Chandrasekhar X-Ray Center

CXC Archive Interface Control Document
Level 2 Specifications for:
Aspect Histogram:
Processing and Data Products

(http://space.mit.edu/ASC/docs/AspHist_ICD.ps.gz)

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Document and Change Control Log

Date	Version	Section	Status
21 January 99	0.0	all	Initial Draft
26 January 99	0.1	all	Change units to physical; changed sectioning..
2 February 99	0.2	all	Add coord sys. for bin, world; add param file extension
5 February 99	1.0	all	Incorporate suggested changes, and then some.
01 March 99	1.0	Appendix A	New section - do give explicit examples of 3 coordinate systems. Changed history from appended parfile to cxc header comments.

Unresolved Issues

The following is a list of unresolved, un-reviewed, or un-implemented items:

1. Need a definition of positive roll (page 5.)
2. Need a reference for specification of GTI (page 7).
3. Need updated aspect offsets ICD (page 10)
4. need review of keywords needed on input (page 10)
5. Need specification of alternate coordinate keywords for table axes (page 6).
6. 990301 Need parameter keyword names (page 7).

Contents

1 General Description

This document describes the interface to be employed in transferring the Aspect Histogram file used in the CXC processing pipelines and analysis tools to or from the CXC Data Archive, according to the requirements stipulated in the "ASC Data System Requirements" (Applicable Document 1). In addition, the processing steps are given.

1.1 Purpose

AXAF processing, described in Applicable Document 1, consists of processing AXAF Level 1 products to derive new products, such as images, spectra, light-curves, or exposure-maps. This document describes the structure and content of one product, the aspect histogram, which is required for a subset of this processing and for further analysis, either via pipeline or interactive processing.

1.2 Scope

This interface shall apply to data products that are used by CXC Level 2 pipelines or tools and distributed to the CXC Data Archive (see Applicable Document 1 and the "ASC Data System Software Design," Applicable Document 2) during the course of the AXAF mission.

1.3 Applicable Documents

The Applicable Documents required for background and detail are as follows:

1. ASC AMO-2400 (SE03)
   ASC Data System Requirements (ASC.302.93.0008)

2. ASC AMO-2401 (DS01)
   ASC Data System Software Design (ASC.500.93.0006)

3. ASC FITS File Designers' Guide
   `http://hea-www.harvard.edu/ãrots/asc/fits/ascfits.ps` (and references therein).

1.4 Functional Description

1.4.1 Data Content Summary

Data sets read by the processing pipelines shall consist of data files conforming to the FITS format (See the "ASC FITS File Designers' Guide", Document 3) and references therein.) These files contain header keyword entries and binary table extensions. Following rules outlined in Document 3, all these files will contain a possibly null primary header followed by a main binary table (the "principal HDU") and auxiliary extensions ("auxiliary HDU").

1.4.2 Recipients and Utilization

The primary recipients of reference data products, via distribution from the archive, are AXAF observers, who will utilize these data products for scientific data analysis.

1.4.3 Pertinent Relationships with Other Interfaces

Changes to the definition of Aspect System Products, as described in Document **??**TBD, may affect the data products described in the current document.

TBD by dph aspect doc references.

1.4.4 Assumptions and Constraints

The aspect histogram is computed under the assumption that the SIM offsets are included and that the SIM offsets are small compared to the scale of mirror vignetting.

1.4.5 Products Not Covered

Products that are used for maintenance and diagnostic purposes (those that are not supplied to the user for scientific data analysis) are not currently included within the interface defined by this document.

1.4.6 Substructure Definition and Format

The "ASC FITS Designers' Guide" (Document 3) defines and lists header components for the primary header and for all binary table extensions. These will be used with appropriate modifications, if any. These will be used in accordance with Table 6 in the "ASC FITS Designers' Guide."

In general, when FITS headers are shown, column or row numbers are arbitrary unless otherwise indicated. It is the *column name and its attributes* which specify the requirement. **Additional columns or extensions not specified here are permitted in the file without violating the interface.** Processing software can ignore them, pass them through, or use them if they are "known" quantities. (Example usage of this are columns derived from simulation containing *a priori* known values, to be directly compared with specified columns containing derived values.) Likewise, **HDU order is arbitrary,** except for the primary HDU. HDU are intended to be referenced by name, not position.

