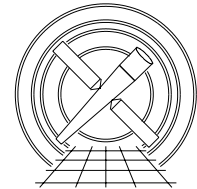




MIT Kavli Institute



Chandra X-Ray Center

## MEMORANDUM

August 11, 2006

**To:** Jonathan McDowell, SDS Group Leader  
**From:** Glenn E. Allen, SDS  
**Subject:** Adjusting ACIS Event Data to Compensate for CTI  
**Revision:** 6.0  
**URL:** <http://space.mit.edu/CXC/docs/docs.html#cti>  
**File:** `/nfs/cxc/h2/gea/sds/docs/memos/memo_cti_correction_6.0.tex`

The ACIS instrument teams at PSU and MIT have shown that a significant improvement in the energy resolution of existing ACIS event data can be obtained by compensating for some of the effects of the parallel and serial charge-transfer inefficiencies (CTIs) of the CCDs. To achieve this improvement, charge is added to each  $3 \text{ pixel} \times 3 \text{ pixel}$  event island. While some pixels in the island gain charge, others may lose charge. Yet, the net change for an event is always positive. The amount of charge added to each event is based on an estimate of the average amount of charge that is lost as charge packets are clocked across the charge traps on the ACIS detectors. The average amount of charge lost depends on the density of charge traps on the detector, the location of the event on the CCD, and the number of traps that have already been filled by “precursor events” in the same CCD column (i.e. on how many empty traps an event must cross to get to the read out). The algorithm described in section 1.4 is used to compute the CTI-adjusted values of PHAS. These adjusted values are contained in a new column called PHAS\_ADJ. The original, unadjusted values are retained in the column PHAS. Note that only the column PHAS is written to the output file by default. The column PHAS\_ADJ can be included if the parameter eventdef includes “f:phas\_adj.” Once the values of PHAS\_ADJ are computed for an event, these values are used to compute the values of FLTGRADE, GRADE, PHA, ENERGY and PI for the event. At the present, the parallel CTI is calibrated for all but ACIS-S1 and the serial CTI is calibrated for only ACIS-S3. These calibration data are appropriate for observations with frame times of about 3.2 s.

## 1 Changes to `acis_process_events`

### 1.1 Additional Parameters

1. `apply_cti,b,h`, “yes”, “no”, “yes”, “Apply CTI adjustment?”
2. `ctifile,s,h`, “CALDB”, “”, “ACIS CTI ARD file (NONE — none — CALDB — <filename>)”
3. `max_cti_iter,i,h`, 15, 1, 20, “Maximum number of iterations for the CTI adjustment of each event”
4. `cti_converge,r,h`, 0.1, 0.1, 1.0, “The convergence criterion for each CTI-adjusted pixel in adu”

When Catherine Grant tested the PSU CTI-adjustment tool, she found that the median number of iterations required to satisfy a convergence criterion of 0.1 adu is four. No event required more than ten

iterations. Therefore, a default maximum of fifteen iterations should be sufficient to determine the values of PHAS\_ADJ. The default convergence criterion is 0.1 adu because this is the default value used for the PSU CTI-adjustment tool.

## 1.2 Additional Input

The tool `acis_process_events` must read the CTI ARD file in addition to the other files it already reads. The format of the CTI ARD file is summarized in section 2.

## 1.3 Additional Output

If `apply_cti = "yes,"` the output event file has the same format as a Level 1 or Level 2 ACIS event file except that the file includes the the additional keywords "CTIFILE," "CTLCORR" and "CTLAPP" and may also include the additional column "PHAS\_ADJ." The keyword CTIFILE contains the name of the CTI ARD file used to process the data. The keyword CTLCORR = T (True). The keyword CTLAPP, which is copied from the input CTI ARD file, is a string-encoded description of the types of CTI adjustments performed for each CCD<sup>1</sup>. If the parameter `eventdef` includes, for example, "f:phas\_adj," then the values of PHAS\_ADJ are written to the output file. The column named PHAS contains the original, unadjusted values of the charge distributions of the event islands.

If `apply_cti = "no,"` no CTI adjustment is applied, CTIFILE = "NONE," CTLCORR = F" (False) and CTLAPP = "NNNNNNNNNN."

## 1.4 Processing

The tool should produce a warning if TIMEDEL is not in the range specified by the corresponding calibration-boundary ("CBD") keyword.

