SPACE
TELESCOPE
SCIENCE
INSTITUTE
Operated for NASA by AURA

UVIS CCD EPER CTE measurements performed during the April 2007 Ambient Calibration campaign (SMS UV02S01)

Massimo Robberto (STScI)

Abstract
The UVIS spare detector (UVIS build 2) has been installed in WFC3 and used for a short ambient ground test campaign in April 2007. Tests have been performed using the Extended Pixel Edge Response (EPER) measure of the Charge Transfer Efficiency. In this ISR I describe the methods and results of the test. The Charge Transfer Efficiency appears to be higher than 99.9999%, in agreement with previous DCL measures.

1. Introduction

Charge Transfer Efficiency (CTE) losses are known to progressively degrade the performance of CCD detectors in space, due to cosmic-ray induced temporary or permanent damage to the silicon lattice. Even if the appearance of CTE losses cannot be prevented, it is important to get an early assessment of the rate of CTE damage in order to allow optimal planning of the most demanding science programs to be carried out by a new instrument. Such an estimate requires accurate pre-flight measurements of the CTE efficiency.

The WFC3 instrument has been recently tested in ambient (room temperature) conditions with the UVIS spare detectors (UVIS build 2, containing FPA40 and FPA50) installed. The detector was operated at -53C, i.e. much warmer than the nominal operating temperature of -83C.

2. WFC3 CCD detectors format: nomenclature and structure

Each CCD detector contains 2051x4096 active pixels, but the raw images returned by the WFC3 electronics generally contain a larger number of pixels. This is due to the detector **overscan** regions. There are in general two types of overscan regions: 1) **physical**, i.e. portions of the detector which are not exposed to light, and 2) **virtual**, i.e. pixel signals

that are generated by the readout electronics without a real charge packetbeing extracted from the CCD. The physical overscan is a characteristic of the detector hardware, whereas virtual overscan is a software function; the number of rows and columns of virtual overscan generated with an image is controllable via the readout timing pattern.

Overscan pixels, either real or virtual, can be located or generated at different sides of the CCD. **Serial** overscan corresponds to unexposed pixels at each end of each serial shift register. Vice-ersa, **parallel** overscan corresponds to additional pixels located before or after all of the exposed rows of the detector have been read out. Both serial and parallel overscan pixels can be either physical or virtual.

To understand the structure of the overscan regions in the WFC3 CCD detectors, onemust also note that each row is divided into two regions which, although they belong to the same physical chip, can be associated with different amplifiers, either A-B or C-D, a pair for each chip. The association between CCD name, amplifiers and fits file extension in the WFC3 data is presented in Table 1:

Table 5.1
WFC3 CCD conventions

	CCD name	Amplifiers	CCD extension
UVIS Build 1	CCD018	C, D	[1]
	CCD178	A, B	[4]
UVIS Build 2	CCD040	C, D	[1]
	CCD050	A, B	[4]

WFC3 has physical overscan pixels located along the edges of the detector in the serial direction only. There are 25 overscan columns along each edge, or 50 columns total. In addition, there are two regions of virtual overscan. In standard four-amplifier readout mode there are 60 columns (30 in each half) of serial overscan in the center of each row between the exposed areas corresponding to the two halves, and 38 rows (19 on each chip) of parallel overscan abutting the inter-detector gap. See Figure 1 for an illustration of the location of the overscan regions. The serial physical overscan pixels at the edges are known as "serial prescan" or "leading edge" overscan pixels; the serial virtual overscan pixels in the center are known as "trailing edge" overscan pixels.

WFC3 has a different convention in the case of the EPER measures. EPER has a subarray mode in which both the overscan and active pixel areas have been modified. Instead of the central 60 columns of serial overscan, we have now 600 columns (300 in each half); the parallel overscan region at the detector gap is also modified from 38 rows (19 on each chip) to 600 columns (300 on each chip).
To keep the size of EPER images small, a number of active pixels are skipped during the readout, namely:
1) The first "bottom" 280 rows of each quadrant;
2) The first "external" 413 columns of each quadrant.

Another relevant difference is that the 25 columns of physical overscan are still present, but the signal is not physically sampled. Instead, the signal is generated by the electronics just like a virtual overscan region: the physical overscan region has been "virtualized". The final image size for each CCD amplifier is therefore 2070 rows by 1960 columns, i.e.

