XIS Technical Description

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Chapter 5

X-Ray Imaging Spectrometer (XIS)

5.1 Preface

5.1.1 Purpose

This is an independently compiled version of the XIS chapter of the Suzaku Technical Description\(^1\) issued by the Guest Observer Facility at NASA GSFC. The Suzaku Technical Description is updated only annually at the release of the announcement of the opportunity (AO) in early September. The document can therefore be obsolete soon as the XIS performance and calibration change rapidly. We thus provide here updated version so that the instrument team can communicate with the users in a more timely fashion. The latest version is available at http://www.astro.isas.jaxa.jp/~tsujimot/td_xis.pdf.

This document is updated continuously and describes the present status of the instrument. You may need to reprocess your data to exploit the latest calibration results. Users who need the information in the past need to refer to the past editions of the Suzaku Technical Description.

5.1.2 Scope & Target Audience

This document is targeted for users of the XIS in a broad sense. Sections recommended to read are listed below in some typical use cases.

1. For novice users who want to know the basics of the XIS, read the overview section (§ 5.3).
2. For users planning to submit observation proposals using XIS, read the observation planning section (§ 5.4) and the performance & calibration section (§ 5.5). The difference from the previous AO can be found in the call for proposal document.
3. For users analyzing XIS data, read the performance & calibration section (§ 5.5) and the onboard processing section (§ ??).
4. For those who are involved in the operation of the XIS, read the operation section (§ 5.6).

For other major use cases, read relevant sources of information, some of which can be found in the references (§ 5.7).

\(^1\)http://heasarc.nasa.gov/docs/suzaku/prop_tools/suzaku_td/
5.2 Overview

5.2.1 Basics

The X-ray Imaging Spectrometer (XIS; Koyama et al. 2007) celebrated its first light on August 11, 2006 about a month after the launch of Suzaku. The instrument has been operated successfully since then, producing a lot of scientific results. The entire instrument has a weight of 48.7 kg and consumes 67 W at a bus voltage of 50 V in normal operation.

![Image](https://example.com/image.png)

**Figure 5.1:** A photo of one of the four XIS sensors before installation to the satellite.

The XIS is composed of four units of the X-ray charge coupled device (CCD) cameras (Fig. 5.1). Si-based CCD devices are employed for X-ray sensors, in which incident X-ray photons are converted into a number of charges via photoelectric absorption and subsequent ionization by photoelectrons and their secondaries. The incident energy is measured as the amount of resultant number of charges, which is proportional to the energy. Each XIS unit is placed at the focal plane of four independent, identical, and co-aligned X-Ray Telescope (XRT; Serlemitsos et al. 2007) modules, which are called the XRT-I0, XRT-I1, XRT-I2, and XRT-I3. The XIS is operated in the photon-counting mode, in which each X-ray events are discriminated from others and are reconstructed to derive its position, energy, and arrival time. This gives the XIS an imaging-spectroscopic capability in the 0.2–12.0 keV band over an 18′×18′ region.

**Similar instruments** The XIS is similar to its predecessor, the Solid-state Imaging Spectrometer (SIS) onboard the ASCA satellite, in its working principle. Many improvements were made based on successful use of the SIS over eight years. It is also similar to its brothers: *Chandra* ACIS (Garmire et al., 2003), *XMM-Newton* EPIC (Turner et al., 2001; Strüder et al., 2001), and *Swift* XRT (Burrows et al., 2004) in its principle.

X-ray CCD instruments, including the XIS, are characterized by its flexibility in operation and rapid changes in the performance in the orbit. In particular, micro-meteorite hits leave unrecoverable damage to a part of the instrument. The entire imaging area of the XIS2 was lost in November
2005 and a part of the XIS0 in June, 2009.

**Merits** The XIS has several advantages over other instruments.

- The XIS is suited to investigate extended emission of low surface brightness for the following reasons.
  - It has a low and stable background environment by a combination of the low Earth orbit of the satellite and the instrument design.
  - It has a large effective area, which is comparable to the EPIC at the Fe K band.
  - The energy resolution and gain is well calibrated over the entire chip.

