# Radiation Testing of Marconi CCDs for Wide Field Camera 3

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**Abstract**

The degradation in the charge transfer efficiency (CTE) performance of CCDs employed on space missions is a serious concern for the Wide Field Camera 3 (WFC3) project. The GSFC Detector Characterization Laboratory (DCL) has irradiated two large format Marconi CCD44 devices as part of a program designed to quantify the expected changes in performance of the WFC3 flight devices during the mission lifetime. Both devices performed extremely well prior to irradiation. The charge transfer efficiency (CTE) was measured using 55Fe, resulting in a parallel CTE of .999997 ± $1.0\text{x}10^{-6}$, and a serial CTE of .999998 ± $1.0\text{x}10^{-6}$. The readout noise was measured at a very low 2.1-2.3 $e^-$ rms. Dark current was well within the project performance requirements of less than 20 electrons/pixel/hour. The post-radiation results showed normal deterioration of the CTE in both devices; the parallel CTE of .999962 ± $5.0\text{x}10^{-6}$, and a serial CTE of .999992 ± $5.0\text{x}10^{-6}$ are well within the expected range. The readout noise did not change, and dark current was again well within project requirements.

**Introduction**

The WFC3 is a new imaging instrument which will be deployed aboard the Hubble Space Telescope during Servicing Mission 4. The instrument is designed with two channels: a Near-UV/Visible (UVIS) channel covering the 0.2 to 1.0 mm wavelength range, and a Near-IR channel extending from 0.85 mm to a long wavelength cutoff of 1.7 mm. The UVIS channel will acquire images with a high sensitivity and with a large (160 arcsec) FOV.

Throughout its lifetime the instrument will be subject to bombardment by high energy particles. It is well known that the damage caused by these particles degrades the charge transfer efficiency CTE of CCDs, and it is important to understand how their performance will be affected. The DCL has radiation tested two engineering grade, large format Marconi CCD44 devices (CCD44V1 and CCD44UV1). These devices are 2K x 4K, backside illuminated CCDs with 15 micron pixels, which are representative of the technology to be implemented in the WFC3 flight devices.

Both devices were characterized prior to irradiation and performed well; the readout noise, CTE and dark current all exceeded project specifications. The devices were irradiated at the UC Davis synchrotron with $1 \text{ x } 10^9 \text{ cm}^{-2}$ of 63 MeV protons which is expected to produce the equivalent of 1 year of on-orbit proton damage. The post-radiation results showed normal deterioration of the CTE in both devices, but the readout noise did not change, and dark current was again well within project requirements.

**Dark Current**

A sequence of dark exposures of 1, 2, and 4 hour duration were taken at three different temperatures: -80C, -90C, and -100C. Preliminary results show that the pre- and post-radiation mean dark currents do not exceed the project specification of less than 20 electrons/pixel/hour. The proton irradiation causes defects in the silicon lattice. These defects are responsible for excessive dark current generation in some pixels (warm and hot pixels). Figure 1 and Table 1 show the expected increase in the tail of dark current distribution from pre- to post-irradiation.

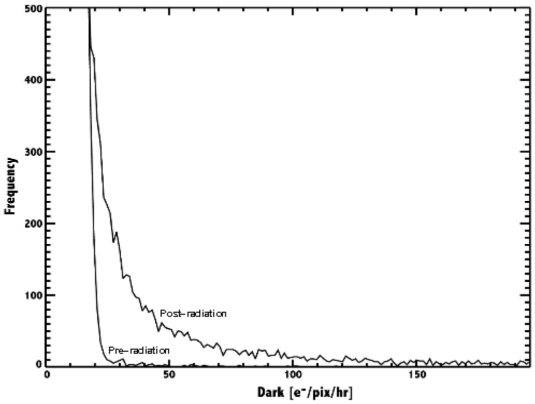


Figure 1.

| Threshold [mean x] | CCD44V1 Pre-Radiation [pixels] | CCD44V1 Post-radiation [pixels] | CCD44UV1 Pre-Radiation [pixels] | CCD44UV1 Post-Radiation [pixels] |
|---|---|---|---|---|
| 1 | 2144020 | 2204010 | 2125510 | 2424320 |
| 3 | 17340 | 186341 | 4014 | 101283 |
| 5 | 974 | 29450 | 1995 | 28960 |
| 10 | 56 | 6292 | 1139 | 7992 |
| 20 | 14 | 2913 | 873 | 3753 |
| 30 | 5 | 1941 | 775 | 2588 |
| 50 | 4 | 1175 | 607 | 1563 |
| 100 | 2 | 541 | 271 | 724 |
| 200 | 2 | 243 | 171 | 344 |
| 500 | 2 | 101 | 133 | 169 |
| 600 | | | 130 | 140 |

Table 1.