If `apply_cti = "yes,"` then the algorithm described hereafter is used to compute the real-valued, CTI-adjusted values of a pulse-height event island PHAS\_ADJ. The column PHAS contains the unadjusted pulse-height information. The values of FLTGRADE, GRADE, PHA, ENERGY, and PI are based on the values of PHAS\_ADJ, not PHAS (see Tables 1 and 2). The column PHA has integer values whether the CTI-adjustment is applied or not.

By default, only the values of PHAS are written to the output file. This information is retained to ensure that users can rerun `acis_process_events` to recompute the pulse-height information using an updated CTI ARD file or to remove the CTI adjustments.

The columns PHAS\_ADJ and PHAS are arrays. For TIMED FAINT-mode observations, the relative CHIPX and CHIPY coordinates associated with PHAS\_ADJ<sub>*i,j*</sub> are distributed as shown in figure 1 with *i* and *j* ∈ [1, 3]. For example, if a TIMED FAINT-mode event occurs at (CHIPX, CHIPY) = (960, 571), then PHAS\_ADJ<sub>1,2</sub> corresponds to the CCD coordinates (959,571) and PHAS\_ADJ<sub>2,3</sub> corresponds to the CCD coordinates (960,572). The algorithm described below applies only to a 3 pixel × 3 pixel event island. For TIMED VFaint-mode observations, *i* and *j* ∈ [1, 5] and the appropriate 3 pixel × 3 pixel region to use is the central nine pixels of the 5 pixel × 5 pixel event island (i.e. the region associated with PHAS<sub>*i,j*</sub>, where *i* and *j* ∈ [2, 4] instead of *i* and *j* ∈ [1, 5]). The outer sixteen pixels of the 5 × 5 island are not modified by the CTI-adjustment algorithm. The values of PHAS\_ADJ are identically the same as the values of PHAS for these sixteen pixels.

If `apply_cti = "yes,"` the following steps describe how to apply the CTI adjustment. For an event detected on CCD\_ID = *n* at a location (CHIPX, CHIPY) = (*x*<sub>CCD</sub>, *y*<sub>CCD</sub>)<sup>2</sup>,

1. Copy the contents of PHAS to PHAS\_ADJ.
2. Set the arrays DIFF\_X = 0 and DIFF\_Y = 0.

<sup>1</sup>CTLAPP = "XXXXXXXXXX," where X = N (no CTI adjustment was performed), P (only a parallel CTI adjustment was performed) or B (both parallel and serial CTI adjustments were performed). At present, the possible values of CTLAPP are "NNNNNNNNNN," "PPPPNNPNNN," "PPPPPNPNPP" and "PPPPBPBPPP."

<sup>2</sup>If the values of *x*<sub>CCD</sub> and *y*<sub>CCD</sub> are real numbers instead of integers, they should be rounded to the nearest integer before proceeding.

3. Copy the values of DIFF\_X to DIFF\_X\_PREV and the values of DIFF\_Y to DIFF\_Y\_PREV.
4. Copy the values of PHAS\_ADJ (not PHAS) to PHAS\_TMP.
5. For the column of a 3 pixel  $\times$  3 pixel event island that is closest to the serial read-out node, compute the effects of serial CTI. Steps 5 and 6 should be performed only if the appropriate serial-CTI trap-density map exists for CCD\_ID =  $n$ . The CTI ARD may not contain some serial-CTI trap-density maps if the effects of serial CTI are not fully calibrated.

- i. For NODE\_ID = 0,  $i = 1$  and  $j \in [1, 3]$ . If  $\text{PHAS}_{1,j} \geq$  the split threshold, then

$$\text{DIFF\_X}_{1,j} = \text{DELTPHAX}_{1,j}. \quad (1)$$

- ii. For NODE\_ID = 1,  $i = 3$  and  $j \in [1, 3]$ . If  $\text{PHAS}_{3,j} \geq$  the split threshold, then

$$\text{DIFF\_X}_{3,j} = \text{DELTPHAX}_{3,j}. \quad (2)$$

- iii. For NODE\_ID = 2,  $i = 1$  and  $j \in [1, 3]$ . If  $\text{PHAS}_{1,j} \geq$  the split threshold, then

