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ACS Charge Transfer Efficiency. Results from Internal and External Tests

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Abstract. We present results of in-flight charge transfer efficiency (CTE) monitoring performed with different tests. Internal tests (Extended Pixel Edge Response [EPER] and First Pixel Response [FPR]) and external photometric test of stars in a field $6'$ off the core of the globular cluster 47 Tucanae. The results of internal and external tests on parallel CTE are comparable. CTE losses increase linearly with time and they are worst at low signal levels and for low background. We provide a formula to correct for CTE losses for all flux levels, sky values and times. We also outline our plan for future monitoring of CTE.

1. Introduction

The charge transfer efficiency (CTE) per pixel is the fraction of charge transferred from one pixel to the next during readout. In an ideal CCD, the CTE would be exactly 1.0, with no charge being lost. But imperfections in the crystalline lattice of a real CCD, caused either by the manufacturing process or the space radiation environment, can act as charge traps. Although the amount of charge lost per pixel (Δ Q) is typically a very small fraction of the total charge (Q), the total CTE over N pixel transfers is CTE^N, which becomes increasingly significant as larger CCD arrays are manufactured and flown in space. Here we summarize the results of in-flight CTE monitoring performed through both internal and external tests. More details can be found in the instrument science reports (ISR) at the URL http://www.stsci.edu/hst/acs/documents/isrs.

2. Internal test

The internal monitoring programs consist of two tests performed for both the Wide Field Channel (WFC) and High Resolution Channel (HRC): Extended Pixel Edge Response (EPER) and the First Pixel Response (FPR). Since internal tests do not involve observations of real astronomical objects – the light source is always the internal Tungsten lamp (rather than stars) – they do not independently lead to a CTE correction suitable for science data. But the data can be collected with great breadth and frequency (at all signal levels, throughout the life of the detector), so relative changes are therefore useful for monitoring CTE trends.

EPER is a measurement of the excess charge found in the CCD overscans, which appears as an exponential tail following the last real pixels in the array, which tapers down to the bias level within just a few pixel transfers (see Figure 1 showing how the EPER test is performed for WFC). This tail is "deferred charge" which has been trapped during the readout, and then released on a time scale of milliseconds.

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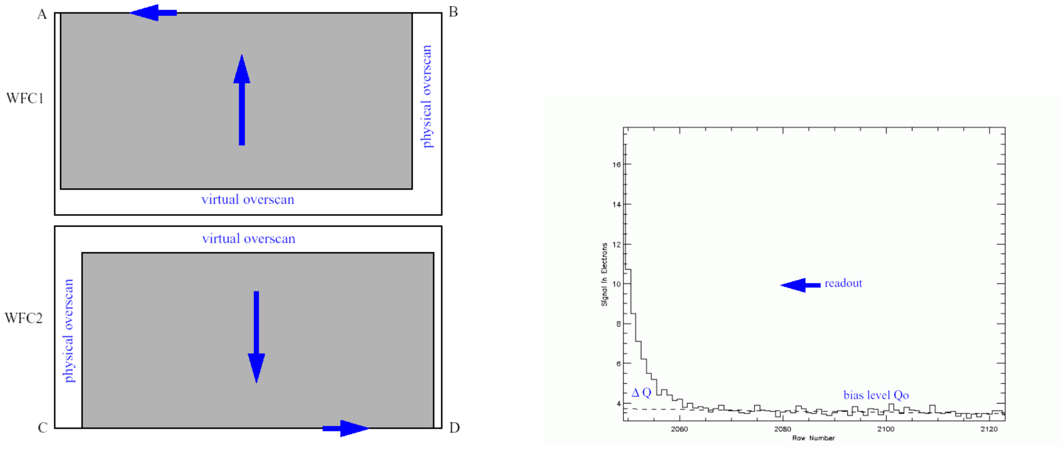

Figure 1: WFC EPER Flats with extra-large trailing overscans (75 pixels) are produced in both the parallel (vertical arrow) and serial (horizontal arrow) clocking directions. A, B, C and D indicate the location of the readout amplifiers (left panel). After subtracting the bias level Q_0, the the excess charge in the overscan is measured. This "tail" is deferred charge which has been trapped during readout, and released on a timescale of milliseconds (right panel). A similar EPER test is also performed for the HRC.

