# Temperature Dependence of Radiation Induced Trapping Phenomena in CCDs.

R.G. Murowinski[a], Gao Linzhuang[b], M.J. Deen[c]

## Abstract

CCDs flown in spacecraft are subject to radiation damage from the energetic protons they encounter. This radiation causes degradation in a number of electro-optical characteristics: the dark current and dark current noise increase, the charge transfer efficiency (CTE) decreases and the output MOSFET noise behaviour changes.

We have sufficiently irradiated CCDs and MOS transistors in a proton beam to create similar displacement damage to 5 years in a highly elliptical earth orbit. The post-damaged CCD noise spectra shows a clear noise excess. At many combinations of temperature and gate bias, the noise excess occupies the spectral domain normally captured during dual correlated sampling slow-scan operation. As a result, proton irradiation produces increased CCD read noise. The excess noise is a result of a number of generation-recombination (ge-re) processes in the output transistor. We present results showing the measured temperature dependence of the ge-re time constants.

The ge-re traps generated in bulk silicon are also the dominant mechanism for loss of CTE in a radiation damaged transistor. Measurements have been made of the CTE and the apparent image displacement in the CCDs as a function of temperature and level of damage. We are investigating the relationship between these electro-optical changes and the ge-re trapping noise measured in the output transistor.

---

[a] R. Murowinski is with the Dominion Astrophysical Observatory, 5071 W. Saanich Road, Victoria B.C. Canada V8X 4M6.

[b] Gao Linzhuang is on exchange at the Dominion Astrophysical Observatory from the Beijing Astronomical Observatory, Beijing, 100080 P.R.China.

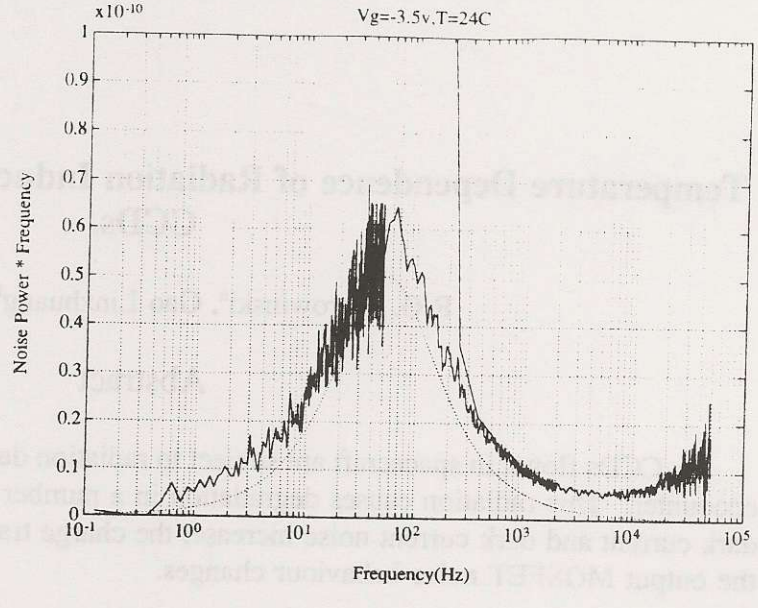
[c] M.J. Deen is with the School of Engineering Science at Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6.