$$\text{DIFF\_X}_{1,j} = \text{DELTPHAX}_{1,j}. \quad (3)$$

- iv. For NODE\_ID = 3,  $i = 3$  and  $j \in [1, 3]$ . If  $\text{PHAS}_{3,j} \geq$  the split threshold, then

$$\text{DIFF\_X}_{3,j} = \text{DELTPHAX}_{3,j}. \quad (4)$$

The quantity  $\text{DIFF\_X}_{i,j}$  is an estimate of the amount of charge that should be added to pixel  $(i, j)$ . ( $\text{DIFF\_X\_PREV}$  is the same thing except from the previous iteration.) The quantity  $\text{DELTPHAX}_{i,j}$  represents the amount of charge lost from pixel  $(i, j)$  due to the effects of serial CTI and is a function of the CCD used, the location of an event on the CCD, and the charge deposited on the CCD.

The value of  $\text{DELTPHAX}_{i,j}$  used in equations 1, 2, 3 and 4 is computed as follows.

- i. Find the row  $m$  in HDU 1 of the appropriate CTI ARD file that satisfies the conditions

$$\text{CCD\_ID}_m = n, \quad (5)$$

$$\text{CHIPX\_LO}_m \leq x_{\text{CCD}} \leq \text{CHIPX\_HI}_m, \text{ and} \quad (6)$$

$$\text{CHIPY\_LO}_m \leq y_{\text{CCD}} \leq \text{CHIPY\_HI}_m, \quad (7)$$

where  $\text{CCD\_ID}$ ,  $\text{CHIPX\_LO}$ ,  $\text{CHIPX\_HI}$ ,  $\text{CHIPY\_LO}$ , and  $\text{CHIPY\_HI}$  are the names of columns in the CTI ARD file (see sec. 2). Note that the values of  $x_{\text{CCD}}$  and  $y_{\text{CCD}}$  should be rounded to the nearest integer if they are not integers.

- ii. For row  $m$ , find the two non-zero (real!) values  $\text{PHA}_k$  and  $\text{PHA}_{k+1}$  such that

$$0 < \text{PHA}_k \leq (\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < \text{PHA}_{k+1}, \quad (8)$$

where  $\text{PHA}_k$  and  $\text{PHA}_{k+1}$  are elements of the column PHA in the CTI ARD file.

- iii. Compute the effective ‘‘VOLUME’’ occupied by the charge in pixel  $(i, j)$  using the linear interpolation

$$\text{VOLUME}_{i,j} = \left( \frac{(\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) - \text{PHA}_k}{\text{PHA}_{k+1} - \text{PHA}_k} \right) \times (\text{VOLUME\_X}_{k+1} - \text{VOLUME\_X}_k) + \text{VOLUME\_X}_k, \quad (9)$$

where  $\text{VOLUME\_X}_k$  and  $\text{VOLUME\_X}_{k+1}$  are the  $k^{\text{th}}$  and  $(k+1)^{\text{th}}$  elements of the column  $\text{VOLUME\_X}$  in the CTI ARD file (see sec. 2). This formula is valid if and only if  $1 \leq k < \text{NPOINTS}$  (i.e. if  $\text{PHA}_1 \leq (\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < \text{PHA}_{\text{NPOINTS}}$ , where  $\text{PHA}_1$  and  $\text{PHA}_{\text{NPOINTS}}$  are the smallest and largest values of the vector PHA for row  $m$ , respectively).

If  $0 < (\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < \text{PHA}_1$ , then use the linear extrapolation

$$\text{VOLUME}_{i,j} = \left( \frac{(\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) - \text{PHA}_1}{\text{PHA}_2 - \text{PHA}_1} \right) \times (\text{VOLUME\_X}_2 - \text{VOLUME\_X}_1) + \text{VOLUME\_X}_1. \quad (10)$$

Note that if  $\text{VOLUME}_{i,j} < 0$ , then set  $\text{VOLUME}_{i,j} = 0$ .

If  $(\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) \geq \text{PHANPOINTS}$ , then use the linear extrapolation

$$\text{VOLUME}_{i,j} = \left( \frac{(\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) - \text{PHANPOINTS-1}}{\text{PHANPOINTS} - \text{PHANPOINTS-1}} \right) \times (\text{VOLUME\_X}_{\text{NPOINTS}} - \text{VOLUME\_X}_{\text{NPOINTS-1}}) + \text{VOLUME\_X}_{\text{NPOINTS-1}}. \quad (11)$$

If  $\text{VOLUME}_{i,j} < 0$ , then set  $\text{VOLUME}_{i,j} = 0$ .

