AXAF
Science Center

MEMORANDUM

January 4, 1999

To: WWW Pages, Distribution
From: M. Garcia
Subject: Nominal Dither Parameters, Lissajous figures
original April 30 1998, updated May 6 1998, Jan 4 1999

The dither for AXAF is controlled by commanding a set of dither angle parameters, which correspond to a set of dither rate commands. There is an independent set of parameters for each axis, consisting of the dither amplitude (A), dither frequency (W), and dither phase (P).

The dither has several goals and constraints.

- **MAX rate:** set by PCAD/ACA considerations, the maximum rate allowed is $0.1''$/sec, this is a true spacecraft rate (ie, a two axis rate). There is in reality some margin (perhaps a factor of 2), but TRW has shown they meet PCAD requirements at $0.1''$/sec (from RAC email). Note that in TRW analysis, rates up to $0.22''$/sec are used (ie, FAX from John Donaghy May 5 1998.

- **MAX angle:** set by PCAD/ACA considerations, the maximum dither angle is $20''$ amplitude ($40''$ peak-to-peak). Again there is some margin here.

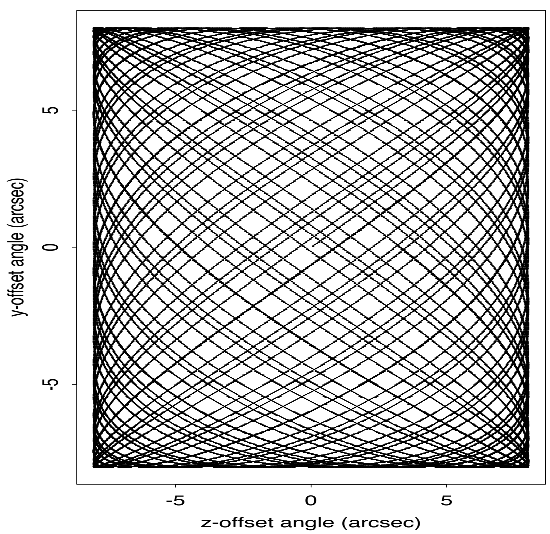
- **HRC protection during acquisition:** In order to protect the HRC from bright objects during the ACA star acquisition process, a new dither mode has been introduced to the flight s/w such there is an 'acquisition dither' with an amplitude of $5''$. If dither is enabled during slew, then the amplitude is clamped to the K-constant value during the star acquisition process. The dither period (frequency) is unchaged. When the guide stars are acquired and the Kalman filter starts, the spacecraft transitions to NPM and the dither amplitude increases to the NPM value. If guide stars are not found, but the ACA is able to lock onto stars using its 'bright star search', the dither is then also increased to the NPM value once the Kalman filter is running. The dither frequency must therefore be high enough to protect the HRC during this period of reduced amplitude dither. The maximum time spent in this reduced amplitude dither phase is $\sim$ 20minutes. If the fall-back bright star aqcuisition fails, the s/c is likely to auto-transition to a safe mode, which should automatically reduce the HRC HV.

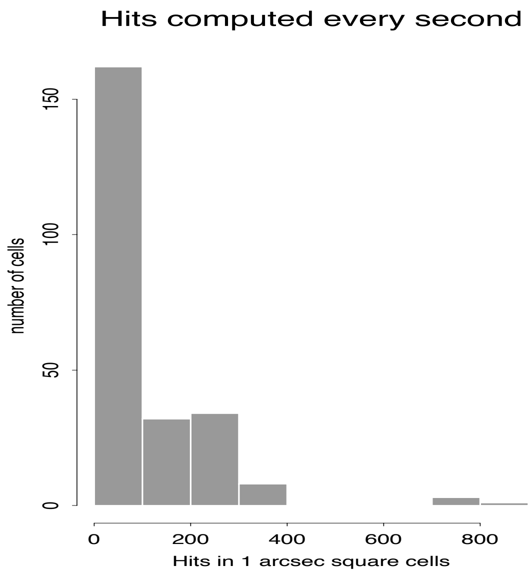
- **Flat Fielding considerations:** One purpose of the dither is to smooth over the flat-fields on a scale such that the flats are known to $\sim 1\%$. Given data obtained at XRCF and during sub-assembly calibration, this corresponds to a $40'' \times 40''$ square area for the HRC, and a $16'' \times 16''$ square area for the ACIS.