Rows: 2051 image - 281 image + 300 overscan = 2070 rows

Columns: 25 prescan [no sample] + 2048 image - 413 image + 300 overscan) = 1960 columns

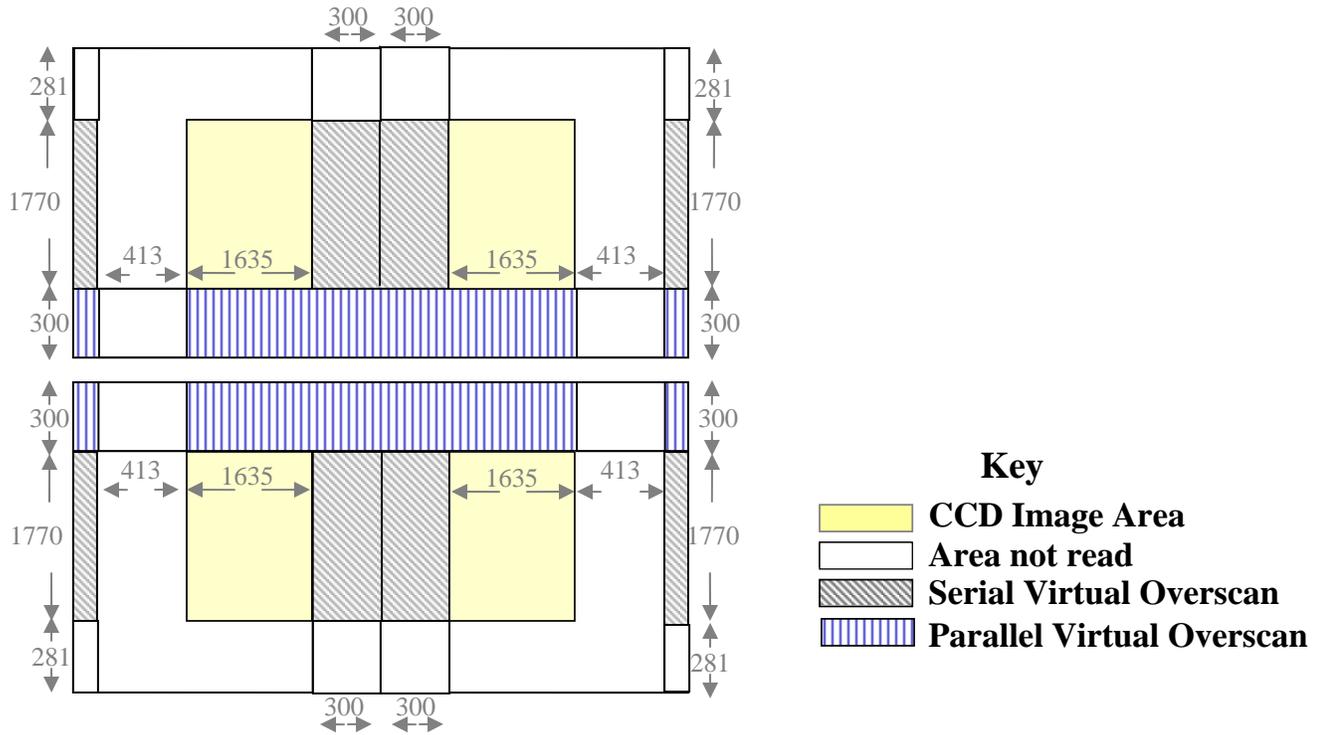Figure 2 illustrates the geometry of the EPER subarray.

