ACIS Fid Light Cooling

Summary

The purpose of this note is to document the implications of allowing the ACIS fid light assemblies (FLAs) to be operated at a temperatures which are limited only by the detector housing survival heaters (-73C or -75C). This is driven by a proposal to mitigate warming of the ACIS focal plane temperature by turning off the ACIS detector housing heater and the FA6 heater.

The Star Working Group has reviewed the existing test data and equipment specifications and concluded that operating the FLAs at temperatures as low as -72C poses negligible additional risk to the safety and continued nominal operations of the ACIS FLAs. **But see the Key questions below**.

If the heaters are turned off, the DH temperature variation will result in shifts of the fid light mount points that require a one-time on-orbit calibration and enhancements to the ground aspect pipeline software and calibration database elements.

Key open questions

- Joe Vogrin's memo shows measured DH temperatures of -73.1 C (prime) and -75.6 C (redundant) during thermal vac survival heater testing. The star working group needs to re-open the discussion of FLA safety in light of this information.
- During that testing, were the fid lights turned on and do we have ACA and FLCA data for them?

ACIS FLA thermal specifications

The ACIS FLA equipment spec EQ7-0339 states:

- **3.2.5.2.1.1 Interface Temperature**: The FLA shall be capable of operating over a temperature range of -65C to +35C, and shall meet all performance requirements over an on-orbit interface temperature of -60C +/- 5C.
- **3.2.5.2.1.2 Interface Temperature Variation**: During any observation of up to 48 continuous hours, the interface temperature will not vary more than +/- 4C (TBR). [*Is there an update?*]

The FLA CDA Data Package (NAS8-37710, July 1994) states an operating temperature requirement of -60C +/- 1C [sic] and a capability of -71C.

- ACIS detector housing
- ACIS detector housing zoom

FLA ground testing and qualification

Based on review of the FLA CDA Data Package (NAS8-37710, July 1994), the the qualification to -65C and capability of -71C is based on:

- Operational rating of -65C for the LED (manufactured by HP)
- Cold testing to -90C of six LEDs of the type used in the FLA (AXAF.93.333.003)
- Thermal cycling of a portion of an FLA: 14 cycles from -65C to +45C and 25 cycles from -76C to +45C (AXAF.94.333.062)

As noted in AXAF.94.333.062, the primary temperature concern is in the integrity of the soldered and potted leads, the failure of which would lead to an open circuit. In order to verify that no such open circuit occurred during thermal cycling, a photometer attached to a strip chart recorder was used to continuously monitor the light output. No indication of an open circuit was seen.

Observatory thermal vacuum testing

In addition, during AXAF thermal vacuum testing the integrated FLAs were subjected to temperatures of -73.1 C (171 hours) and -75.6 C (9.5 hours) as part of survival heater testing. Details are given in the recent memo by Joe Vogrin: Chandra ISIM TV Test Temperatures and Associated Data in Support of Decreasing ACIS Focal Plane Temepratur e. The question of whether the fid lights were powered during this phase of testing is under investigation.

Revise operating range down to -72C

The Star Working Group recommends that the allowed operating range of the ACIS FLA be extended down to -72C:

- The -65C rating on the LEDs is shown to be conservative by demonstrated operation at -90C by a representative sample of LEDs.
- An FLA showed no unexpected performance variations during repeated thermal cycling down to -76C.
- The NGST engineer who did the thermal testing (John Starkus) was consulted and he expressed no reservations about operating at -72C.
- The capability listed in the CDA package is -71C.

Actual temperatures may be -73.1 C or even -75.6 C (if primary heater fails). . The Star Working Group needs to re-examine this topic.

Possibility of new qualification testing

The possibility of doing additional qualification testing of flight spare or engineering model FLA units was investigated. According to John Starkus, there are no existing fully-assembled FLA units. Some parts might be available for assembly, but the unit would not be flight-like and the results of testing would not be especially compelling.

Operational scenario

When the DH and FA6 heater control is turned off, the detector housing temperature will vary between -73C (limited by cold survival heaters) and approximately 60 C. The maximum variation during a single orbit has not been explicitly calculated, but Neil Tice writes (Email, July 3, 2007):

> If the spacecraft attitude stays fixed and the ACIS remains in the FOV, then the temperatures will remain fairly stable. If however during the 48 hour period, the spacecraft goes from an aft sun to a forward sun attitude then the temperature could shift from -65C to -71C during that time. It probably won't occur very quickly however due to the mass of the detector housing. Even so I do not believe the shifts would be more than 5C.

It is also expected that the actual temperature of the FLAs will be within about 2 C of the reported detector housing temperature (MSID 1CBAT). This is based on telemetry quantization and ACIS DH modeling done previously for ACIS bakeout studies. These temperatures will be monitored to ensure that FLA temperatures are within the allowed operating range.

Thermal stability of fid light positions and post-facto aspect

The fid lights are mounted on a plate of aluminum 6061 which connects to the rest of the detector housing box (also Aluminum 6061 ?). To a good approximation this assembly is structurally disconnected from the ACIS detectors or other elements that would significantly affect the CTE. In this case when the DH temperature shifts the fid light mount points will expand or contract radially within the plane of the mount plate. The CTE will be that of Al6061, approximately 23 ppm / degC at -60 C.

* Fid light configuration

If left uncorrected this effect could lead to substantial errors in both image reconstruction and absolute astrometry. The worst-case scenario occurs if one fid light is unavailable for the aspect solution (e.g. in the case of a star spoiler). That can result in a mean fid light distance from the center of ~80 mm, implying an aspect solution error of (-60 - T) * 0.037 arcsec, where T is the actual DH temperature on the mount plate. The -60 value represents the temperature at which the fid positions are currently calibrated.