- iv. Find the HDU in the CTI ARD file that has the serial-CTI trap-density map for  $\text{CCD\_ID} = n$  (see sec. 2). Set  $\text{TRAPDENS}_{i,j}$  equal to the value of the map at the position  $(\text{CHIPX}, \text{CHIPY}) = (x_i, y_i)$ , where  $x_i = x_{\text{CCD}} - 1, x_{\text{CCD}},$  and  $x_{\text{CCD}} + 1$  for  $i = 1, 2,$  and  $3$  and  $y_i = y_{\text{CCD}} - 1, y_{\text{CCD}},$  and  $y_{\text{CCD}} + 1$  for  $j = 1, 2,$  and  $3$ .
- v. Compute the value of  $\text{DELTPHAX}_{i,j}$ :

$$\text{DELTPHAX}_{i,j} = \text{TRAPDENS}_{i,j} \times \text{VOLUME}_{i,j}. \quad (12)$$

6. For the two columns of a  $3 \times 3$  pixel event island that are farthest from the serial read-out node, compute the effects of serial CTI.

- i. For  $\text{NODE\_ID} = 0, i \in [2, 3]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}) \text{ and } (\text{PHAS}_{i-1,j} < \text{the split threshold})]$  or  $[(\text{CHIPX} = 256) \text{ and } (i = 3) \text{ and } (\text{PHAS}_{i,j} \geq \text{the split threshold})]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j}. \quad (13)$$

For  $\text{NODE\_ID} = 0, i \in [2, 3]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i-1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) \geq (\text{PHAS}_{i-1,j} + \text{DIFF\_X\_PREV}_{i-1,j} + \text{DIFF\_Y\_PREV}_{i-1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i-1,j}. \quad (14)$$

Do not use equation 14 if  $(\text{CHIPX} = 256)$  and  $(i = 3)$ .

For  $\text{NODE\_ID} = 0, i \in [2, 3]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i-1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < (\text{PHAS}_{i-1,j} + \text{DIFF\_X\_PREV}_{i-1,j} + \text{DIFF\_Y\_PREV}_{i-1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{FRCTRLX}n \times (\text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i-1,j}). \quad (15)$$

Do not use equation 15 if  $(\text{CHIPX} = 256)$  and  $(i = 3)$ .

- ii. For  $\text{NODE\_ID} = 1, i \in [1, 2]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}) \text{ and } (\text{PHAS}_{i+1,j} < \text{the split threshold})]$  or  $[(\text{CHIPX} = 257) \text{ and } (i = 1) \text{ and } (\text{PHAS}_{i,j} \geq \text{the split threshold})]$  or  $[(\text{CHIPX} = 512) \text{ and } (i = 2) \text{ and } (\text{PHAS}_{i,j} \geq \text{the split threshold})]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j}. \quad (16)$$

For  $\text{NODE\_ID} = 1, i \in [1, 2]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i+1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) \geq (\text{PHAS}_{i+1,j} + \text{DIFF\_X\_PREV}_{i+1,j} + \text{DIFF\_Y\_PREV}_{i+1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i+1,j}. \quad (17)$$

Do not use equation 17 if  $[(\text{CHIPX} = 257) \text{ and } (i = 1)]$  or  $[(\text{CHIPX} = 512) \text{ and } (i = 2)]$ .

For  $\text{NODE\_ID} = 1$ ,  $i \in [1, 2]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i+1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < (\text{PHAS}_{i+1,j} + \text{DIFF\_X\_PREV}_{i+1,j} + \text{DIFF\_Y\_PREV}_{i+1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{FRCTRLX}n \times (\text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i+1,j}). \quad (18)$$

Do not use equation 18 if  $[(\text{CHIPX} = 257) \text{ and } (i = 1)]$  or  $[(\text{CHIPX} = 512) \text{ and } (i = 2)]$ .