Unless explicitly noted, the `HDUNAME` and `EXTNAME` header keywords will be identical.

2 Aspect Histogram: Data Product Specification

Data Product Summary

Data Product	Aspect Histogram
Instrument(s)	HRC, ACIS
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	TBD
Filetype	FITS bintable
Created by tool	asphist
Used by tool(s)	mkexpmap
Sample file	asphist_out.fits

Summary Description of the Product The aspect histogram will be stored as a FITS binary table, which tabulates the non-zero exposure durations in bins of aspect pointing offsets in right ascension (R.A.), declination (Dec.), and roll. Several coordinate systems will be recorded to allow conversion from the native offsets to bin number or world coordinates. Since the good-time-intervals are crucial to application of the aspect histogram, the GTI table used to compute it will be attached as an extension.

Those parameters deemed crucial for knowledge of the history will be encoded into the FITS header of the principal HDU according to the CXC FITS conventions described in Document 3.

2.1 HDU Components

The following table describes the file structure by Header-Data Unit number, type, extension name, content, and HDU classes. An asterisk (*) denotes the ASC principal HDU. The HDUNAME is identical to EXTNAME.

HDU	HDU TYPE	EXTNAME	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	NULL
1*	BINTABLE	ASPHIST	ASPHIST	ASC TEMPORALDATA ASPHIST	Table of exposure durations per offset bin, weighted by live-time-factors and GTI.
2	BINTABLE	GTI	GTI	OGIP GTI ALL	Good-Time Intervals table used to filter aspect offsets records.

2.2 HDU Header Components

The "ASC FITS Designers' Guide" (Applicable Document 3) defines and lists general header components for the primary header and for all binary table extensions. Since there is always a focal-plane instrument in use, each aspect histogram has associated observational and instrumental parameters. These will be made explicit by including the associated header components from the relevant observation. In particular, the histogram sky-pixel sizes used are determined by the focal-plane instrument. The components for each HDU are:

0. Primary HDU: (Null)

   Image mandatory
   Null configuration control
   Short timing
   Short observation

1. Principal table HDU: ASPHIST

   Bintable mandatory
   Table coordinates
   Full configuration control
   Full observation
   Full timing

2. Auxiliary table HDU: GTI

   Bintable mandatory
   Table coordinates
   Short configuration control
   Short timing
   Short observation

3. Auxiliary table HDU: PARAM

   Bintable mandatory
   Short configuration control
   Short timing
   Short observation

2.3 Column and Axis Descriptions: ASPHIST

2.3.1 Tabulated Values

The quantities stored in the table are the sky tangent-plane offsets from the telescope optical axis in units of sky pixels. The x and y coordinates are parallel to right-ascension and declination tangent-plane coordinates, respectively. The roll is defined in the sense TBD. The sky pixels are typically — but not necessarily — the size of the projected detector pixels. Aspect histogram bins are stored in a table, as opposed to an image, and only bins with non-zero durations are tabulated.

Need definition of positive roll.

The origin of the offsets is the nominal pointing, given by `RA_NOM`, `DEC_NOM`, and `ROLL_NOM` (there is not necessarily any offset with non-zero duration at this location).

The Science Instrument Module (SIM) offsets are included in the definition of the aspect offsets being binned into a histogram. That is, there is a non-zero offset if the telescope axis were stable, but the SIM moved. This is reasonable because a different region of the sky is exposed, but the shift is not enough to appreciably alter the vignetting function with respect to the detector pixels.

The offsets in sky tangent-plane pixels and in roll degrees will be tabulated explicitly in the binary table as specified by the following table:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TNULL	Comment
X_OFFSET	pixel	1E	N/A	N/A	*NaN*	Offset in sky tangent-plane pixels relative to boresight, in the R.A. direction (X). The legal limits (`TLMIN, TLMAX`), are not specified because large-field (e.g., slew) histograms could be constructed, though typical amplitudes are on the order of 20 arcsec (5.5e-03 deg).
Y_OFFSET	pixel	1E	N/A	N/A	*NaN*	Offset in sky tangent-plane pixels relative to boresight in the Dec. direction (Y).
ROLL_OFFSET	deg	1E	−180	180	*NaN*	Offset in roll in degrees (sense TBD).
DURATION	s	1E	0.0	N/A	*NaN*	Exposure duration for offset bin, weighted by live-time-factor and GTI.