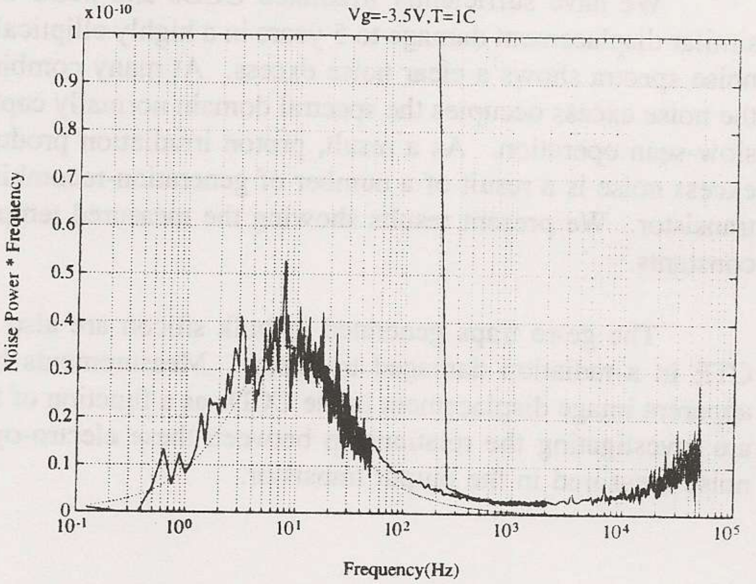
These figures show the effect of temperature on ge-re noise. They are graphs of noise power * frequency (in units of volts$^2$) versus frequency for a particular LDD MOSFET at a constant gate bias. This device had previously been subjected to $5.0X10^8$ protons / cm$^2$ (1.0 MeV). The upper graph presents data taken at a temperature of 24C, the middle graph is 1C and the lower is -25C.

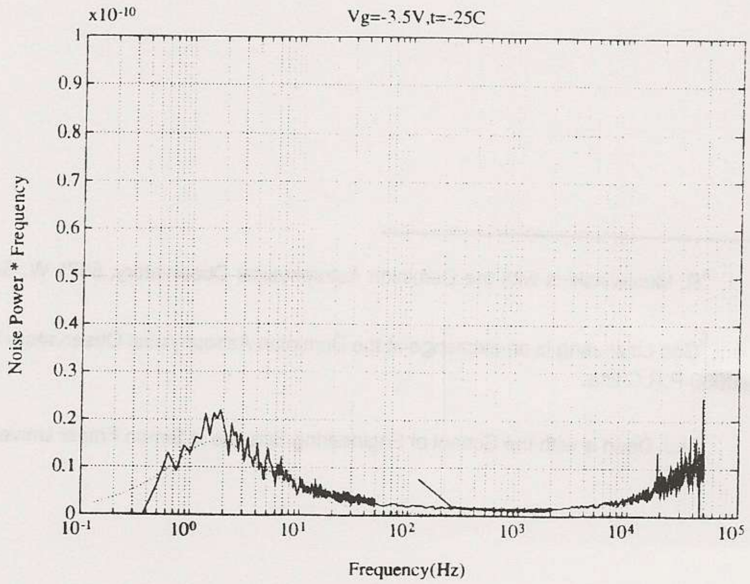
Overplotted on the same graph is a fit for the model of ge-re noise intensity

$$S_{(g-r)} = K * \frac{\tau}{1+\omega^2\tau^2}$$

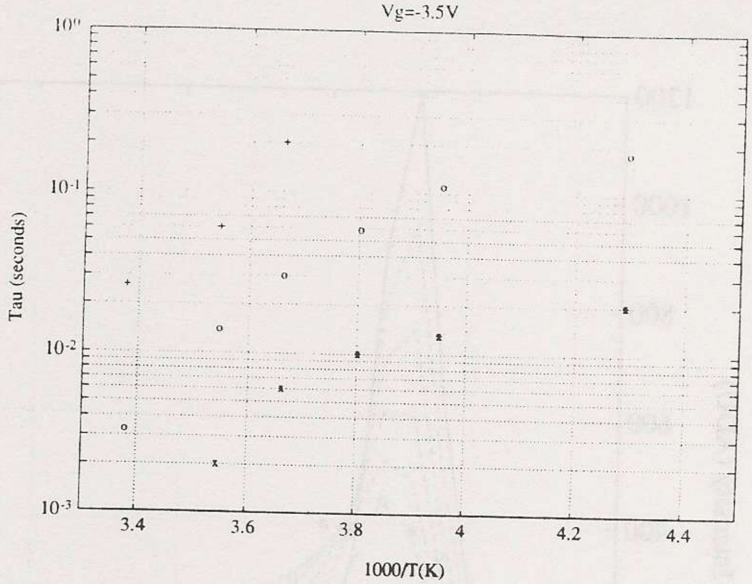
We see a clear dependence of the excess generation-recombination noise on temperature.