- **Minimum Observation Time:** The dither frequency should be set high enough so that at least one complete dither patters occurs during the shortest science observation. As this is 1000 sec, the dither frequency $w = 2\pi/T = 2\pi/1000 = 0.0036$ radian/sec= 0.001 cycles/sec

- **ACIS readout time, pixel smearing:** The ACIS is read out once per 3.3 sec in its nominal, timed exposure mode. The dither effectively 'smears' a single $0.5''$ ACIS pixel over a larger region of the sky, that smearing is equal to the dither rate times the ACIS frame time. Photons coming from anywhere on the sky within this smeared region appear on this single pixel, so the sky image is effectively smeared.

- **Dither pattern:** The pattern should 'fill in' a square region, rather than tracing the same line over and over. This requires that the ratio of the x and y dither frequencies must not be the ratio of two whole numbers. Also, the speed of the motion scales directly with the frequency (see below) and one does not want the pitch and yaw speeds to be very ($\sim 2\times$) different, but at the same time the farther apart the two frequencies are, the more different each trace of the Lissajous pattern is. The ROSAT PSF has a residual elongation in the direction of dither, most likely due to imperfect knowledge of the aspect camera flat-field. Based on these considerations we will use frequencies in the ratio of $1 : \sqrt{2}$. The Lissajous figures will always generate a pointing profile such that the aim point spends a longer time at the edges of the box than at the center, because derivative of the *sin* (or cos) is at a minimum when the function is at an extreme. Below is 30,000 sec (the median GTO target time) of a Lissajous figure using the suggested default parameters of $W_z = 2\pi/707$, $W_y = 2\pi/1000$ (in units of radians/sec). The histogram on the right is of the 'density' of the image on the left in units of $1''$square, ie, the position is computed every 1.0 sec and the image is divided into cells $1''$ on a side. The minimum density is not zero, but is 36. The maximum number of 'hits' occurs in the four corners, and is between 750 and 800 hits.


y-offset angle (arcsec)
z-offset angle (arcsec)
-5
0
5


Hits computed every second
number of cells
Hits in 1 arcsec square cells
0
50
100
150
0
200
400
600
800

Definitions (thanks in large part to Mike Juda):

The dither generates a Lissajous figure in pitch (z) and yaw (y), with offset angles of the form:

$$y = A_y * sin(W_y \times t + P_y)$$
$$z = A_z * sin(W_z \times t + P_z)$$

The ground commands $A_y, A_z, W_y, W_z, P_y, P_z$, through OR entries, or from default values in the ODB. The dither speed is the derivative of the offset angles above,

$$S_y = A_y * W_y cos(W_y \times t + P_y)$$
$$S_z = A_z * W_z cos(W_z \times t + P_z)$$

Let us define period of the dither pattern to be T (seconds), then the frequency $W = 2\pi/T$ (radians/sec). In one period the dither moves one axis over a distance $4A$, during a time T, so the average speed in one axis $= < S >= 4A/T$ (″/sec). Because the z/y axis are independent, the true (two axis) speed is the root sum of the squares of the one axis speeds,

$$< s >= 4\sqrt{(A_y/T_y)^2 + (A_z/T_z)^2}.$$

The maximum speed occurs when $cos(W + P) = 1$, and is $S_m = AW = 2\pi(A/T)$. The maximum true (two axis) speed is

$$s = 2\pi\sqrt{(A_y/T_y)^2 + (A_z/T_z)^2}.$$

Let us assume $T_z = T = 707$sec, then $T_y = 1000$sec$= \sqrt{2}T$. Then $< s >= 4\sqrt{3/2}(A/T)$, $s = 2\pi\sqrt{3/2}(A/T)$.

Time (t) in these equations probably resets to zero when the dither is turned on or off *(see email addendum)*, but is not effected by the automatic changes in the amplitude of the dither during acquisition. Therefore we expect that the 'dither phase angle' at the start of each observation to be essentially random.

ACIS Considerations:

For the ACIS, there are two competing requirements on dither. One wants 1) to dither far and fast enough such that during the shortest observation (1000 sec) we cover the flat-field cell size' of $16''$. On the other hand, one wants 2) to dither slow enough that we do not smear the ACIS pixels 'significantly' during an observation.