2.3.2 Coordinate Systems

When the histogram is computed, the number of bins, ranges, and bin sizes are specified or determined from the data. For further discussion and detailed definition of the coordinate systems, we will define the number of bins on the sky axes as N, ranging from x_1 to x_N, with bin size, Δ. In addition, there are M bins in the roll direction, ρ, ranging from ρ_1 to ρ_M. The y axis transforms analogously to the x. In the FITS convention, the coordinates refer to the *center* of a bin. The boundaries of bin x_i are therefore assumed to be the semi-open interval, $(x_i - \Delta/2) \leq x_i < (x_i + \Delta/2)$. The offsets in sky tangent-plane pixels are called `X_OFFSET`, `Y_OFFSET`, and `ROLL_OFFSET`. The corresponding bins are referred to as `X_OFFBIN`,`Y_OFFBIN`,and `ROLL_OFFBIN`. The world-coordinate versions are `RA_OFFSET` and `DEC_OFFSET` (there is no corresponding world coordinate for roll).

Primary Coordinate System The primary coordinate system needs no definition in terms of FITS table coordinate keywords (`TCRPX, TCRVL, TCDLT`) because the stored values are already in physical units. The bin sizes are not specified by standard FITS keywords. They can be inferred from the secondary coordinate sytems or from the parameter file extension (see Section **??**).

Secondary Coordinate Systems The `X_OFFSET`, `Y_OFFSET`, and `ROLL_OFFSET` axes will have transformations to bin number. Furthermore, the former two will also have transformations defined to `RA` and `DEC` of the optical axis. The following table gives the alternate transformation coefficients (enumerated by secondary axis, S) for each primary axis (column) (enumerated by P). Values to be calculated are given in terms of the aspect histogram generation parameters defined previously. Note that the order of assignment of P to a column is arbitrary, and the order of assignment of S to alternate coordinates for column P is also arbitrary.

TTYPEP	P, S	TYPES	PIX	DELT	VAL	UNIT	Note
X_OFFSET	1, 1	X_OFFBIN	x_i	1	$(x_i - x_1)/\Delta + 1$	N/A	1
	1, 2	RA_OFFSET	x_i	Δ	`RA_NOM`- x_i	deg	2
Y_OFFSET	2, 1	Y_OFFBIN	y_i	1	$(y_i - y_1)/\Delta + 1$	N/A	3
	2, 2	DEC_OFFSET	y_i	Δ	y_i+`DEC_NOM`	deg	4
ROLL_OFFSET	3, 1	ROLL_OFFBIN	ρ_i	1	$(\rho_i - \rho_1)/\Delta\rho + 1$	N/A	5

Notes

1— Sky X tangent-plane offset bin for value x_i, with bin size Δ and bin 1 having the value, x_1. (Note that x_1 is generally negative.)

2— `RA` of optical axis for value x_i, with bin size Δ.

3— Sky Y tangent-plane offset bin for value y_i, with bin size Δ and bin 1 having the value, y_1. (Note that y_1 is generally negative.)

4— `Dec` of optical axis for value y_i, with bin size Δ.

5— Roll bin for value ρ_i, with bin size $\Delta\rho$ and bin 1 having the value, ρ_1.

2.3.3 Special Header Keywords

There are two keywords which provide crucial history regarding the generation of the histogram. They are the resolution parameters for the RA and DEC bin-sizes (which are equal: `RADECRES`), and the roll bin-size (`ROLLRES`). They will be stored in the principal header according to the parameter history recording mechanism described in the CXC FITS Guide (Document 3).

param names TBR

2.4 Column Descriptions: GTI Extension

The GTI HDU is a standard component. A specification can be found in TBD.

Need GTI spec reference.

2.5 Size Estimate

For a nominal dither pattern of semi-amplitude 20 arcsec in both X and Y, with resolution of 0.5 arcsec, there will be about 22 kB of data per roll bin if every (X, Y)-bin had an entry. There should be no more than a few roll bins. The total volume of header information will be comparable to this size. Hence, an aspect histogram product will be of order 50-100 kB.