FPR measures a leading-edge loss of charge. FPR frames have a special clocking pattern where the first half of a frame is flushed (read out quickly), freshly exposing every charge trap. Then the other half of the frame is read out normally (see Figure 2 showing how FPR is used for the HRC). As the first column (or row) in the normal half of the chip is transferred across the flushed half, it loses charge as it fills most of the traps. We measure the charge lost in that first pixel, and compare it to the charge present in all the subsequent pixels in a column (or row), which suffer little or no charge loss.

2.1. Results of internal tests

- CTE loss is greatest at the lowest signal level. We observe a power-law dependence on signal level, at each epoch.

- As expected, parallel CTE is much worse than serial CTE for both WFC and HRC. No trend in time can be determined for serial CTE.

- Parallel CTE degradation for WFC is very linear at all signal level, so we can confidently extrapolate the future in-flight performance (see Figure 3). No significant difference is observed between the two chips.

- From HRC parallel EPER and FPT test we find different power laws. This may be interpreted as an "optimistic" versus a "pessimistic" estimate of the same effect, because of the different nature of the tests.

3. External test

External tests are based on observations of a field located 6′ off the center of the globular cluster 47 Tucanae. Observations have been performed twice a year during cycles 11,12 and 13. Here we present results for the WFC based on the first four epoch observations, and extrapolation to future times.

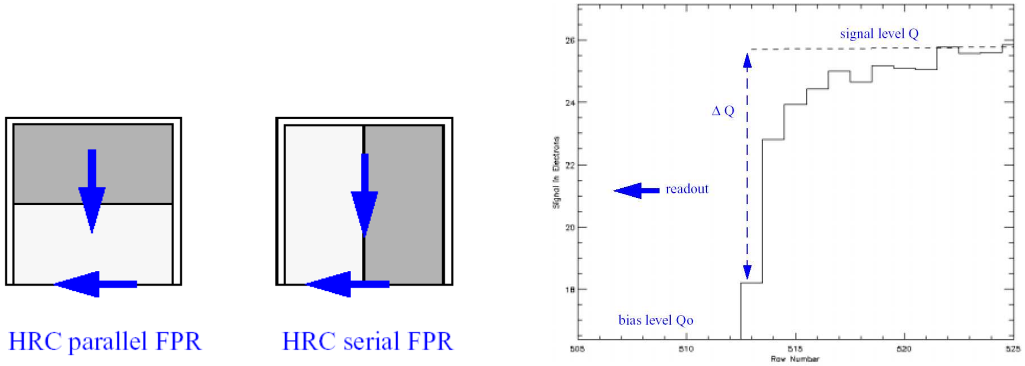

Figure 2: HRC FPR: one side of the chip is flushed (light gray) while the other side is read out normally (dark gray). Amplifier C is used for all tests (left panel). Right panel: the plot illustrates the parallel HRC test for the lowest signal level of $\sim$ 25 electrons (i.e. the worst case). A similar test is also performed for the WFC, but only for the serial register.

The goal of the observations is compare the relative photometry of individual stars as a function of the number of pixel transfers during readout.

The observational strategy is as follows: to vary the relative positions and hence the number of pixel transfers of individual stars on the WFC, we utilize 2 large scale dithers of $\sim 1/2$ the size of the WFC ($102''$) along each axis. Because of the corner placement of the amplifiers, individual stars which undergo n parallel transfer when images on chip 1, will undergo 2048-n transfers when imaged on chip 2 (see Figure 4).

Details on the data analysis can be found in Riess & Mack (2004). Here, we summarize the main points. Star list are generated from an IDL implementation of DAOfind. Stars are selected as positive fluctuations surpassing a threshold of 0.05 e^-/sec and satisfying sharpness and roundness thresholds. Regions around bright stars are masked out to avoid contamination from spurious sources. The sky background is measured as the median counts in annuli of inner radius 10 pixels and outer radius 15 pixels centered on each star.