Figure 1. Schematic of the standard WFC3 UVIS image format.
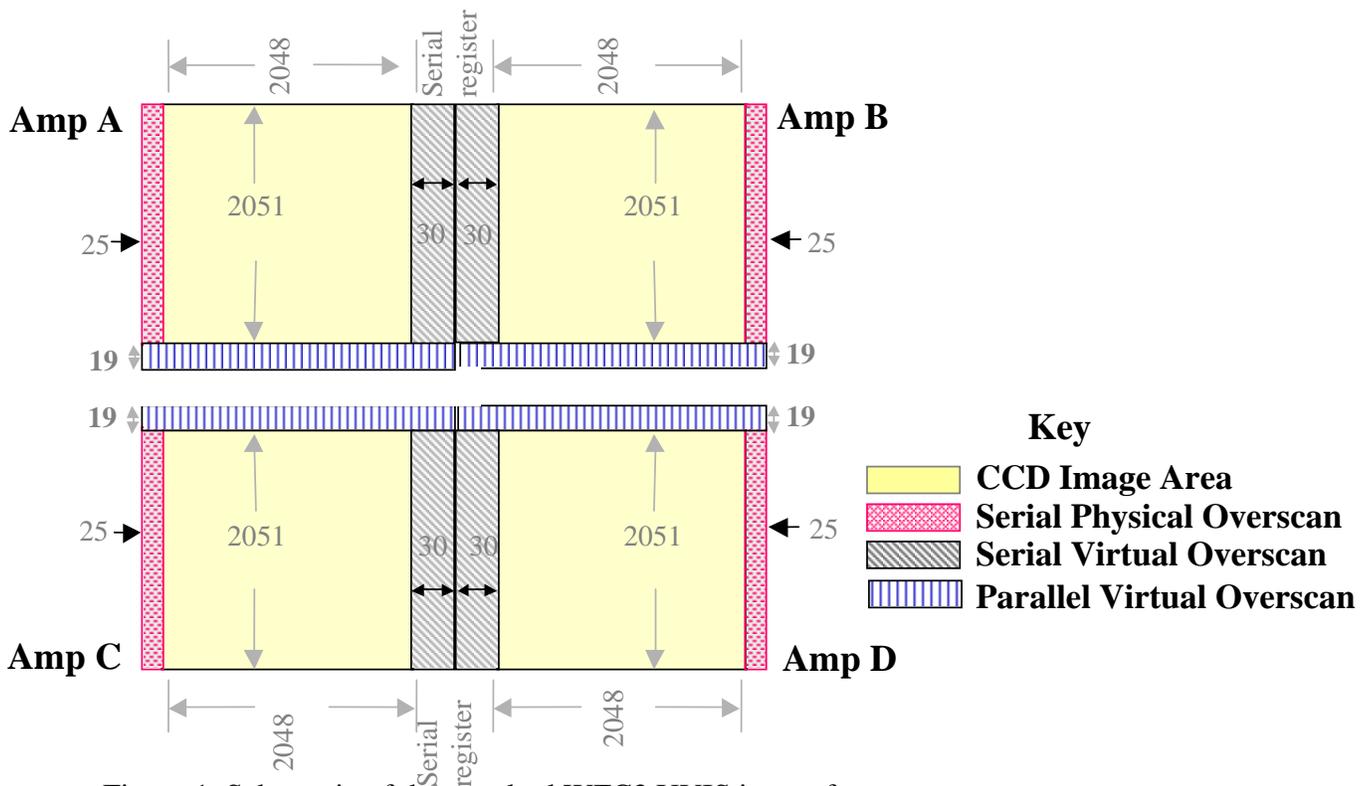
Figure 2: similar to Figure 1, with the dimensions of the EPER subarray

3. Extended Pixel Edger Response (EPER) measures

In EPER measures, the detector is uniformly illuminated (flat field) and extra rows or columns are read. The presence of CTE losses generates deferred charges in the extra rows or columns of the detector. The CTE estimated from an EPER measure is given by (Janesick 2001):

$$CTE_{EPER} = 1 - \frac{S_D}{S_{LC}(e^-)N_P}$$ (1.1)

where S_D is the total deferred charge measured in the extended pixel region (e^-), $S_{LC}(e^-)$ is the charge level of the last column (e^-) and N_P is the number of pixel transfers for the CCD register.

The EPER method provides a relative measure of the CTE and may overestimate the real CTE performance of a CCD device. See Janesick (2001) for a discussion of the limitations of the EPER technique.

4. Our experiment

The tests were made during the second Ambient Calibration campaign in April 2007; the original SMS UV02S01 uses flat field images taken using different filters at the nominal detector operating at T_{nom} = -83C. The integration times are tuned for flat field at 5

different signal levels: 3000, 1000, 500, 250 and 100 e⁻. CTE loss is measured from the charge profile in the trailing overscan regions; the expectation is that CTE before launch should be extremely high.