## CTE and Gain

Each device was exposed to an $^{55}Fe$ source for a series of exposure times from a low of 0.5 seconds to a high of 100 seconds. By varying the exposure time to the $^{55}Fe$ source we can vary the amount of time between the clocking out of x-ray events (delta time), the goal being to gain information on the characteristic timescales associated with the charge traps. This suite of images was taken at -80C, -90C and -100C. The array was read with two amplifiers simultaneously which effectively splits the array into two parts: channels A and B.Sample histograms of pre- and post-radiation signal intensities from 5 second images are shown in Figure 2.
The K-alpha line is seen at about 6000 ADU and K-beta line at about 6800 ADU in the pre-radiation (blue) data. The mean value (or center of the peak) of K-alpha is used to compute the gain. The post-radiation (red) histogram shows that K-alpha has broadened out and that K-beta is not resolved.

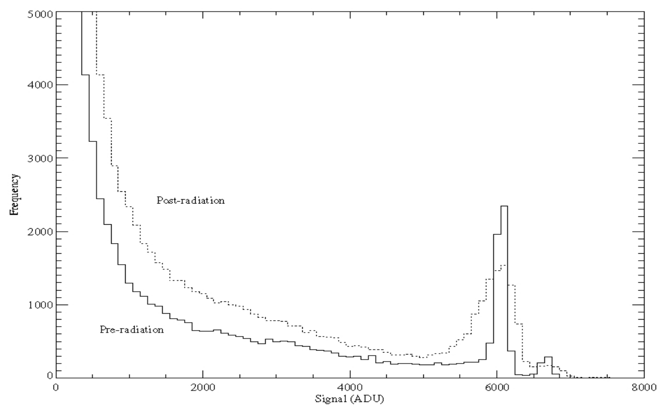


Figure 2.

Figure 3 is an example of a stacking plot of post-irradiated $^{55}Fe$ data, with the upper and lower bounds of the K-alpha band, and the linear best fit to that area. Using this method of obtaining the slope of the best fit line and dividing it by the number of electrons/photon (1620 for $^{55}Fe$) is the primary method used to calculate CTE from the $^{55}Fe$ images.

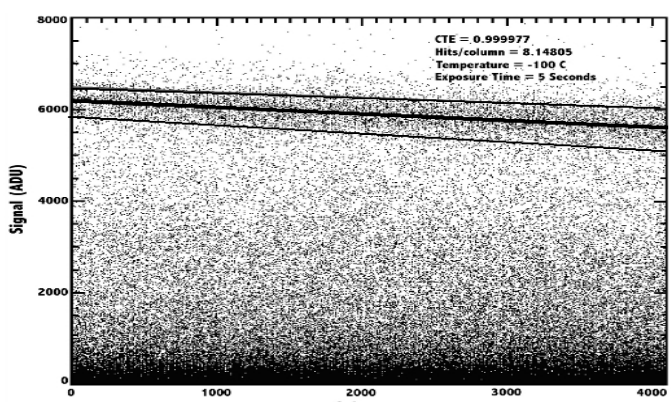

Figure 3.

Figure 4 is a plot of parallel Charge Transfer Inefficiency (CTI) vs Delta Time of the pre-irradiated CCD44UV1 at -80C, -90C, and -100C. Points corresponding to a delta time of ~100 seconds represent ~1 event/column or the most sparse event density practical. Figure 5 shows a similar plot for the irradiated CCD. Note that both figures show an exponential increase in CTI as the event density decreases. This is because at high event densities, corresponding to less time between the clocking out of events, some traps are filled by preceding events, resulting in better charge transfer for trailing events. Note also the marked decrease in CTI at lower temperatures after the radiation damage has occurred. It is preferable to operate a damaged device at colder temperatures, at least over the range of temperatures explored here.

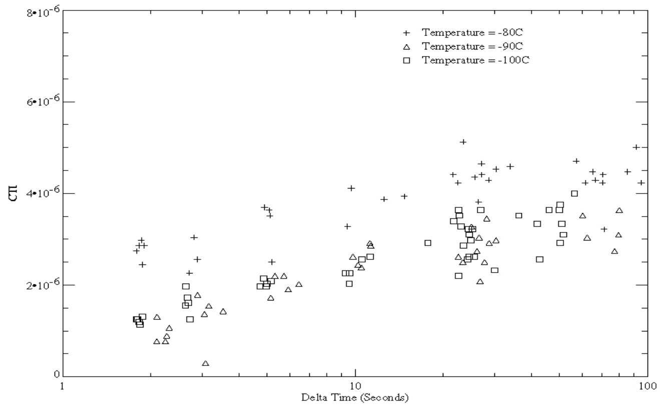


Figure 4.