1. This item sets a lower limit on dither speed.

   $$< s >= 4\sqrt{3/2}(A/T) = 4\sqrt{3/2}(8''/707\text{sec}) = 0.055''/\text{sec}$$
   $$s = 2\pi\sqrt{3/2}(A/T) = 0.087''/\text{sec}$$

   corresponding to dither parameters $A_z = A_y = 8''$, $W_y = 2\pi/1000 = 0.0063$ rad/sec, $W_z = 2\pi/707 = 0.0089$ rad/sec.

2. This item sets an upper limit on the dither speed. If we use the dither speed above, the 'smearing', at the average rate is

   $$\text{smearing} =< s > \times 3.3\text{sec} = 0.18'' = 36\% \text{ of one pixel}$$

   It is probably correct to use the average (rather than peak) rate to compute the smearing, since the image is built up over the entire observation (ie, it is the average of all many individual shorter observations).

So default ACIS dither parameters of $A_z = A_y = 8''$, $W_y = 2\pi/1000 = 0.0063$ rad/sec, $W_z = 2\pi/707 = 0.0089$ rad/sec, seem fine. Note that we could increase the dither period for longer observations, and therefore reduce the smearing. Do we want to do this?

HRC Considerations:

Will the brightest source observed with the HRC damage the MPC pores during the acquisition interval, when $A_y = A_z = 5''$? We will assume (as above) that $T_z = T = 707s$, and $T_y = 1000s = \sqrt{2}T$. During this time $A_z = A_y = 5''$, so the average rate is:

$< s >= 4\sqrt{3/2}(A/T) = 0.035''/\text{sec}$

The 'brightest' source the HRC will look at is $\sim$ 200c/s (ref: Obs Guide), and about 20% of the counts are in a core that is about one pore in size (ref: M. Juda, PC). The source will trace out a line at this core rate, containing:

core rate $= \frac{0.2\times 200c/s}{0.0035''/s} = 1,154$ cts/$''$

This $1''$ long line has $\sim$ 4 pores, so the rate per pore is

core rate $\sim \frac{1{,}154\text{cts}/''}{4''/\text{pore}} = 288$ cts/pore

The 'wings' contribute the remaining 80% in a $1''$ radius region; let us make the approximation that the wings are uniform. This region contains $\pi r^2 = \pi \frac{1''}{0.25''/\text{pore}}^2 \sim 50$ pores. Any given pore is illuminated by the wings until the source has moved 1 diameter, or $2''$, which requires a time $T = \frac{2''}{0.035''/\text{sec}} = 57$ sec. The rate per pore is $\sim 0.8 \times$ 200cts/sec/50pores $=$ 3.2 cts/sec/pore, the total dose per pore is $\sim$ 3.2 cts/sec/pore $\times$ 57 sec $=$ 182cts. This should be added to the dose due to the core, for a total dose $\sim 183 + 288 = 470$ cts. This is $\sim$ the dosage at which the gain drops by 10%, which is 500 cts/pore. So we see that the default 'ACIS' dither parameters may be adequate for the HRC during the acquisition process.

After acquisition, the dither amplitude will go (increase) to the commanded value. We would like to have $A = A_z = A_y = 20''$ in order to match the $40''$ calibration cell-size for the HRC. However, at this amplitude, and at the dither period above, we will violate the maximum spacecraft dither rate of $0.1''$/sec by slightly more than a factor of 2. The maximum amplitude allowed is:

$s = 0.1''/\text{sec} = 2\pi\sqrt{3/2}(A/707)''/\text{sec}$

corresponding to $A = A_z = A_y = 9.2''$. For $A = 20''$ we require $T = T_z = 1537$sec, $T_y = 2173$sec, corresponding to $W_z = 0.0041$ rad/sec, $W_y = 0.0029$ rad/sec.