- An observation done entirely at -73 C would have an error in absolute astrometry of 0.5 arcsec. This is

significant in light of the current uncertainty of 0.4 arcsec (1-sigma).
- A shift of 5 C during an observation would result in a temporal drift of the apparent source position, giving an error in image reconstruction of 0.18 arcsec. For a bright on-axis point source this would be noticable in the X-ray data.

With knowledge of the FLA mount plate temperature to within 2 C and appropriate on-orbit calibration data, the ground aspect solution uncertainty will be less than 0.07 arcsec worst case. This is acceptable.

On-orbit calibration

In the absence of detailed thermo-mechanical modeling of the system, it will be necessary to perform on-orbit calibration to determine the dependence of the fid light positions on DH temperature. Details are TBD, but in general the calibration would require:

- A change in DH temperature of at least 3 bits (7.5 C), and preferably 10 C during a contiguous observation.
- Configuration that allows determination of time-dependent errors in dy, dz, dtheta in an interval of time corresponding to one bit change in temperature:
    - At least 2 bright (but not heavily piled) point sources within 4' of on-axis, with a separation suitable for measuring any axial distortion.
    - **Or** A grating observation with a not-heavily-piled zero-order source and grating arms sufficiently bright to fit a line
- At least 200 counts in a point source and 500 counts [TBR] in a grating arm, within each interval.
- Star field:
    - Good ACA guide stars
    - Not too dense so that all three ACIS fid lights are well-separated from spoiler stars.
- PI consent for delayed data distribution [?]:
    - The default aspect solution is expected to be degraded, although a choice of fids such as 3,4,5 is expected to reduce the error by a factor of 4 or more from the worst case estimate above. That means an **error of < 0.1 arcsec for a 10 degC change**. However, the lack of a good thermo-mechanical model of the DH and detector necessarily imply some uncertainty in that estimate.
    - For the first such calibration there could be a data distribution delay of up to a week to determine and apply the optimal aspect solution.
    - If we are well-prepared beforehand with software and DSops can easily apply the new aspect solution in SAP, then the delay could be only a day or two.
- A previously observed and non-variable source is preferred to minimize surprises in the data analysis.
- Grating and imaging observations both require high-quality aspect so there is no obvious preference for one or the other. It might be possible to identify specific observations that would be less impacted by degraded aspect, however the goal in any case is to use 'self-calibration' with the X-ray data to recover the best aspect solution.
- The LTS in Aug and Sep 2007 shows one candidate observation, obsid 7445 (Eta Car, HETG, 100 ksec at 62 deg sun pitch)

Existing ground data

Extensive room temperature ground test data with observations of the fid lights in the integrated spacecraft. This potentially gives the opportunity to directly measure the temperature dependence of the fid light positions, comparing room temperature data to the on-orbit -60 C data. However, examination of a summary plot of effective HRMA focal lengths (essentially the scale factor) based on fid light data shows variations by a factor of 20 in 10000, presumably due to variations in temperature. This uncertainty is large compared to the effect of interest, so these data are not likely to prove useful.

As mentioned, during AXAF thermal vacuum testing the integrated FLAs were subjected to temperatures of -73.1 C (171 hours) and -75.6 C (9.5 hours) as part of survival heater testing. Assuming the fid lights were being observed during these tests one might derive data concerning the effect CTE of the FLA mount plate as the temperature dropped. Initial examination of available data tapes (from Rob Cameron's collection) did not turn up appropriate telemetry data. In any case the data will not be adequate for the required calibration, and there may be other unexpected differences from the present operational situation.

Aspect pipeline software changes

The ground aspect pipeline software and calibration database will need enhancements to support correction of the fid light positions based on the ACIS DH temperature (1CBAT and 1CBBT):

- Add new column data to the CALDB CALALIGN1 data block (in the pcad*align*.fits files):
  - FID_Y_TEMP_CORR: Position correction in Y (mm/degC) based on delta temperature from specified reference temperature
  - FID_Z_TEMP_CORR: Position correction in Z (mm/degC)
- Add new header keyword to the CALDB CALALIGN1 data block: FIDREF_T (fid position reference temperature)
- New code to retreive the ACIS DH temperature from ACIS L0 engineering files and store the values in a temporary (non-archived) aspect pipeline product.
- Perform a linear fit (or quadratic, TDB) on the temperature data and store coefficients as header keywords in the ACACAL data product.
- For HRC fid lights the temperature correction coefficients will be 0.0, but otherwise there need not be a distinction in processing for HRC and ACIS.
- Based on the interpolated ACIS DH temperature (from the linear fit) as a function of time, correct the fid light positions before the fitting step.

Fid light brightness

At colder temperatures the fid light LEDs emit more light at a given drive current. Based on the testing in AXAF.93.333.003 one expects an increase in brightness by 22% (or 0.22 mags). If no change is made to the default ACIS fid drive current then the fids will have a measured brightness of 6.7 to 6.8 mags, which is acceptable.

Failure scenario

The primary temperature concern is in the integrity of the soldered and potted leads. The failure mechanism would be an open circuit in which the LED would fail to provide output light.

In the unlikely event of a failure, it can be expected that a single fid light would fail first. In this event it would be possible to immediately return to a -60C operating temperature while evaluating the data and re-assessing the operational strategy.

No formal evaluation has been done on the impact to mission plannning of having only 5 ACIS fid lights. Given that HRC uses only 4 fids for each detector, there should be no difficulty in planning with ACIS using 5 fids.

TomAldcroft - 27 Jun 2007.