The tests performed in ambient conditions, with the detector at -54C, a subset of three exposures, namely:

1) A bias frame, with the shorter possible exposure time (0.5s)
2) A Flat field frame with exposure time 11.0 s in the F280N filter, to provide the 100e flux
3) A Flat field frame with exposure time 7.0 s in the F390M filter, to provide the 500e flux.

5. Analysis

Immediately after the data had been taken, quick look analysis showed that the WFC3 pipeline needs to be modified to handle the unusual format of EPER subarray mode. A fix has been implemented by D. Lindler to rearrange the data in the expected format. Note that with this fix the (current) version of the wfc3_acq pipeline stores the EPER data from the 2 chips in the FITS extensions 1 and 2, rather than 1 and 4 like the OPUS system does.

The three images have been analyzed with IDL, using variations of the basic script attached in the Appendix. The F280N was found to have very low signal (~7 counts = 11e with our 1.5 e/adu gain), indicating that the exposure time in this filter was too short and adjustments will be needed to reach the required 100e flat field level. The F390W image provides ~520e, which is nicely close to the desired 500e. This is not surprising, as the exposure time in this filter was fine tuned by H. Bushouse on the basis of earlier tests.

Figure 3 and 4 show, with different dynamic range, the frames obtained with the F390W filters. The flat field illumination and the virtual regions are evident and can be compared to the schematic shown in Figure 2. A close inspection of these images shows a "spillover" of charges at the sides of the detector, at the location of the passage from the first 25 pixels of physical overscan that have been fast clocked (Figure 5) to the active pixels. The first row after the fast overscan appears much brighter, regardless whether it is on the active pixel area or on the parallel overscan region at the "top" of the detector. This behavior is more evident on the right side of the detector (amplifiers B and D) and hints to some trailing effect from the charge actually accumulated on the physical overscan region.
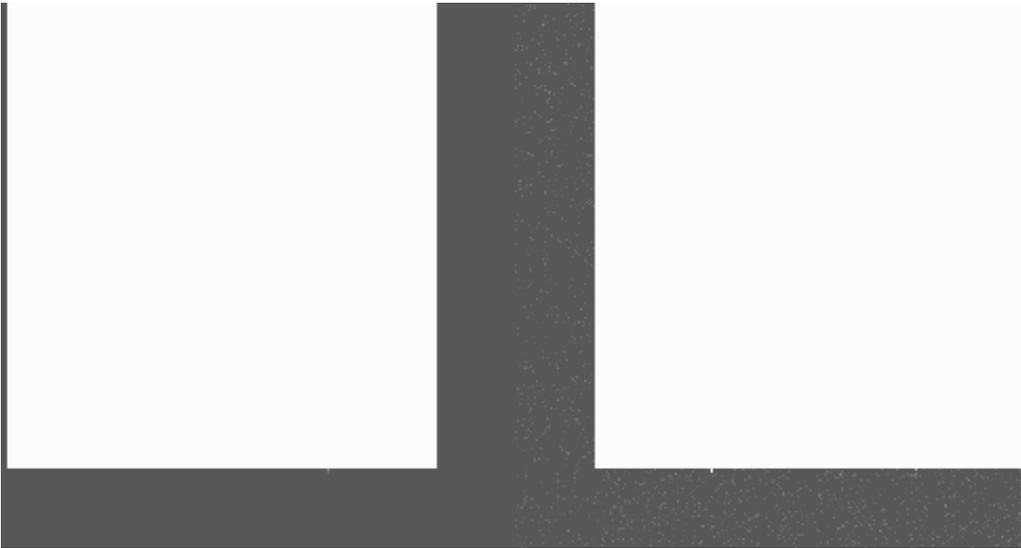
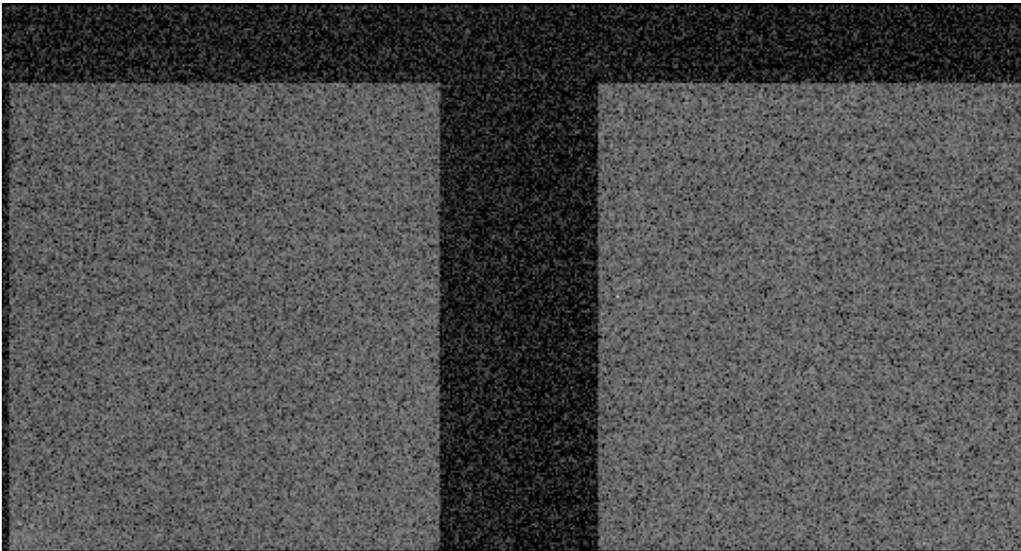Figure 3: F390W image of CCD050 in WFC3 UVIS Build 2