- The XIS is more tolerant for pile-up in observing bright sources than others for the following reasons.
  - The PSF for XIS is much larger than those in ACIS and EPIC while the plate scale is comparable. This means a heavy oversampling of a PSF.
  - It has a wide range of clocking modes provided as user options.

- Together with the HXD, simultaneous wide-band spectral coverage can be obtained.

**Responsible parties** The XIS was developed and has been maintained jointly by Japan and the United States, with participating organizations including the MIT, ISAS, Kyoto University, Osaka University, Rikkyo University, Ehime University, Miyazaki University, Kogakuin University, Nagoya University, Aoyama Gakuin University, and major participating contractors including the Mitsubishi Heavy Industries (MHI), the NEC-Toshiba Space Systems, and the System Engineering Consultation (SEC) Co. Ltd.

### 5.2.2 Components

#### 5.2.2.1 Sensors

**Format** Each CCD camera has a single CCD chip, which consists of the imaging area and the frame stored area. The imaging area is exposed to the sky for observations, while the frame stored area is shielded. Each chip is composed of four segments called segment A, B, C, and D. Each segment has its own readout node (Fig. 5.3).

The imaging area has a pixel size of 1024\(\times\)1024 pixels. The pixel scale is 24\(\mu\)m pixel\(^{-1}\) and the physical size is 25 mm in square. The plate scale is 1.04” pixel\(^{-1}\) and the total sky coverage is 18’ in square.

**Illumination** The XIS1 is back-side illuminated (BI) chip. The other three sensors (XIS0, 2, and 3) are front-side illuminated (FI) chips. The BI and FI chips are superior to each other in the soft and hard band responses, respectively.

**Optical blocking filter (OBF)** X-ray CCDs are sensitive also to optical and UV photons. To suppress these signals, the optical blocking filter (OBF) is installed on the surface of the CCD. The OBF is made of polyimide with a thickness of 1000 Å, which is coated with a total of 1200 Å of Al (400 Å on one side and 800 Å on the other).
Calibration sources For in-flight calibration, three $^{55}$Fe calibration sources with a half life of 2.73 years are installed in each unit. The $^{55}$Fe sources emit strong Mn Kα and Kβ lines at 5.9 keV and 6.5 keV, respectively.

Two sources illuminate two corners of the segments A and D of the imaging area at the far side of the readout node. The other one is installed in the door. It was used to illuminate the entire chip before opening the door for the final check before launch and the initial check after launch. Because the door was opened for observations, the door calibration source is not used any longer. Scattered X-rays from the door calibration sources may appear in the entire imaging area.

5.2.2.2 Cooling System

To reduce the dark current, the sensors is kept at $\sim -90^\circ$C all the time. Thermo-electric coolers (TECs) using the Peltier effect are used for cooling, which are controlled by the TEC Control Electronics (TCE).

5.2.2.3 Electronics

**Analogue electronics** The analog electronics (AE) system drives the CCD by providing driving clocks for exposure and charge transfer, sampling the voltage, amplifying the data, and converting to the digital values.

The XIS has two identical units of the AE and TCE, which are stored in the same housing for each unit. One unit (AE/TCE01) is used for XIS0 and XIS1, while the other (AE/TCE23) is used for XIS2 and XIS3.

**Digital electronics** The digital electronics (DE) system processes the digitized data. The DE has two pixel processing units (PPU01 and PPU23) and a main processing unit (MPU). The digital data from the AE are stored in the Pixel RAM in the PPUs; PPU01 for data taken with AE/TEC01 and PPU23 for AE/TEC23.
The PPUs access the raw CCD data in the Pixel RAM, carry out event detection, and send event data to the MPU. The MPU edits the telemetry packets and sends them to the satellite's main digital processor.

5.2.3 CCD Pixels & Coordinates

**RAW XY coordinate**  Pixel data collected in each segment are read out from the corresponding readout node and sent to the Pixel RAM. In the Pixel RAM, pixels are given RAW X and RAW Y coordinates for each segment in the order of the readout, such that RAW X values are from 0 to 255 and RAW Y values are from 0 to 1023. These pixels in the Pixel RAM are named *active pixels*.