3 Aspect Histogram: Processing Specifications

This section contains a top-level description of the processing of the aspect histogram, including the inputs, outputs, definitions, and overview of the algorithm.

3.1 Interface Specifications

Name: asphist

Purpose: Calculate pointing duration in bins of aspect offset in right-ascension, declination, and roll.

Input files:
aspect offsets
good-time-intervals (GTI)
live-time-factors (LTF)

Keywords expected:
DTASPSOL - aspect record time increment
RA_NOM
DEC_NOM
ROLL_NOM

Input parameters:
– RA, Dec. resolution (arcsec)
– roll resolution (arcmin)

Output files: Aspect Histogram – FITS bintable (see Section 2)

3.2 Definitions

Aspect Offsets: See ICD "Data Product Interface Document: Level 1 aspect offset products" (Rev. 0.5 DRAFT Oct 7 1998).

Pending revision of the above ICD, the following is assumed:

The aspect offsets file contains time-ordered records of offsets in R.A., Dec., and roll from a Nominal R.A., Dec., and roll (RA_NOM, DEC_NOM, ROLL_NOM), equally spaced in time at small intervals ($0.256 - 1.0$ seconds). Any large gaps will be deleted via application of an appropriate GTI. Units of offsets are in tangent-plane pixels for RA and Dec, w/ WCS coordinate systems in the header.

SIM offsets (tangent-plane x,y,roll) have been applied to the R.A., Dec., and roll offsets.

The offset is the difference in tangent-plane pixels of the boresight (telescope optical axis) from the nominal position. The same offsets may represent different physical detector pixels at different times due to the SIM motion.

Example: telescope axis aspect is stable — RA,Dec,roll constant, but SIM moves. — offsets change. (meaning, a new pixel sees the optical axis)

Example: telescope moves, SIM stable — aspect offsets change (meaning, same pixel sees optical axis)

In both cases, a different region of the sky is exposed by the detector. In the first, the optical axis stays at the same point in the sky. In the latter, the optical axis is at a different sky position. We can accept this as far as response (ARF vs position or time) is concerned only because the SIM motion is small compared to the vignetting function. Pixel-to-sky transformations care, even if shifts are small.

GTI - start, stop times defining intervals of "good" data (well defined elsewhere, a standard product.)

LTF: - Live Time Factor, an observational efficiency factor, or duty-cycle. For HRC, this is a table. For ACIS, it is a single number.

Resolution: the bin-sizes in R.A., Dec, and roll.

R.A. and Dec. are well-defined - these are the increments which are considered a significant change in R.A. or Dec. in the absence of roll, and are the bin-sizes of the histogram. These should be 1/2 the size of the smallest significant feature of importance — typically the on-axis spatial resolution.

Roll resolution is less straightforward. Near-axis, a large roll can be tolerated because it doesn't shift the sky coordinates much in pixels. Far off-axis, small rolls may cause a relatively large shift. Hence, we need to consider the spatial resolution off-axis and a commensurate roll resolution, but ensure that near on-axis, this isn't too big.

At an off-axis angle, θ, in arcmin, for roll, ρ, in arcmin, the deviation in arcsec is $dp = (\theta\rho)(\pi/180) = 0.0174\theta\rho$.

As a guide to choosing roll bins, the 50% PSF width are tabulated against off-axis angle. The corresponding roll angle, is that angle which gives a change in source position on the detector equal to the PSF width.

θ	$W(50\%)$	ρ	comment
$0'$	$0.5''$	0	
$8'$	$8''$	$58'$	acis-i radius
$15'$	$20''$	$76'$	(hrc-i radius)

Conversely, those rolls give the following deviations in position at 1 and 2 arcmin off-axis angles:

θ	ρ	dp
$1'$	$58'$	$1''$
$1'$	$76'$	$1.3''$
$2'$	$58'$	$2''$
$2'$	$76'$	$2.6''$

If we require deltas due to roll to be ≤ 0.5 arcsec in the $0-2$ arcmin off-axis range, then roll bins must be of order 26 arcmin. If we require deltas to be on the order of the on-axis spatial resolution (i.e., match the physical pixels), then roll bins are about 4 arcmin (ACIS) or 1.4 arcmin (HRC).

Specifications on the roll indicate a range of about 3 arcmin per 48 hour interval.