- iii. For  $\text{NODE\_ID} = 2$ ,  $i \in [2, 3]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}) \text{ and } (\text{PHAS}_{i-1,j} < \text{the split threshold})]$  or  $[(\text{CHIPX} = 513) \text{ and } (i = 2) \text{ and } (\text{PHAS}_{i,j} \geq \text{the split threshold})]$  or  $[(\text{CHIPX} = 768) \text{ and } (i = 3) \text{ and } (\text{PHAS}_{i,j} \geq \text{the split threshold})]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j}. \quad (19)$$

For  $\text{NODE\_ID} = 2$ ,  $i \in [2, 3]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i-1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) \geq (\text{PHAS}_{i-1,j} + \text{DIFF\_X\_PREV}_{i-1,j} + \text{DIFF\_Y\_PREV}_{i-1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i-1,j}. \quad (20)$$

Do not use equation 20 if  $[(\text{CHIPX} = 513) \text{ and } (i = 2)]$  or  $[(\text{CHIPX} = 768) \text{ and } (i = 3)]$ .

For  $\text{NODE\_ID} = 2$ ,  $i \in [2, 3]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i-1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < (\text{PHAS}_{i-1,j} + \text{DIFF\_X\_PREV}_{i-1,j} + \text{DIFF\_Y\_PREV}_{i-1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{FRCTRLX}n \times (\text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i-1,j}). \quad (21)$$

Do not use equation 21 if  $[(\text{CHIPX} = 513) \text{ and } (i = 2)]$  or  $[(\text{CHIPX} = 768) \text{ and } (i = 3)]$ .

- iv. For  $\text{NODE\_ID} = 3$ ,  $i \in [1, 2]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}) \text{ and } (\text{PHAS}_{i+1,j} < \text{the split threshold})]$  or  $[(\text{CHIPX} = 769) \text{ and } (i = 1) \text{ and } (\text{PHAS}_{i,j} \geq \text{the split threshold})]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j}. \quad (22)$$

For  $\text{NODE\_ID} = 3$ ,  $i \in [1, 2]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i+1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) \geq (\text{PHAS}_{i+1,j} + \text{DIFF\_X\_PREV}_{i+1,j} + \text{DIFF\_Y\_PREV}_{i+1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i+1,j}. \quad (23)$$

Do not use equation 23 if  $(\text{CHIPX} = 769) \text{ and } (i = 1)$ .

For  $\text{NODE\_ID} = 3$ ,  $i \in [1, 2]$  and  $j \in [1, 3]$ . If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i+1,j} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < (\text{PHAS}_{i+1,j} + \text{DIFF\_X\_PREV}_{i+1,j} + \text{DIFF\_Y\_PREV}_{i+1,j}))]$ , then

$$\text{DIFF\_X}_{i,j} = \text{FRCTRLX}n \times (\text{DELTPHAX}_{i,j} - \text{DELTPHAX}_{i+1,j}). \quad (24)$$

where  $\text{FRCTRLX}n$  is the name of a keyword in the CTI ARD file (see sec. 2) and represents the fraction of the trapped charge that is released in the first pixel following the pixel which lost the charge. Do not use equation 24 if  $(\text{CHIPX} = 769) \text{ and } (i = 1)$ .

7. For the bottom row of the 3 pixel  $\times$  3 pixel event island, compute the effects of parallel CTI. Steps 7 and 8 should be performed only if the appropriate parallel-CTI trap-density map exists for  $\text{CCD\_ID} = n$ . The CTI ARD may not contain some parallel-CTI trap-density maps if the effects of parallel CTI are not fully calibrated. The bottom row of  $\text{PHAS}_{i,j}$  is given by  $i \in [1, 3], j = 1$  (fig. 1). If  $\text{PHAS}_{i,1} \geq \text{the split threshold}$ , then

$$\text{DIFF\_Y}_{i,1} = \text{DELTPHAY}_{i,1}. \quad (25)$$

The quantity  $\text{DIFF\_Y}_{i,j}$  is an estimate of the amount of charge that should be added to pixel  $(i, j)$  of the event island. The quantity  $\text{DELTPHAY}_{i,j}$  represents the amount of charge lost from pixel  $(i, j)$  due to parallel CTI and is a function of the CCD used, the location of an event on the CCD, and the charge deposited on the CCD. This quantity is computed using the same linear interpolation (and extrapolation) method used to compute  $\text{DELTPHAX}_{i,j}$ , where  $(\text{PHAS}_{i,j} + \text{DIFF\_X\_PREV}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j})$  is replaced by  $(\text{PHAS}_{i,j} + \text{DIFF\_X}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j})$ ,  $\text{VOLUME\_X}$  is replaced with  $\text{VOLUME\_Y}$  and the serial-CTI trap-density map for  $\text{CCD\_ID} = n$  is replaced with the parallel-CTI trap-density map for the CCD.