In the same segment, pixels closer to the read-out node are read-out earlier and stored in the

---

**Figure 5.3:** Schematic view of the data flow in one XIS unit.
Pixel RAM earlier. Hence, the order of the pixel read-out is the same for segments A and C, and for segments B and D, but different between these two segment pairs, because of the different locations of the readout nodes. In Fig. 5.3, numbers 1, 2, 3 and 4 marked on each segment and the Pixel RAM indicate the order of the pixel read-out and the storage in the Pixel RAM.

In addition to the active pixels, the Pixel RAM stores the copied pixels, dummy pixels and H-over-clocked pixels (Fig. 5.3). At the borders between two segments, two columns of pixels are copied from each segment to the other. Thus these are named copied pixels. Two columns of empty dummy pixels are attached to the segments A and D. In addition, 16 columns of H-over-clocked pixels are attached to each segment.

**ACT XY coordinate** Actual pixel locations on the chip are calculated from the RAW XY coordinates and the segment ID during ground processing. The coordinates describing the actual pixel location on the chip are named ACT X and ACT Y coordinates (Fig. 5.3). It is important to note that the RAW XY to ACT XY conversion depends on the on-board data processing mode.

### 5.2.4 Major Events

The detector performance changes both continuously and discontinuously in the orbit. This is especially the case for CCD instruments. Users need to seek for the latest information to make the best use of the instrument. Some major changes and their causes are:

- Continuous degradation of gain and energy resolution by increasing charge transfer inefficiency due to radiation damages.
- Continuous degradation of low-energy gain due to accumulating contaminating material on the optical blocking filter.
- Discontinuous changes in the non X-ray background due to solar flares.
- Discontinuous changes in the gain and energy resolution by the installation of the charge injection operation and the change in its setting.
- Discontinuous loss of a part of the detector performance due to micro-meteorite hits.
- Discontinuous changes in the detector performance due to policy changes in the operation to keep up with the changes above and others.

Table 5.1 shows the major events in the chronological order since the start of the mission. The XIS log at [http://www.astro.isas.jaxa.jp/suzaku/log/xis/](http://www.astro.isas.jaxa.jp/suzaku/log/xis/) gives a complete list of events relevant for data reduction.
Table 5.1: Operation history

<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005-08-11</td>
<td>All</td>
<td>First light with 1E0102.2–7219</td>
</tr>
<tr>
<td>2006-01-18</td>
<td>All</td>
<td>Onboard software update to remove grade 7 events onboard.</td>
</tr>
<tr>
<td>2006-02-17</td>
<td>XIS023</td>
<td>Event threshold was changed to 100.</td>
</tr>
<tr>
<td>2006-10</td>
<td>All</td>
<td>SCI operation started.</td>
</tr>
<tr>
<td>2006-11-09</td>
<td>XIS2</td>
<td>A micro-meteorite hit. The entire imaging area became dysfunctional.</td>
</tr>
<tr>
<td>2008-01-30</td>
<td>All</td>
<td>MPU0 is lost and replaced with MPU2.</td>
</tr>
<tr>
<td>2009-04-01</td>
<td>All</td>
<td>P-sum clocking mode officially supported.</td>
</tr>
<tr>
<td>2009-11-02</td>
<td>All</td>
<td>MPU1 reset after a ROM update.</td>
</tr>
<tr>
<td>2009-12-18</td>
<td>XIS1</td>
<td>A micro-meteorite hit. No major impact in scientific capability.</td>
</tr>
<tr>
<td>2009-04-01</td>
<td>All</td>
<td>SCI operation support terminated.</td>
</tr>
<tr>
<td>2010-04-01</td>
<td>All</td>
<td>Edit mode selection automated.</td>
</tr>
<tr>
<td>2011-03-09</td>
<td>All</td>
<td>XIS halted due to non-maskable interruption and was restarted.</td>
</tr>
<tr>
<td>2011-06-01</td>
<td>XIS1</td>
<td>Injection charge increased to 6 keV for Normal (no option).</td>
</tr>
<tr>
<td>2011-08-22</td>
<td>XIS1</td>
<td>Injection charge increased to 6 keV for Normal (1/4 win).</td>
</tr>
<tr>
<td>2011-09-01</td>
<td>XIS1</td>
<td>Injection charge increased to 6 keV for Normal (0.1s burst).</td>
</tr>
<tr>
<td>2011-09-29</td>
<td>All</td>
<td>The default PPU ratio changed to the optimum for each editing mode combination.</td>
</tr>
<tr>
<td>2011-10-06</td>
<td>XIS1</td>
<td>Injection charge increased to 6 keV for Normal (1/4 win+1.0s burst, 1/8 win).</td>
</tr>
<tr>
<td>2011-10-11</td>
<td>XIS1</td>
<td>Injection charge increased to 6 keV for Normal (1/4 win+0.1s, 0.3s, &amp; 0.5s burst).</td>
</tr>
<tr>
<td>2011-10-25</td>
<td>XIS1</td>
<td>Injection charge increased to 6 keV for Normal (0.5s, &amp; 0.62s burst).</td>
</tr>
<tr>
<td>2012-01-26</td>
<td>All</td>
<td>Support for XIS1 2.0s burst with CI=6 keV terminated.</td>
</tr>
<tr>
<td>2012-04-01</td>
<td>All</td>
<td>XIS restarted after the satellite UVC. TEC2 power terminated to save power.</td>
</tr>
<tr>
<td>2012-07-11</td>
<td>All</td>
<td>Choice of using the HXD nominal position was removed.</td>
</tr>
<tr>
<td>2012-07-14</td>
<td>XIS2</td>
<td>TEC2 for the XIS2 was terminated permanently for saving power.</td>
</tr>
</tbody>
</table>
5.3 Observation Planning