WFC is expected to be more affected by CTE losses than HRC because of the larger number of pixel transfers. However, detailed analysis of HRC data is still in progress. For the WFC, we see strong evidence for photometric losses in the parallel direction whose value grow with decreasing stellar flux and background. No evidence for CTE losses is seen in the serial direction yet. From the analysis of stars with different count rates, different background levels and at different times Riess & Mack (2004) have derived a formula that allows users to correct photometric measurements at all times and for all combinations of stellar fluxes and background values.

$$YCTE = 10^A \times SKY^B \times FLUX^C \times Y/2048 \times (MJD - 52333)/365 \tag{1}$$

where SKY is the background in e^-, FLUX is the flux of the star in e^-, Y is the number of transfers and MJD is the observation date (Julian day – 2400000). Coefficients A, B and C are listed in Riess & Mack (2004) for different aperture radii. For an aperture radius of 3 pixels, A=0.14, B=-0.31, C=-0.64.

Since background mitigates CTE losses, for most of the science applications which involve long integrations with efficient broad band filters the expected impact of CTE degradation is limited and manageable. The worst case arises from short integrations in narrow band filters. In a 30 sec integration with F502N, the background level is only 0.1 e^-/sec/pixel. A 20th mag star will yield few counts in this filter and the CTE losses may reach $\sim$ 0.4 mag by the end of the decade.

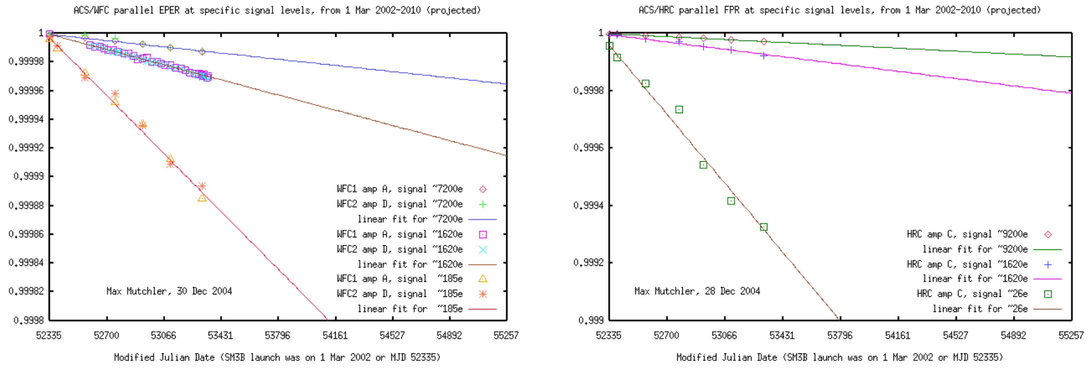

Figure 3: WFC parallel CTE from EPER test at selected signal level, over time (left panel). The linearity of CTE degradation is apparent. This gives us confidence in projecting our results into the future. Right panel: Linear decline with time at specific signal levels for HRC, from FPR test.