8. For the middle and top rows of the 3 pixel  $\times$  3 pixel event island, compute the effects of parallel CTI. The middle and top rows of  $\text{PHAS}_{i,j}$  are given by  $i \in [1, 3]$ ,  $j \in [2, 3]$  (fig. 1). If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}) \text{ and } (\text{PHAS}_{i,j-1} < \text{the split threshold})]$ , then

$$\text{DIFF\_Y}_{i,j} = \text{DELTPHAY}_{i,j}. \quad (26)$$

If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i,j-1} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) \geq (\text{PHAS}_{i,j-1} + \text{DIFF\_X}_{i,j-1} + \text{DIFF\_Y\_PREV}_{i,j-1}))]$ , then

$$\text{DIFF\_Y}_{i,j} = \text{DELTPHAY}_{i,j} - \text{DELTPHAY}_{i,j-1}. \quad (27)$$

If  $[(\text{PHAS}_{i,j} \geq \text{the split threshold}), (\text{PHAS}_{i,j-1} \geq \text{the split threshold}) \text{ and } ((\text{PHAS}_{i,j} + \text{DIFF\_X}_{i,j} + \text{DIFF\_Y\_PREV}_{i,j}) < (\text{PHAS}_{i,j-1} + \text{DIFF\_X}_{i,j-1} + \text{DIFF\_Y\_PREV}_{i,j-1}))]$ , then

$$\text{DIFF\_Y}_{i,j} = \text{FRCTRLY}n \times (\text{DELTPHAY}_{i,j} - \text{DELTPHAY}_{i,j-1}). \quad (28)$$

where  $\text{FRCTRLY}n$  is the name of a keyword in the CTI ARD file (see sec. 2) and represents the fraction of the trapped charge that is released in the first pixel following the pixel which lost the charge.

9. Use the estimate of the effects of serial and parallel CTI to adjust the 3 pixel  $\times$  3 pixel event island PHAS. For  $i$  and  $j \in [1, 3]$ ,

$$\text{PHAS\_ADJ}_{i,j} = \text{PHAS}_{i,j} + \text{DIFF\_X}_{i,j} + \text{DIFF\_Y}_{i,j}. \quad (29)$$

Pixels whose amount of charge  $<$  the split threshold are not modified.

10. Repeat steps 3–9 until the absolute values of  $\text{PHAS\_ADJ}_{i,j} - \text{PHAS\_TMP}_{i,j}$  are less than the value of the parameter `cti_converge` for all pixels in the 3 pixel  $\times$  3 pixel event island (i.e. until the changes in each of the values of  $\text{PHAS\_ADJ}_{i,j}$  from one iteration to the next are less than the value of the parameter `cti_converge`). The maximum number of times that steps 3–9 should be performed is specified by the parameter `max_cti_iter`. If the CTI-adjustment process does not converge after `max_cti_iter` iterations, set the values of  $\text{PHAS\_ADJ}$  to be the values obtained during the last iteration and set `STATUS` bit 20 (of bits 0–31) equal to one.
11. Based on the input conditions shown in Table 1, compute the values of PHA, ENERGY, PI, FLT-GRADE, GRADE, etc. as shown in Table 2.
12. Write out the results.

## 2 New CTI ARD

Since the effects of CTI are temperature dependent, a different CTI ARD file is required for each of the different focal-plane temperatures. The CTI ARD files have the following structure.

Table 1. Input Conditions

Case	Parameter apply_cti <sup>a</sup>	Parameter doevtgrade	Parameter calculate_pi	Keyword CTL_CORR
1 <sup>b</sup>	yes	yes	yes	F
2	yes	yes	yes	T
3	yes	yes	no	F
4	yes	yes	no	T
5	yes	no	yes	F
6	yes	no	yes	T
7	yes	no	no	F
8	yes	no	no	T
9	no	yes	yes	F
10	no	yes	yes	T
11	no	yes	no	F
12	no	yes	no	T
13	no	no	yes	F
14	no	no	yes	T
15	no	no	no	F
16	no	no	no	T

<sup>a</sup> If DATAMODE = GRADED, GRADED\_HISTO, CC\_GRADED, or CC33\_GRADED, then follow the instructions for apply\_cti=no because it is not possible to perform a CTI adjustment.