5.3.1 User Options

Available options  The XIS has numerous instrumental settings, which are fine-tuned to serve for a wide range of observational purposes. A few of them are left as user options. Different options can be used for different sensors.

1. Clocking mode
2. Editing mode
3. PPU ratio
4. Lower event threshold
5. Area discrimination

In many use cases, the default setting works. In most cases, the appropriate choice of the clocking mode is enough; there is little need to change the other options.

The choice of the XIS or HXD nominal position is no longer available; all observations are made at the XIS nominal position (the center of the XIS field of view) unless otherwise requested.

Observations requiring non-default setting  Users need to consider an appropriate choice of the clocking mode when they are planning observations of bright (>10 s\(^{-1}\) or \(\sim10\) mCrab in 0.5–10 keV) sources or those requiring a higher timing resolution than 8 s.

Declaration of the use of non-default setting  Use of non-default options should be stated clearly in the technical justification of the proposal document. The choice of the clocking mode needs to be filled in in the cover page. These choices can be tentative.

For successful proposals, an inquiry is sent about three weeks prior to the observation. The choice of user options can be revised at this time.

Last-minute changes  The behavior of very bright sources is often unpredictable. The XIS operation team waits for the choice of options until the last minute if necessary. The deadline is 10:00 JST (1:00 in UT) every weekday and Saturday, at which the operation team starts generating the command sequence. Users need to submit the final choice of options by the deadline 1–3 days before the start of their observation. Prior consultation with the XIS operation team is necessary for their availability and the exact deadline.

Consultation  The appropriate choice of options is the responsibility of users. Users should refer to the XIS quick reference at http://www.astro.isas.jaxa.jp/~tsujimot/pg_xis.pdf and consult the XIS operation team at xisope@astro.iasa.jaxa.jp for advice if necessary. The team will make the best use of the operational flexibility to maximize the scientific output of the observations.

5.3.1.1 Clocking Mode

The clocking mode specifies how the CCD pixels are read out. Each clocking mode has its own \(\mu\)-code, a pattern of voltage clocking for exposure and charge transfer. It enables full read, partial read, or stacked read (Table 5.2). With a partial or stacked read, a higher pile-up limit and timing resolution can be achieved at a sacrifice of observing efficiency and imaging information.
There are two major types for the clocking modes: the Normal mode and the P-sum mode. The Normal mode is for timed-exposure readout. It can be combined with a window option (partial read in space), burst option (partial read in time), or both (partial read both in space and time). Fig. 5.4 shows the time sequence of exposure, frame-store transfer, readout, and storage to the Pixel RAM (in PPU) for the Normal clocking mode.