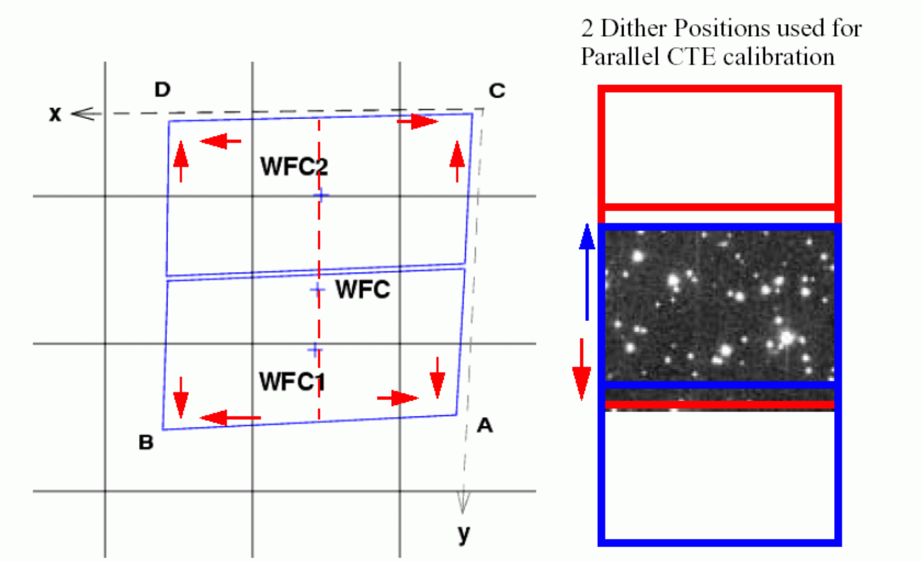

Figure 4: Schematic showing the location of the readout amplifiers and the WFC direction of readout (left panel). The right panel illustrate the two pointings used to vary the number of parallel transfers.

We conclude that for real science applications, the use of the CTE correction formula should limit the precision of flux measurements of typical faint sources to no worse than a few percent by the end of the decade.

More details on the CTE tests summarized in this paper can be found in Riess & Mack (2004), Mutchler & Sirianni (2003) and in the ACS website at the URL http://www.stsci.edu/hst/acs/performance/cte.

4. Future calibration plan

We plan to analyze the HRC data and eventually provide a formula for photometric corrections similar to that derived for WFC. New WFC data from cycle 13 and 14 will be analyzed to monitor the status of CTE losses.

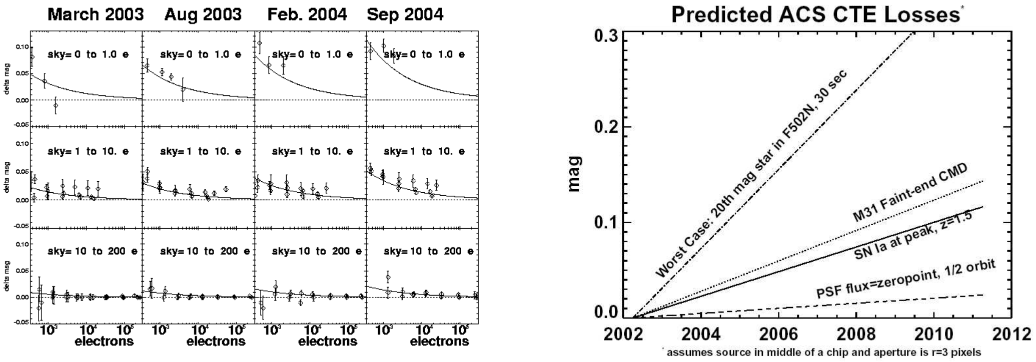

Figure 5: Left panel: photometric losses (at y=2048) for different sky levels and dates, respectively, for aperture radii of 5 pixels. The fitted line uses the global time dependent formula (1). Right panel: projected CTE losses for example science applications.

The following calibration programs aimed at monitoring CTE are being performed during Cycle 14:

- **Program 10732** Internal CTE monitoring. Data are collected at regular intervals using internal lamps only. This program emulates the ACS pre-flight ground calibration tests and post-launch SMOV tests, so that the results can be directly compared.
- **Program 10730** External CTE monitoring. Observations of 47 Tucanae with different filters and exp times. Large dithers (102″) are used to change the position of stars in the field relative to the amplifiers. This program will provide improved determinations of CTE losses for the HRC.
- **Program 10771** CTE and QE measurements for ACS instruments at different temperatures. Internal and external measurements are performed with temperatures -77, -74, -80 (WFC) and -80, -76, -85 (HRC). The external tests are performed by observing a field of the globular cluster 47 Tucanae with large dithers, as it is done in program 10730.

References

Mutchler, M. & Sirianni, M., 2005-03

Riess A. & Mack J., 2004, *Instrument Science Report* ACS 2004-006 (Baltimore: STScI), available through http://www.stsci.edu/hst/acs