Defaults: R.A.,Dec (one parameter) - 0.5 arcsec roll: 10 arcmin

Aspect Histogram: The Aspect Histogram is a 3-dimensional histogram in which each bin represents a range of aspect offsets in R.A., Dec. (in tangent-plane pixels TBR) and roll, and whose value is the total exposure time, weighted by live-time and filtered by GTI, at that offset.

The data are not stored as a 3D image, since many bins may be empty, but are stored as a table of bins with non-zero exposure.

See Section 2 for a file format specification.

Processing Steps

1. Read parameters.
2. Open offsets file, read relevant header keywords, prepare to read offset records.
3. Read GTI table
4. Read LTF table
5. Compute histogram limits: from min, max offsets and resolution parameters, compute histogram number of possible bins; initialize oct-tree.
6. Bin offsets:
   (a) read an offset record until falls within current GTI
   (b) compute bin from offsets
   (c) compute duration - either aspect record duration, or $t - \texttt{TSTART}$, or $\texttt{tstop} - t$, depending on where it is within GTI. If time is greater than TSTOP, increment GTI.
   (d) determine LTF bin; weight duration by LTF
   (e) if last aspect, write file; otherwise, repeat

An efficient binning method (and current implementation) is an oct-tree, which handles 3-dimensional data ($2^{\text{dimension}} = 8$).

3.3 Questions/Issues:

1. - is LTF a number or table? (A: both)
2. - is a centered model or interpolated model necessary? (depends on specification of aspect offsets and grid of the offsets.) (A: no)
3. - what are expected roll ranges? (A: 3 arcmin)
4. - need updated aspect offsets ICD.
5. - need review of keywords needed on input

3.4 Comments:

Current method is a "stepwise" treatment of the offsets. The aspect is considered to be constant from one record's time until the next. One could also consider the aspect offset times to be the central time rather than the left edge of an input bin. A more sophisticated treatment would be to apply a linear interpolation of the aspect between records, determine when the interpolated function intersects output bin boundaries, and interpolate the duration. These alternate methods are probably not significantly better than the stepwise method for very small aspect offset intervals.

Current model:

`o` represents an aspect record time and offset. The digit above is the record number.

`###...###` is the GTI interval.

`dn` is a duration for interval n, delimited by `[`.

```
       |                             3
       |                             o---------|
       |                             |         |
       |                             |         o------------|
       +                  2          |         4            |
       |                  o-----------                      |
output |                  |                                 |
  bin  |                  |                                 |
       +                  |                                 |
       |       1          |                                 |
       |       o-----------                                 |
       |       |        d1      d2        d3       d4       o----------
     0 +       |      [---[----------[---------[--------]   5
     o-|--------      [#################################]
       |                              GTI
       |
       ------------------------------------------------------------------
                                      Time
```

Centered model: The GTI and the offset record times are the same, but the interpretation has changed: the times are now considered centered between offsets.

```
       |                             3
       |                       ------o-----|
       |                       |           |   4
       |                       |           |---o-----|
       +                  2    |                     |
       |             -----o-----                     |
output |             |                               |
  bin  |             |                               |
       +             |                               |
       |       1     |                               |
       |   ----o------                               |      5
       |   |                                         |------o----------
     0 +   |              d2         d3         d4    d5
     o-|----          [--------[-----------[---------[--]
       |              [#################################]
       |                              GTI
       ------------------------------------------------------------------
                                      Time
```

Interpolated model: Aspect records denoted by `o` are in the same coordinates as before, GTI is the same. Now points are to be connected by linear segments. The +-marks roughly indicate when the segment crosses an output bin (or is midway between records if in the same bin), and align with duration boundaries.

```
       |                             3
       |                             o
       |                                  +    4
       |                                       o
       +                  2  +                    +
       |                  o
output |
  bin  |               +
       +
       |       1
       |       o                                            5
       |                                                    o
     0 +
     o |              [d1[-d2[-----d3-----[---d4--[-d5--]
       |              [#################################]
       |                              GTI
       ------------------------------------------------------------------
                                      Time
```

It can be seen that the models differ in detail. However, for small and uniform time increments, results would probably be effectively identical.

A Examples of Coordinates and Transformations

These are additional notes on the specification of multiple coordinate transformations from aspect_offset histogram bins to bin number and to world coodinates.