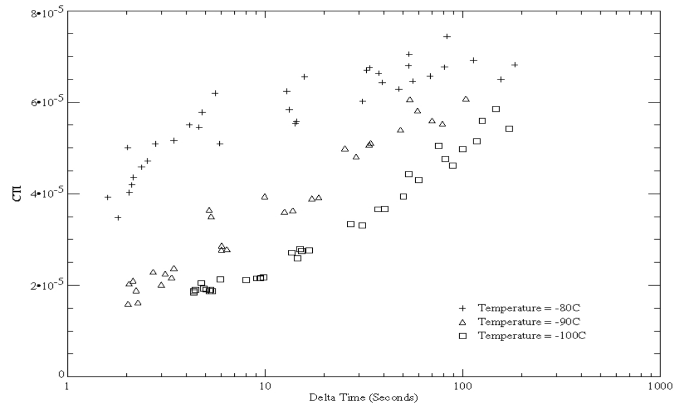


Figure 5.

Table 2 lists the calculated CTE for both devices, pre- and post-radiation, for the three temperatures, and for both channels. This table shows the similar behavior of the two CCDs.

| | CCD44V1 | | CCD44UV1 | |
|---|---|---|---|---|
| | **Parallel CTE** | **Serial CTE** | **Parallel CTE** | **Serial CTE** |
| **Pre-radiation** | | | | |
| -80C, Channel A | 0.999996 | 0.999998 | 0.999996 | 0.999998 |
| -80C, Channel B | 0.999996 | 0.999998 | 0.999996 | 0.999998 |
| -90C, Channel A | 0.999997 | 0.999998 | 0.999997 | 0.999998 |
| -90C, Channel B | 0.999997 | 0.999998 | 0.999997 | 0.999998 |
| -100C, Channel A | 0.999997 | 0.999999 | 0.999997 | 0.999999 |
| -100C, Channel B | 0.999997 | 0.999999 | 0.999997 | 0.999999 |
| **Post-radiation** | | | | |
| -80C, Channel A | 0.999947 | 0.999994 | 0.999932 | 0.999987 |
| -80C, Channel B | 0.999949 | 0.999993 | 0.999933 | 0.999985 |
| -90C, Channel A | 0.999961 | 0.999990 | 0.999942 | 0.999989 |
| -90C, Channel B | 0.999959 | 0.999987 | 0.999942 | 0.999982 |
| -100C, Channel A | 0.999977 | 0.999995 | 0.999958 | 0.999993 |
| -100C, Channel B | 0.999977 | 0.999993 | 0.999954 | 0.999989 |
| **Gain for Channel A** | **3.83** | | **3.51** | |
| **Gain for Channel B** | **3.72** | | **3.85** | |

**Average value for Parallel CTE taken at Delta Time = 50 Seconds.**
**Average value for Serial CTE taken for entire data set.**

Table 2.

## Read Noise

The readout noise was measured to be a very low 2.1-2.3 $e^-$ rms for both channels using two different sources: a bias corrected, 10 second dark image, and the overscan area of several image files. The read noise in ADU is given by the width of a Gaussian fit to the pixel intensities. The gain is applied to convert to $e^-$ rms.

## Conclusions

1. The two engineering grade Marconi devices performed extremely well and behave similarly, both pre- and post-irradiation.

2. Project specifications are met with 1) read noise of 2.2 ± 0.1 $e^-$ rms, 2) a pre-radiation parallel CTE of 0.999997±1.0x$10^{-6}$, and a pre-radiation serial CTE of 0.999998±1.0x$10^{-6}$, a post-radiation parallel CTE of 0.999951±5.0x$10^{-6}$, and a post-radiation serial CTE of 0.999987±5.0x$10^{-6}$ (numbers are an average for both devices at -90 C), and 3) dark current below 20 electrons/pixel/hour for both devices in pre- and post-radiation data.

3. Both devices exhibited a marked temperature dependency for CTI in the post-radiation data, as well as a trend towards higher CTI for sparser photon event density in both pre- and post-radiation data.

## Future Work

Further work is in progress on CTE measurements. Extended Pixel Edge Response (EPER) and First Pixel Response (FPR) measurements are in progress in order to extend our understanding of the performance of radiation damaged devices, with the ultimate goal of being able to predict the performance of the WFC3 detectors over the instrument's lifetime. Further experimentation will also allow an investigation of methods for mitigating the degradation in CTE performance and in making appropriate corrections to real photometric data.