Worst Case HRC Acquisition Dither:

The velocity of the dither pattern is slowest when the dither angles are at their maxima: that is, in the corners of the dither box. The 'worst case' HRC acquisition studied below is one for which this occurs. This requires that the 'dither phase' for both Y and Z is $\pi/2$, or:

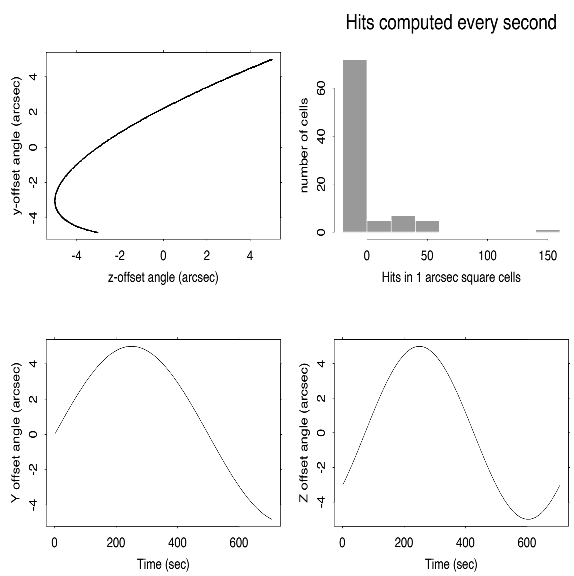
$$\pi/2 = (2\pi/1000) \times t = (2\pi/707) \times (t + x)$$

Which is true for $t = 250$sec, $x = -73.25$sec. The figure below shows this case, for time running from $0 < t < 1200$, or for 20 minutes. The maximum density spot is the upper right corner, when the dither pattern dwells for 145 seconds in a $1''$ square box. In a 0.5 square box, containing $\sim$ 4 HRC pores, the dither dwells for 101 seconds, and in a $0.25''$ square box, containing $\sim$ 1 HRC pore, the dither dwells for 71 seconds.

As previously, we will assume that the total 'dose' in a pore can be approximated by the dose from the PSF core plus the dose from the wings. If we set the maximum dose to 500 counts, then the maximum point source rate R_{max} is:

$$500 counts = R_{max} \times 71\text{sec} \times 0.2 + R_{max} \times 145\text{sec} \times 0.8$$

Solving gives $R_{max} = 3.6$ counts/sec. This could be a problem, as there may be a substantial number of sources with rates above this limit. The worst case could be avoided if it is possible to set the 'dither phase' for each HRC observation in order to avoid this case. Splus code to calculate the figure below can be found at /home/garcia/axaf/asc/mp/op19/Feb98/lis.hist5.S ($1''$ squares), lis.hist5.5.S ($0.5''$ squares), and lis.hist5.25.S ($0.25''$ squares).



Summary:

Default dither parameters for the ODB, which are to apply to both ACIS and the HRC during the acquisition phase, should be:

$A_z = A_y = 8''$, $W_y = 2\pi/1000s = 0.0063$ rad/sec, $W_z = 2\pi/707s = 0.0089$ rad/sec, $P_y = P_z = 0$.

Default parameters for the HRC, to be added onto all ORs with HRC as the SI, should be:

$A_z = A_y = 9.2''$, $W_y = 2\pi/1000s = 0.0063$ rad/sec, $W_z = 2\pi/707s = 0.0089$ rad/sec, $P_y = P_z = 0$.

We should investigate if it is desirable and possible to

1. Increase the dither period for longer ACIS observations (in order to reduce pixel smearing)

2. Increase the HRC dither period (to $T = T_z = 1537$ sec, $T_y = 2173$ sec, corresponding to $W_z = 0.0041$ rad/sec, $W_y = 0.0029$ rad/sec) and amplitude (to $20''$) after the acquisition process (in order to match the HRC flat-field scale and still not violate the maximum spacecraft dither rate).

Email on the TIME in the dither equations

Received: from head-cfa.harvard.edu (cfa259 [131.142.42.104])
by head-cfa.harvard.edu (8.9.1a/8.9.0) with ESMTP id JAA14217;
Fri, 11 Dec 1998 09:08:07 -0500 (EST)
Message-Id: <199812111408.JAA14217@head-cfa.harvard.edu>
X-Mailer: exmh version 2.0.2 2/24/98
To: Nanci.Kascak@trw.com
Cc: mgarcia, Steve.Shawger@trw.com, das, mjuda, mvz, ssm, taldcroft, wsdavis, pquast@elrond.sp.trw.com
Subject: Re: Dither modes for PCAD
Date: Fri, 11 Dec 1998 09:08:07 -0500
From: Dan Schwartz <das@head-cfa.harvard.edu>
Content-Type: text
X-UIDL: da30a4d5e31364bb058ff48b35c0b875

Since yesterday, I looked in the OBC DM05 rev G, section 3.2.3.3.5. There are phase angles Omega.P and Omega.Y which are initialized to 0., and then are incremented by the dither rate times the minor cycle interval. So it seems clear that the dither reference time is reset to zero at the "start" of each dithered pointing.