Schematic of a small region of an aspect histogram grid:

```
.---.---.---.---.---.---.---.---.---.
| +   +   + | +   +   + | +   +   + |
|           |           |           |
| +   o   + | +   o   + | +   o   + |
|           |           |           |
| +   +   + | +   +   + | +   +   + |
.---.---.---.---.---.---.---.---.---.
| +   +   + | +   +   + | +   +   + |
|           |           |           |
| +   o   + | +   o   + | +   o   + |
|           |  A        |           |
| +   +   + | +   +   + | +   +   + |
.---.---.---.---.---.---.---.---.---.
| +   +   + | +   +   + | +   +   + |
|           |           |           |
| +   o   + | +   o   + | +   o   + |
|           |           |           |
| +   +   + | +   +   + | +   +   + |
.---.---.---.---.---.---.---.---.---.
```

Coordinate Axes:

```
Logical:   |-----------|-----------|-----------|   X_OFFBIN --->
                 1           2           3
Physical:  .---.---.---.---.---.---.---.---.---.   X_OFFSET --->
            -4  -3  -2  -1   0   1   2   3   4
World:     .---.---.---.--A.---.---.---.---.---.   <--- R.A.
```

Key:

- `.` X_OFFSET bin boundaries (size of sky pixel)
- `+` X_OFFSET "pixel" centers
- `|` X_OFFBIN boundaries (aspect histogram grid)
- `o` centers of X_OFFBIN bins
- `A` Nominal Aim point (if the offsets had this value, then the telscope axis would be pointed at (RA_NOM, DEC_NOM)).

X_OFFSETs are tabulated in the aspect_offsets file and are real variables (can be anywhere in this grid, not just the +'s).

X_OFFSETs are binned at some scale larger than sky pixels, and have an origin of zero at the center by definition (binning is shown here as integer multiple of sky pixels, but that is not necessarily so).

X_OFFSET is the "physical" coord - it is what is tabulated in the ASPECT_HISTOGRAM. The aspect_offsets can have arbitrary real values, but the X_OFFSETs will have discrete real values because binning parameters were specified to calculate the histogram - the exposure duration for each offset bin. (The tabulated histograms offsets in this schematic have the values marked by the o's.)

X_OFFBIN is the "Logical" coord - the bin numbers of the aspect histogram (as if it were binned into an image). The tabulated offsets in the aspect histogram are the values of X_OFFSET at the centers of these offset bins.

RA is the world coordinate, and it the right-ascension of the telescope optical axis for the corresponding X_OFFSET.

In this example, Δ (my bin-size parameter in the table on page 7) is 3 — there are three units of world coordinate per X_OFFBIN (e.g., if sky pixels projected to 1 arcsec, then this is 3 arcsec binning specified to calculate the histogram).

The FITS bintable of the aspect_offsets will tabulate the physical coordinate, which is the value of X_OFFSET, Y_OFFSET at the center of the logical bins.

A.1 Transformations:

To calculate the X_OFFBIN from the X_OFFSET for bin i (at bin center), with spacing Δ:

$$X\_OFFBIN(i) = \frac{(X\_OFFSET(i) - X\_OFFSET(1))}{\Delta} + 1 \quad (1)$$

For example:

$X\_OFFSET(1) = -3$ — this is the reference "pixel", and in FITS convention, pixel 1 is the center of the lower-left pixel. From the figure and coordinate axes, -3 is the physical coordinate in the center of the lower-left bin.

$\Delta = 3$ — there are 3 sky units per aspect histogram bin (in the x-direction).

X_OFFSET can have values of -3, 0, or 3 in the output histogram. e.g., an input X_OFFSET value of -2.0 will fall into the bin whose X_OFFSET limits are -4.5 to -1.5, and whose center is -3.0, and whose width is 3.0.

Explicit example, using Eq. 1

i	X_OFFSET(i)	X_OFFBIN(i)
-3	-3	1
0	0	2
3	3	3

To calculate the telescope axis RA for a given offset, simply subtract the offset from the nominal RA (assuming that they are in the same units):

$$RA(i) = RA\_NOM - X\_OFFSET(i)$$

The negative sign is because RA increases to the left. For declination:

$$DEC(i) = DEC\_NOM + Y\_OFFSET(i).$$