectrum of a dark run without charge injection is shown in Fig. 2. When some amount of charge is injected into the horizontal register, the peak of the pedestal moves as shown in Fig. 3. The temperature dependence of the total charge (dark current + injected charge) is shown in Fig. 4 for three different injection. The rise at low temperature with the largest charge injection is presumably due to shift of the gate voltages with the temperature.

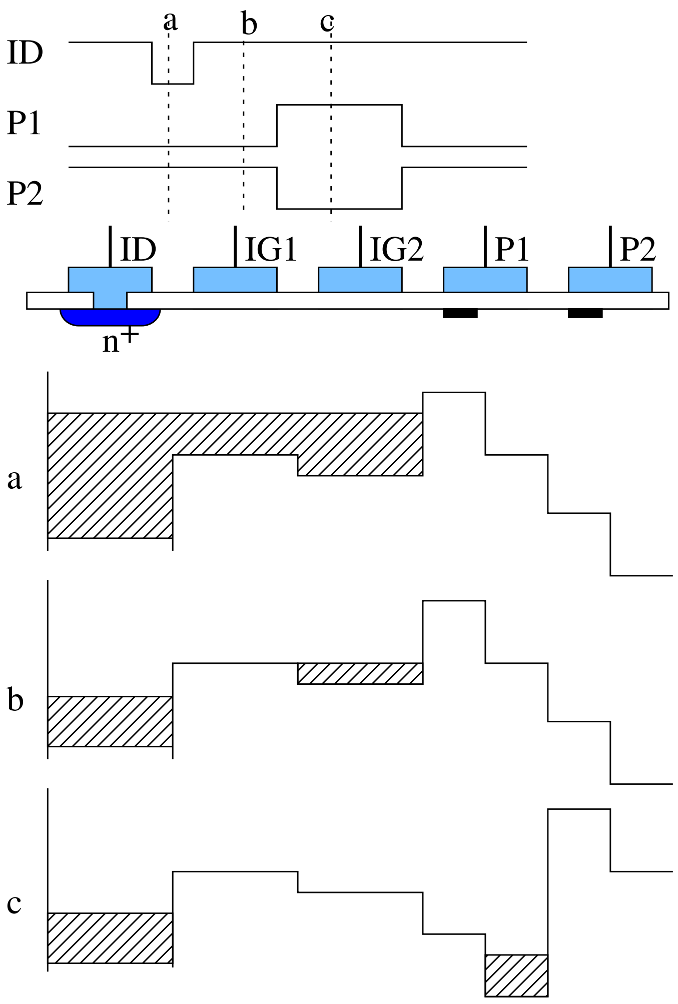

Figure 1: Charge injection scheme of the potential equilibration method.

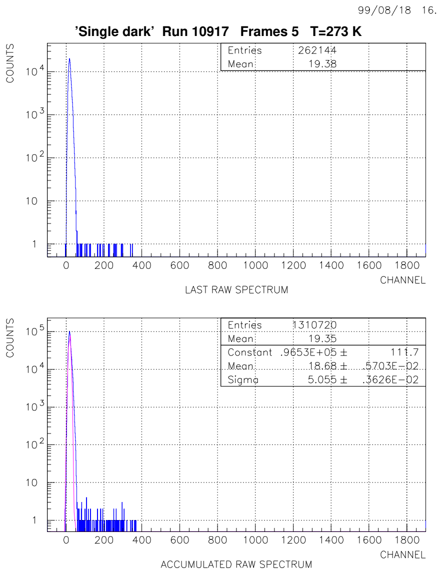

Figure 2: CCD dark spectrum without charge injection.

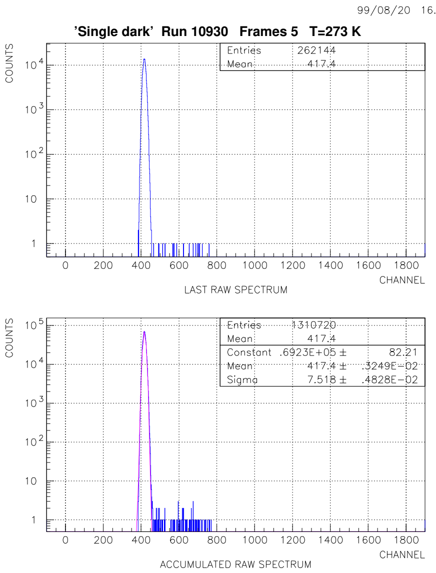

Figure 3: Dark spectrum with horizontal charge injection.