<sup>b</sup> This case is appropriate for standard pipeline processing.

## 2.1 HDU 1 Keywords

- CTLAPP
- FRCTRLY<sub>n</sub>
- FRCTRLX<sub>n</sub>

The keyword CTLAPP describes the type of CTI information in the file for each CCD. For example, CTLAPP = “PPPPNNPNNN,” “PPPPPNPNPP” or “PPPPPBPP,” where “N” means no CTI information is provided for the CCD, “P” means only the parallel CTI adjustment information is included and “B” means that both the parallel and serial CTI adjustment information is included. The keywords FRCTRLY<sub>n</sub> and FRCTRLX<sub>n</sub> represent the fraction of the trapped charge that is released in the first pixel following the pixel which lost the charge.

## 2.2 HDU 1 Columns

- CCD\_ID
- CHIPX\_LO
- CHIPX\_HI
- CHIPY\_LO
- CHIPY\_HI
- NPOINTS
- PHA (a vector with NPOINTS elements)

Table 2. Output<sup>a</sup>

Case	Column PHA <sup>b</sup>	Column ENERGY	Column PI	Column FLTGRADE <sup>b</sup>	Column GRADE	STATUS bit 20 <sup>c</sup>	Keyword CTI_CORR	Keyword CTI_FILE	Keyword GAIN_FILE
1 <sup>d</sup>	C <sup>e</sup>	C	C	C	C	set	T	<cti> <sup>f</sup>	<gain_cti> <sup>g</sup>
2	C	C	C	C	C	set	T	<cti>	<gain_cti>
3	C	DNC <sup>h</sup>	DNC	C	C	set	T	<cti>	copy
4	C	DNC	DNC	C	C	set	T	<cti>	copy
5	DNC	C	C	DNC	DNC	unset	F	“NONE”	<gain> <sup>i</sup>
6	DNC	C	C	DNC	DNC	copy	T	copy	<gain_cti>
7	DNC	DNC	DNC	DNC	DNC	unset	F	“NONE”	copy
8	DNC	DNC	DNC	DNC	DNC	copy	T	copy	copy
9	C	C	C	C	C	unset	F	“NONE”	<gain>
10 <sup>j</sup>	C	C	C	C	C	unset	F	“NONE”	<gain>
11	C	DNC	DNC	C	C	unset	F	“NONE”	copy
12	C	DNC	DNC	C	C	unset	F	“NONE”	copy
13	DNC	C	C	DNC	DNC	unset	F	“NONE”	<gain>
14	DNC	C	C	DNC	DNC	copy	T	copy	<gain_cti>
15	DNC	DNC	DNC	DNC	DNC	unset	F	“NONE”	copy
16	DNC	DNC	DNC	DNC	DNC	copy	T	copy	copy

<sup>a</sup> In all cases, the PHAS values in the output file are the unadjusted values of the pulse heights in the 3 pixel  $\times$  3 pixel (or 5 pixel  $\times$  5 pixel) event islands. The values of PHAS\_ADJ are only (re)computed if apply\_cti=yes.

<sup>b</sup> If apply\_cti=yes, then the values of PHAS\_ADJ are used to compute the values of PHA and FLTGRADE. If apply\_cti=no, then the values of PHAS are used to compute the values of PHA and FLTGRADE. The values of PHA are integers in both cases.

<sup>c</sup> If apply\_cti=yes, then STATUS bit 20 (of 0–31) is set to one for an event only if the PHAS adjustments for the event have not converged after performing the specified maximum number of trials. STATUS bit 20 should be (re)set to zero first before performing the CTI adjustment.

<sup>d</sup> This case is used for standard pipeline processing.

<sup>e</sup> (Re)computed.

<sup>f</sup> The name of the CTI ARD file used to perform the CTI adjustments.

<sup>g</sup> The name of the gain ARD file used to compute ENERGY from PHA. This file is appropriate for CTI-adjusted data.

<sup>h</sup> Copied, not (re)computed.

<sup>i</sup> The name of the gain ARD file used to compute ENERGY from PHA. This file is appropriate for data that has not had the CTI adjustment applied.

<sup>j</sup> The effects of the CTI adjustment are removed.