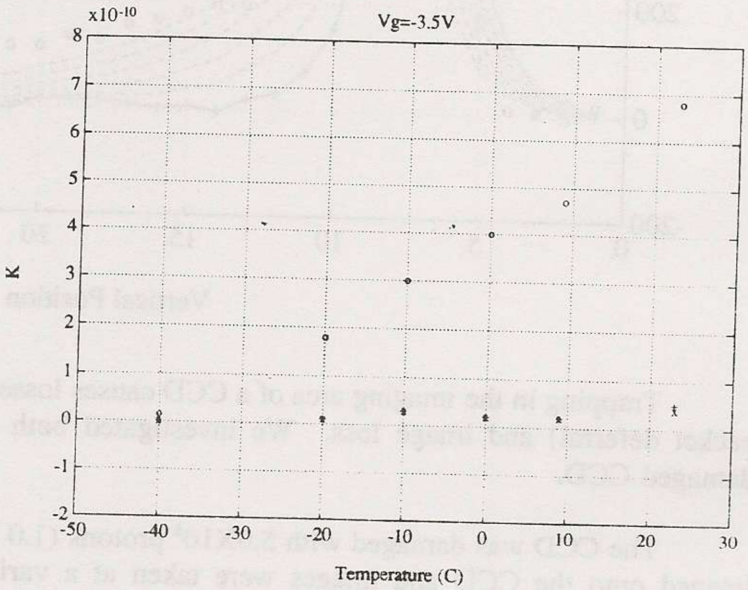



Damaged MOSFET noise spectra were recorded as a function of temperature and subsequently separated into their constituent components: Johnson noise, flicker (1/f) noise and ge-re noise. It was found that most spectra clearly contained ge-re noise from a small number of ge-re centres.



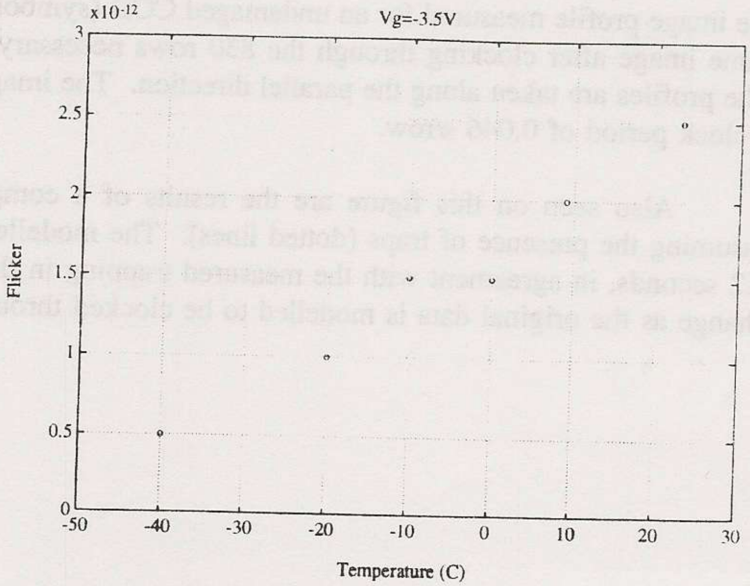

We see here the results of this decomposition of noise as a function of temperature. There were three dominant ge-re centres in this measurement. The ge-re noise was analyzed to determine the values of K and $\tau$ in