The P-sum mode is for the stacked readout. The P-sum clocking mode is available for the FI sensors. However, because it is severely affected by leaked charges in the area damaged by micrometeroid hits, the P-sum clocking support was terminated for the XIS2 and XIS0. Therefore, it is currently available only for the XIS3. Observers using the P-sum clocking mode for the XIS3 need to use a Normal clocking mode for the other sensors.

Normal clocking mode

1. No option: full readout of the entire pixels with a frame time of 8 s.
2. Window option: partial readout in space. In the $1/w$ window mode, the central $1024/w$ pixels are read out in the Y direction and the entire pixels are read out in the X direction, yielding a $1024\times1024/w$ pixel image. The exposure time is $8/w$ s.
3. Burst option: partial readout in time. In the $b$ s burst mode, all pixels are read out, but the effective exposure time is limited to $b$ s ($b < 8$ s). During a 8 s exposure time, events detected in the first $(8 - b)$ s are transferred and discarded without being recorded. Events detected in the remaining $b$ s are transferred and recorded.
4. Window+b burst option: partial readout both in time and space. In $1/w$ and $b$ s burst mode, the central $1024\times1024/w$ pixel image is read out at an exposure time of $8/w$ s. During the exposure time, events in the first $(8/w - b)$ s are discarded and those in the last $b$ s are recorded. The inequity of $8/w > b$ always holds.

The available window and burst options are summarized in Table 5.3.

Some advice in selecting options

- The observing efficiency is always smaller than 1 for window, burst, or both options for their partial read nature. The efficiency can be very small.
- In the window mode, a part of the events falls outside of the window. With a half-power diameter of $2'$ and the telescope wobbling of $\sim0.5'$, this is not negligible especially for $w = 8$
Figure 5.4: Time sequence of the exposure, transfer, and readout. For the window option, 1/4 window is assumed.

with 2.2' for the window height and for the XIS1 with the wobbling direction perpendicular to the window. The telescope wobbling is synchronous to the rotation period of the satellite of $\sim 96$ min, which gives an artificial fluctuation in the count rate with this frequency.

- The window mode does not include the $^{55}$Fe calibration sources at the top corners, so self-calibration of gain and energy resolution using the calibration sources cannot be used.
- The observing efficiency is always larger for the $1/w$ and $b$ burst mode over the $b$ burst mode.
- In short burst modes, out-of-time events are non-negligible.
- It is always helpful to retrieve archive data taken in the same clocking mode that you plan to use to find its features. The Suzaku XIS log at http://darts.isas.jaxa.jp/astro/suzaku/suzakuxislog/top.do serves for this purpose.

P-sum clocking mode The pulse height from 128 rows are stacked into a single row along the Y direction. Charges are transferred continuously, thus the spatial information along the Y direction is lost and replaced with the arrival time information. The arrival time is ticked at a 7.8 ms resolution.
Table 5.3: Window and burst options (XIS nominal position)

<table>
<thead>
<tr>
<th>Option</th>
<th>none</th>
<th>win</th>
<th>burst</th>
<th>win+burst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window</td>
<td>1/1</td>
<td>1/4</td>
<td>1/8</td>
<td>1/1  1/1 1/1 1/1</td>
</tr>
<tr>
<td>Burst (s)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.0</td>
<td>8.0</td>
<td>8.0</td>
<td>2.0 0.62 0.5 0.1</td>
</tr>
<tr>
<td>XIS0</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x   x   x   x   x</td>
</tr>
<tr>
<td>XIS1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x   x   x   x   x</td>
</tr>
<tr>
<td>XIS3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x   x   x   x   x</td>
</tr>
<tr>
<td>Pile-up limit (s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>12</td>
<td>48</td>
<td>96</td>
<td>48 155 192 960</td>
</tr>
<tr>
<td>Obs efficiency&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>0.25</td>
<td>0.08 0.06 0.01</td>
</tr>
</tbody>
</table>

<sup>a</sup> The approximate burst time. The exact time may be different; e.g., 0.297 s for 0.3 s burst due to restrictions in the design of the clock pattern.