I would still be useful to confirm that I understood DM-05 correctly, and perhaps a more precise definition of exactly what time the zero reference is set (e.g., with respect to the NPM flag being set?).

Thanks,
Dan

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Received: from mailhub1.TRW.COM (mailhub1.TRW.COM [129.193.4.4])
by head-cfa.harvard.edu (8.9.1a/8.9.0) with ESMTP id SAA16019;
Mon, 21 Dec 1998 18:36:35 -0500 (EST)
Received: from imssp02.sp.trw.com by mailhub1.trw.com with ESMTP; Mon, 21 Dec 1998 15:36:03 -0800

Received: by imssp02-bak.sp.TRW.COM with Internet Mail Service (5.5.2232.9)
id <Z1Z7Y8T3>; Mon, 21 Dec 1998 15:35:52 -0800
Message-Id: <8907AA9E1A84D2119CCD0000D11BAF1C11D564@mbfp01-bak.sp.TRW.COM>
From: "Kascak, Nanci" <Nanci.Kascak@trw.com>
To: "'Dan Schwartz'" <das@head-cfa.harvard.edu>,
"Kascak, Nanci" <Nanci.Kascak@trw.com>
Cc: mgarcia@head-cfa.harvard.edu, Steve.Shawger@trw.com,
mjuda@head-cfa.harvard.edu, mvz@head-cfa.harvard.edu,
ssm@head-cfa.harvard.edu, taldcroft@head-cfa.harvard.edu,
wsdavis@head-cfa.harvard.edu, "Quast, Peter" <Peter.Quast@trw.com>
Subject: RE: Dither modes for PCAD
Date: Mon, 21 Dec 1998 15:35:52 -0800
MIME-Version: 1.0
X-Mailer: Internet Mail Service (5.5.2232.9)
Content-Type: text/plain;
charset="iso-8859-1"
X-UIDL: c5902977460f7839f2dffc9c7df2efc1
Dan,
You are right. If dither is turned off, the integrated rate term is reset
to zero, which effectively restarts time. Thus, for a tricky observation
turning dither off and on at a certain time will allow you to
deterministically predict the lissajous pattern from that time on. Keep in
mind that the phase terms play into the initial conditions (i.e., you only
start at zero dither angles if the phase is zero or 180)
Nanci
-----Original Message-----
From: Dan Schwartz [mailto:das@head-cfa.harvard.edu]
Sent: Thursday, December 10, 1998 8:09 AM
To: Nanci Kascak
Cc: mgarcia@head-cfa.harvard.edu; Steve.Shawger@trw.com;
das@head-cfa.harvard.edu; mjuda@head-cfa.harvard.edu;
mvz@head-cfa.harvard.edu; ssm@head-cfa.harvard.edu;
taldcroft@head-cfa.harvard.edu; wsdavis@head-cfa.harvard.edu; Peter
Quast
Subject: Re: Dither modes for PCAD
Hi Nanci,
I am forwarding some old e-mail from Mike Garcia which
asks about the reference for time in applying the dither.
We cannot remember or find an answer, and would appreciate
one.
Dan

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> I listened in on the Dither Telecon that John Donaghy
> set up last week...  And had one question I did not
> get to ask.
>
> When (how?)  is the 'time' used in the dither Lissajous equations
> set to zero?  We may have a problem with dither patterns that
> 'dwell' in the corners of the dither box, in that a few bright
> sources we want to look at might give to high a dose.
>
> However, if we can control the 'time' in the dither equation
> (ie, reset it to zero at the start of an obseration), then the
> dither pattern is completely predictable during the observation, and
> we can choose parameters such that the source does not
> dwell in the corner of the dither pattern.
>
> If the time was reset to zero by turning dither off, the on,
> that would probably be fine.  I would guess that linking each
> HRC OR to a preceeding pair of ERs that turn dither off/on would
> generate the neccessary commands (Bill??)
>
> Thanks - Mike
>
>
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