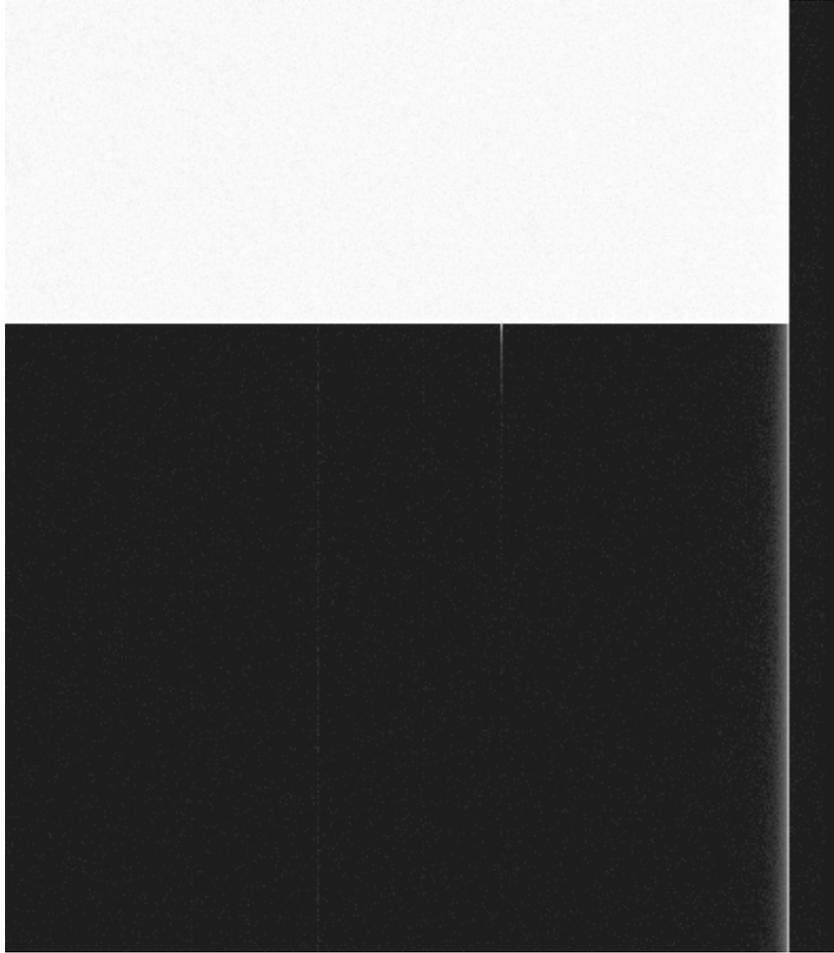Figure 4: same as Figure 3 for CCD040

Figure 5: zoom in the lower right corner of CCD040 showing the charge "spillover" in the virtual overscan region.