$$S_{(g-r)} = K * \frac{\tau}{1+\omega^2\tau^2}$$

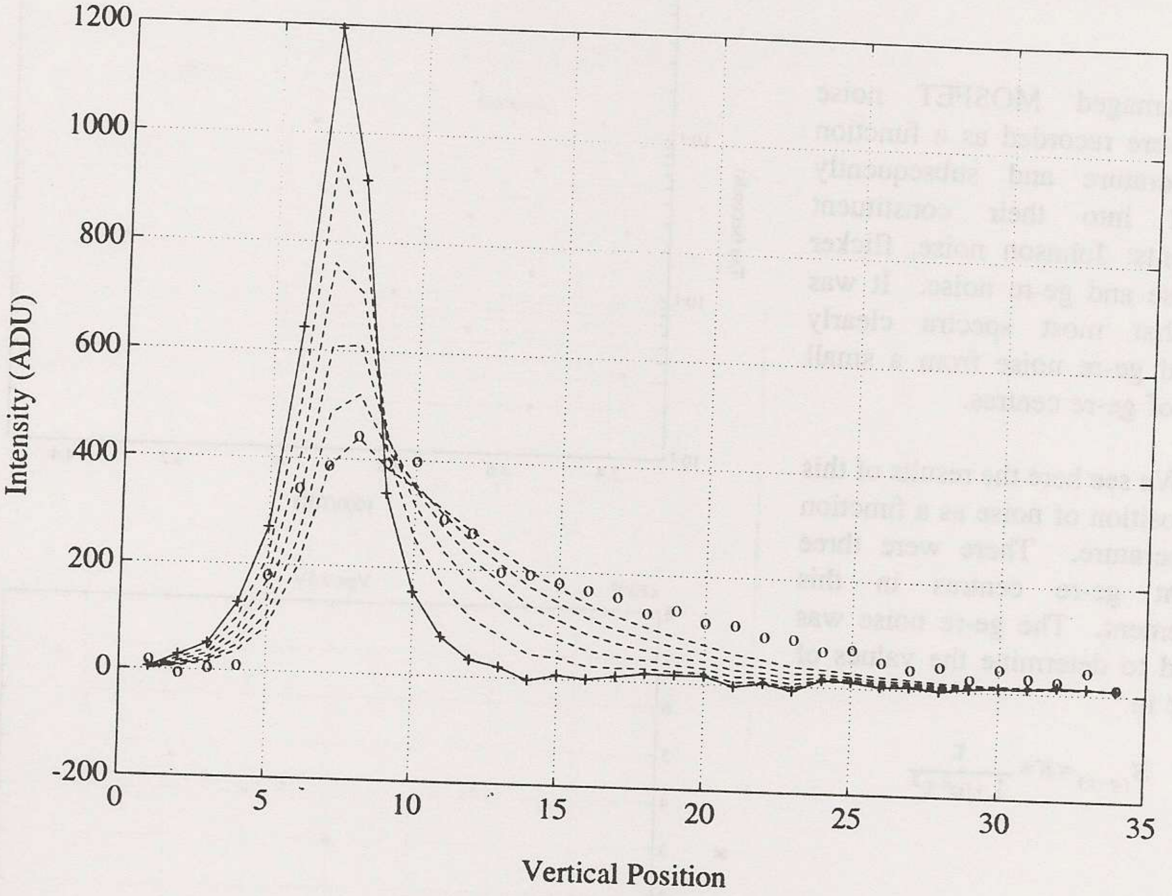



The upper graph shows the variation of the three trapping centres with temperature.

The middle graph shows how the three values of K vary with temperature. It is noted that one trapping centre shows a much stronger variation of K with temperature than the other two centres. We interpret this to be evidence that the trapping centres are occurring in different physical locations in the MOSFET - bulk traps vs interface traps.




The lower graph shows the variation of residual flicker noise with temperature.