The amount of the injected charge was calculated from the difference between the peak positions of the dark spectra with and without the charge injection. Fig. 5 shows the injected charge as a function of the gate voltage. With small charge injection, the amount of the charge looks decreasing exponentially with the gate voltage.

$$Q \propto \exp \alpha (V_{IG1} - V_{IG2}). \tag{1}$$

The injection of charge into the CCD sensor in our method is actually charging a capacitor under the gate IG1. In such a case, a noise proportional to $\sqrt{kTC}$ is introduced, where k is the Boltzmann constant, T is the absolute temperature, and C is the capacitance. This noise is called kTC noise.

We measured the excess noise associated with the charge injection by subtracting quadratically the width of the pedestal of the "source run with the shutter closed" with no charge injection from that with charge injection (Fig. 6). The excess noise is plotted as a function of the injected charge in Fig. 7. From this figure, it seems the excess noise is proportinal to square root of the injected charge. Since electrical charge injection is not a random process, it should not be a contribution from a simple statistical fluctuation of the number of the injected electrons, $\sqrt{N_Q}$, and actually it is less than $\sqrt{N_Q}$. This excess noise can be explained as the kTC noise. Usin Equation 1 the capacitance under IG1 can be written as

$$\begin{aligned} C &= \frac{dQ}{dV_{IG1}} \\ &\propto \frac{d}{dV_{IG1}} \exp \alpha (V_{IG1} - V_{IG2}) \end{aligned}$$

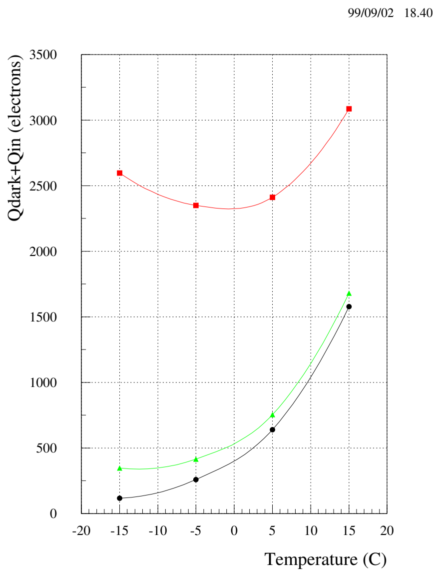

Figure 4: Dark current plus injected charge as a function of temperature. Input gate voltages are; $V_{IG1} = +0.516\ V$ for the largest, $+0.700\ V$ for the second largest, and $+0.900\ V$ without charge injection for the smallest case. $V_{IG2} = -4.02\ V$ for all cases.

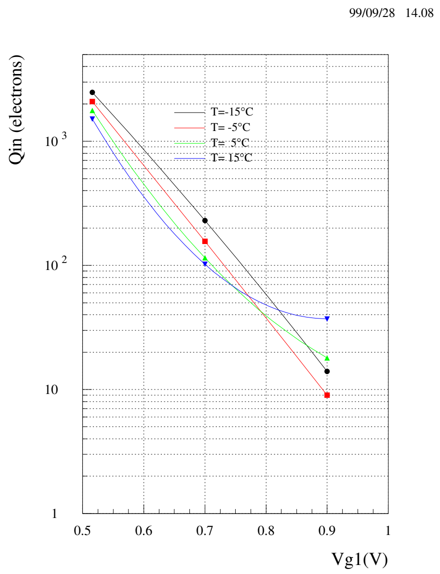

Figure 5: Injected charge as a function of V_{IG1}. V_{IG2} is $-4.02\ V$.