The CTE was measured by averaging, for each quadrant, all columns (parallel CTE) or rows (serial CTE) to produce a single 1-D vector. A robust (iterative) average estimator was used to eliminate possible outliers. Equation (1.1) was used; note that despite the apparent size of the EPER CCD image, the number of rows/columns to be used in Equation (1.1) must be equal to the physical size of the quadrant to properly account for the number of charge transfers, in our case 2048×2051. The bias level to be subtracted was measured in the virtual overscan regions away from the active area. For parallel CTE we used the last row (row 2051), which provides a charge much larger than all other rows, possibly due to some charge diffusion from the neutral material outside the array. It is unclear how this last pixel anomaly may affect the CTE measure, but we note that Janesick (2001) faces a similar phenomenon and makes no mention of limitations.

The CTE values turn out to be measurable only for the F390M filter, due to the higher count rate on the flat field area. The resulting parallel and serial CTE measures are presented in Table 1. The parallel and serial CTE are found to be comparable for both detectors at the "6-9" level.

Table 1: CTE measured in the F390M filter.

	AMP A	AMP B	AMP C	AMP C
Parallel	0.99999970	0.99999965	0.99999967	0.99999973
Serial	0.99999979	0.99999979	0.99999992	0.99999960

Previous tests performed at DCL at -83C (instead of -53C of our tests) using Fe55 line provided similar results. In particular, for CCD040 DCL reported the following table (from http://dcl.gsfc.nasa.gov/private/wfc3/webwebdocs/ccd43-040/C040.html)

1.4.1 Pre-radiation 55Fe (CEI 4.6.9)

	Parallel(+) CTE	Serial(&) CTE
-83C, Channel A	0.999999	1.000000
-83C, Channel B	0.999999	1.000000
(+) Average value for Parallel CTI taken at Delta Time = 20 Seconds.		
(&) Average value for Serial CTI taken at Delta Time = 20 Seconds.		

whereas for CCD050 DCL reports:

1.4.1 Pre-radiation 55Fe

	Parallel(+) CTE	Serial(&) CTE
-83C, Channel A	0.999999	0.999997
-83C, Channel B	0.999999+	0.999999
(+) Average value for Parallel CTI taken at Delta Time = 20 Seconds.		
(&) Average value for Serial CTI taken at Delta Time = 20 Seconds.		

6. Conclusion

We have measured the CTE efficiency of the UVIS build 2 at -53C during the April 2007 Ambient Test campaign. The values found for both parallel and serial CTE are better than "6-9" level, and in general agree with previous DCL measurements performed using the Fe55 method.

REFERENCES

Janesick, J. R. 2001, "Scientific Charge-Coupled Devices", SPIE Press, Bellingham VA.

APPENDIX: basic IDL procedure

```
;
;>> 1) open the files with idl adding /no_unsigned
PATH='/Volumes/WFC3_300/data/ac2/uv02/'
fits_read,PATH+'CSII07109223944_1.fits',a3_1,h3_1,EXTEN_NO=1,/no_unsigned
fits_read,PATH+'CSII07109223944_1.fits',a3_2,h3_2,EXTEN_NO=2,/no_unsigned
;
;>> 2) define the region of interest on the left side (first amplifier)
x0=25.
x1=1660.
y0=0.
y1=1769.
ima3_ampli1 = a3_1[x0:x1,*]
help,ima3_ampli1
;IMA3_AMPLI1    FLOAT     = Array[1636, 2070]
;
;>> 3) build the 1-d vector averaging columns
vector3_1=fltarr(2070)
for i = 0, 2069 do begin & $
  resistant_mean,ima3_ampli1[*,i],3,mmm & $
  vector3_1[i] = mmm & $
endfor
plot,vector3_1[y1-10:y1+10],psym=10,yrange=[2400,3000]
;
;>> 4) estimate the CTE
bias=mean(vector3_1[y1+5:y1+100])
SLC = vector3_1[y1]-bias
print,SLC
;    453.591
SD = vector3_1[y1+1]-bias
print,SD
;    0.280762
Np=2051
CTE_EPER=1D0-SD/(SLC*NP)
print,CTE_EPER
;    0.99999970
;
;>> 5) estimate of the error
DEL_SD = stdev(vector3_1[y1+2:y1+10])
print,1D0*del_SD/(SLC*NP)
;  2.4641277e-07
```