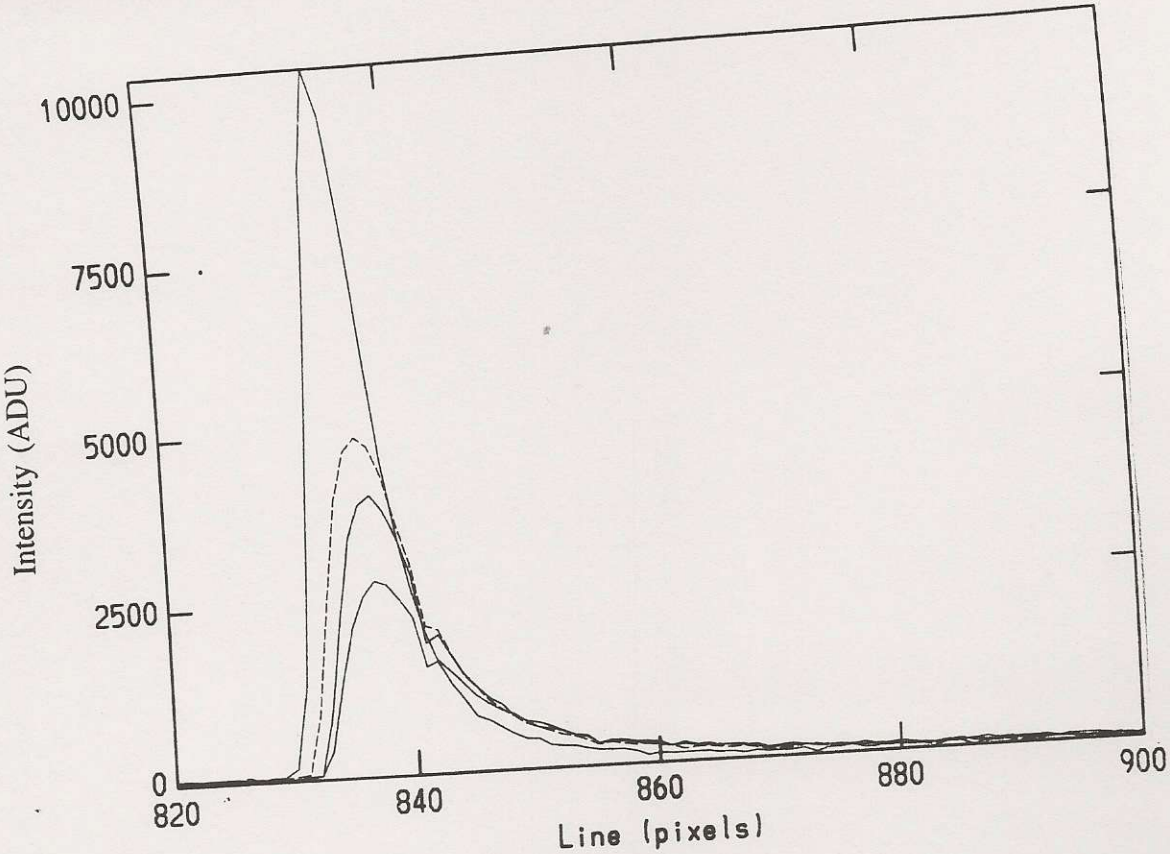



Trapping in the imaging area of a CCD causes losses both through image deferral (charge packet deferral) and image loss. We investigated both of these degradations in a radiation damaged CCD.

The CCD was damaged with $5.0X10^8$ protons (1.0 MeV) /$cm^2$. A stellar-like object was imaged onto the CCD and images were taken at a variety of temperatures, clock rates and intensities.

This figure shows the image profile degradation as a result of traps. The figure presents the image profile measured for an undamaged CCD (symbol +) overlaid with the profile for that same image after clocking through the 830 rows necessary to read out this image (symbol o). The profiles are taken along the parallel direction. The images were measured at -60C and with a clock period of 0.046 s/row.

Also seen on this figure are the results of a computer model of the readout process assuming the presence of traps (dotted lines). The modelled traps are given a time constant of 0.2 seconds, in agreement with the measured trapping in the MOSFETS. Shown is the profile change as the original data is modelled to be clocked through the CCD.




The ability of the charge packet to survive the readout process in a radiation damaged CCD is strongly a function of the charge filling the rest of the image area. If the rest of the pixels have a large amount of charge in them, then their traps are filled, and the probability of an electron in a charge packet encountering an empty trap decreases.

In this figure, we once again see a stellar profile imaged onto the damaged CCD in an area away from the output serial register. The data are taken with the same clock rates and image position but with varying temperature. The profiles represent -60C (tallest), -67C, -74C and -80C in descending profile height. Note that the shape of the profile remains relatively constant, charge seems to be simply "lost", particularly from the leading (left) edge of the packet as the packet appears to defer to the right.

We interpret the charge loss to be a result of charge being trapped by long time constant traps during the readout process. As the CCD gets warmer dark current increases, filling many of these traps before the charge packet is clocked through that region. When the charge packet does traverse the CCD it finds many traps already filled with dark electrons, and it loses less of its charge.