- VOLUME\_X (a vector with NPOINTS elements)
- VOLUME\_Y (a vector with NPOINTS elements)

The columns CCD\_ID, CHIPX\_LO, CHIPX\_HI, CHIPY\_LO, and CHIPY\_HI are used to define a complete set of spatially-separate regions on the ACIS CCDs. Each row of HDU 1 corresponds to one region of an ACIS CCD and includes the vectors PHA, VOLUME\_X, and VOLUME\_Y. Each vector has NPOINTS elements. The vectors VOLUME\_X and VOLUME\_Y are used for serial and parallel CTI, respectively.

### 2.3 HDUs $\geq 2$

Each one of these extensions (up to a maximum of twenty) contains either a parallel or serial trap-density map for one of the ten ACIS CCDs. The values in the trap-density maps represent the number of traps integrated along the read-out direction. For example, the value in the parallel trap-density map for ACIS-I3 at location  $(i, j)$  is the mean number of traps across which an event at  $(\text{CHIPX}, \text{CHIPY}) = (i, j)$  is clocked when it is read-out in the parallel direction. The scaled values of the integrated trap densities are stored as two-byte integers. The scaling parameters are specified in each trap-density extension using the keywords



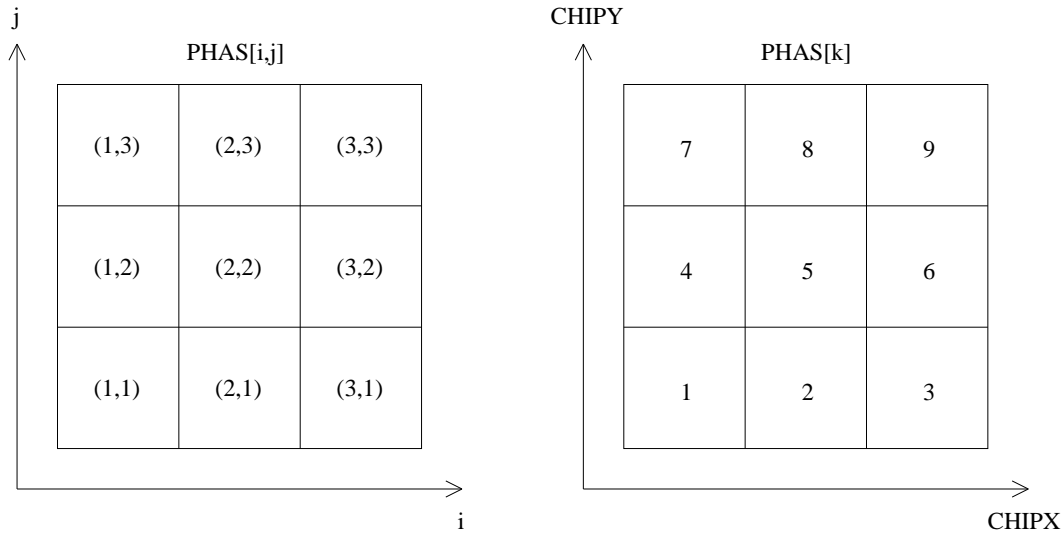


Figure 1: The relative CHIPX and CHIPY coordinates of the nine elements of a  $3 \times 3$  ACIS event island (i.e. the nine elements of PHAS and PHAS\_ADJ for TIMED FAINT-mode events).

BZERO and BSCALE: the trap density = BZERO + BSCALE  $\times$  the value in the trap-density image. The use of two-byte integers instead of four-byte real numbers helps reduce the size of the ARD file.

## 2.4 Size of File

The CTI ARD files are relatively large. Each row of HDU 1 has six two-byte integers and three four-byte real vectors with NPOINTS elements each. If the CTI ARD contains information for one region (the entire CCD) on each of the ten ACIS CCDs and if NPOINTS = 100, the binary table of HDU 1 comprises  $10 \times 1 \times (6 \times 2 + 3 \times 4 \times 100)$  bytes = 12.1 kb of information. The size of each of the twenty trap-density maps is 2.1 Mb (i.e.  $1024 \times 1024$  pixels  $\times$  2 bytes/pixel). Unless the number of regions per CCD becomes much larger than one, the size of HDU 1 is much smaller than the size of the trap-density maps and the size of one CTI ARD file can be as large as 42 Mb (i.e. 20 hdus  $\times$  2.1 Mb/hdu).