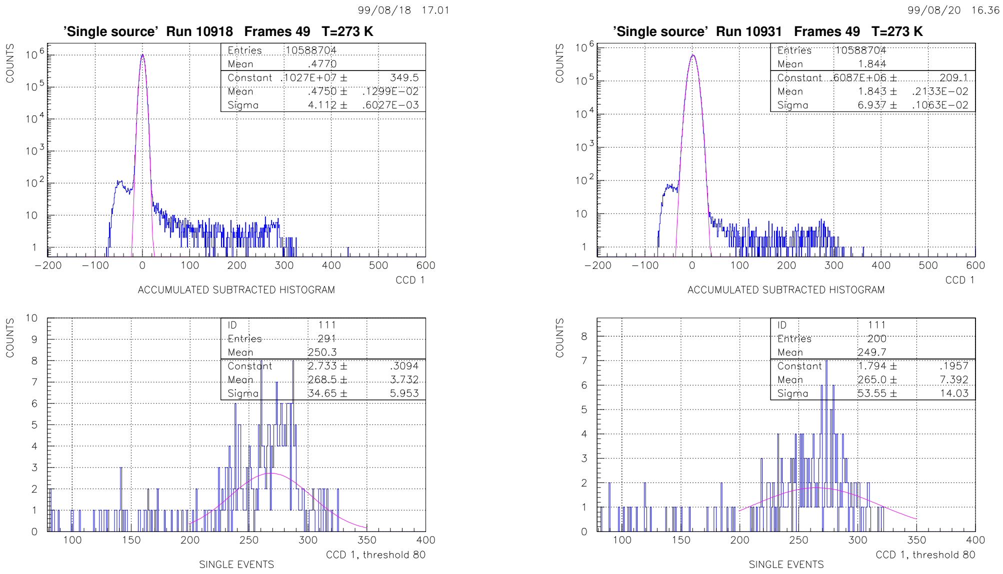

Figure 6: Spectra of source runs with the shutter closed without (left) and with (right) chrarge injection.

$$= \quad \alpha Q. \tag{2}$$

Therefore, the kTC noise which is proportional to $\sqrt{C}$ becomes proportional to $\sqrt{Q}$.

2.2 Charge injection into vertical register

The spectra of the CCD outputs with charge injection into the vertical register are shown in Fig. 8. Because of non-uniformity of the injected charge column by column, the spectrum with the vertical charge injection largely spreads and has many small peaks. Each peak presumably corresponds to the pedestal of one column. With the CCD S5466, it is not practical to inject a controlled amount of charge into the vertical register. Some special input gate structure in which the amount of the injected charge is free from the non-uniformity of the structure (gate oxide thickness, etc.) is necessary.

3 Summary

We have tried charge injection into a CCD sensor type S5466. With the potential equiblium method, it was found that the amount of the injected charge increases exponentially with the voltage difference between two input gates IG1 and IG2. The excess noise associated with the charge injection is sufficiently small and is proportional to square root of the number of the injected electrons $\sqrt{N_Q}$ but less

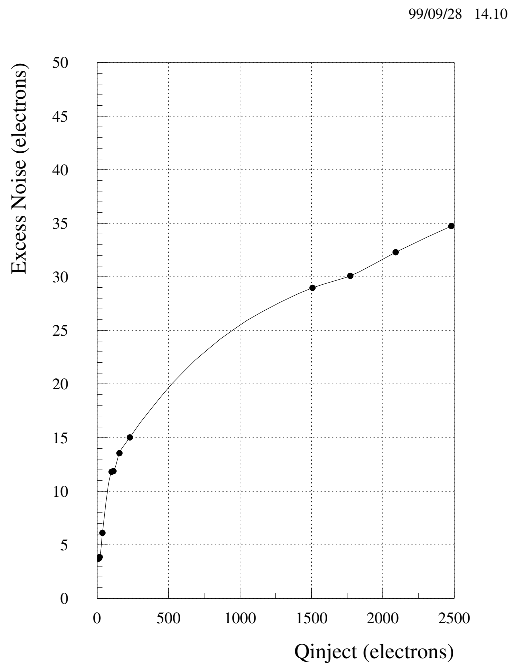

Figure 7: Excess noise as a function of the injected charge.

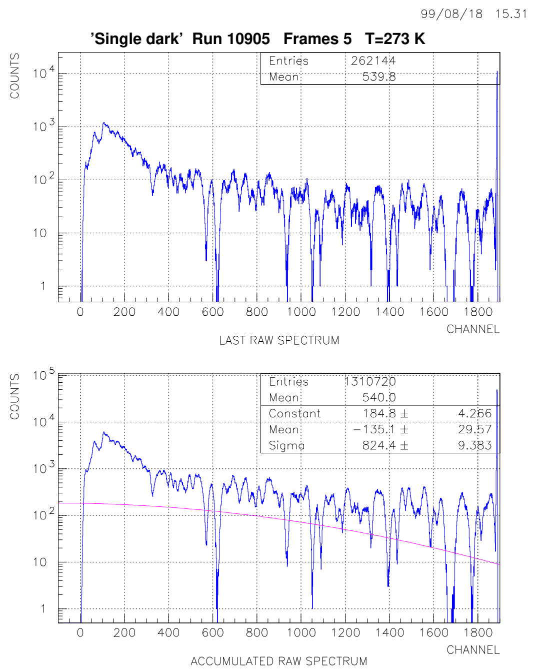

Figure 8: Dark spectrum with charge injection into the vertical register.

than $\sqrt{N_Q}$. It was found not practical to inject a certain amount of charge into the vertical register because of column-by-column non-uniformity.