<sup>b</sup> The observing efficiency. This does not include the loss of events outside of the window in the window and window+burst options. This does not include the loss of effective exposure time by charge transfer of 156 ms.

This is smeared by the point spread function with a HPD of 2', which is equivalent to 0.9 s.

### 5.3.1.2 Editing Modes

The editing mode specifies the telemetry format of events. The XIS has several editing modes (Table 5.4). Four of them are for observational purposes, and the remainders are for diagnostic purposes.

Table 5.4: Editing modes and size per event for observation modes

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Clocking mode</th>
<th>Editing mode</th>
<th>Event size (byte)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>Normal</td>
<td>5×5</td>
<td>28 52 40</td>
</tr>
<tr>
<td></td>
<td>3×3</td>
<td>15 23 19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2×2</td>
<td>8 11 9</td>
<td></td>
</tr>
<tr>
<td>P-sum</td>
<td>timing</td>
<td>4 4 4</td>
<td></td>
</tr>
<tr>
<td>Diagnostics</td>
<td>Normal/P-sum frame</td>
<td>4 4 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dark frame</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Data are compressed onboard. The compression rate varies depending on the grade.

**Editing modes for observations** For Normal clocking modes, three editing modes (5×5, 3×3, and 2×2) are available. The 2×2 mode is used only for the FI sensors. For P-sum clocking mode, the editing mode is fixed to the timing mode. Each editing mode has a different telemetry format, which includes the x and y position and the pulse height (PH) of the event (Fig. 5.5). Different editing mode has different sizes per event (Table 5.4).

1. 5×5 mode: The PH values of each 5×5=25 pixel around the event center are sent to the telemetry.
2. 3×3 mode: The PH values of each 3×3=9 pixel around the event center and the 1-bit information (whether the PH is larger than the outer split threshold or not) for the surrounding 16 pixels are sent to the telemetry.

3. 2×2 mode: The PH values of each 2×2=4 pixel around the event center and the 1-bit information (whether the PH is larger than the outer split threshold or not) for the attached 8 pixels are sent to the telemetry. The 2×2 pixels are selected so that it includes the pixels with the highest, the second highest, the third highest, (and the fourth highest) PH values.

4. Timing mode: The summed PH value of the 1×3 pixels around the event center and the event grade are sent to the telemetry. The PH is summed if the neighboring pixels have a PH value above the inner split threshold.

Although the amount of information for event reconstruction is different among the 5×5, 3×3, and 2×2 modes, no significant difference has been found so far between the former two modes. Only a small difference is seen for the 2×2 mode for its lack of ability to perform trail correction (§ 5.4.2.4).

The 2×2 mode and the timing mode are not available for the XIS1 because the trailing correction does not work properly for the former mode and the amount of flickering pixel is larger than the other sensors for the latter mode.

**Editing mode combinations** Technically speaking, the editing mode can be selected arbitrary for the four sensors. However, for an operational reliability reason, the combination of the editing modes is restricted to those listed in Table 5.5.

**Editing modes for diagnoses** The diagnostic modes are only for diagnostic purposes and not open for general users. The XIS is operated in these modes outside of observing times.

1. Frame mode: The pulse height data of all pixels are dumped.
2. Dark frame mode: The dark level of all pixels are dumped. The dark frame is taken once every day during an SAA passage.
5.3.1.3 PPU Ratio

The PPU ratio controls the relative fractional telemetry allocation for the four sensors. The ratio is fixed to be the optimum value assuming the use of the Normal clocking mode with the same options for all the sensors (5x5, 3x3, and f2x2,b3x3 combination) or the use of the P-sum clocking mode for XIS3 and the Normal clocking mode with the 1/4win + 0.5s burst option for XIS0 and 1 (s3tim,s015x5, s3tim,s013x3, and s3tim,s02x2,s13x3 combination).

<table>
<thead>
<tr>
<th>Mode</th>
<th>5x5</th>
<th>3x3</th>
<th>f2x2,b3x3</th>
<th>s3tim,s015x5</th>
<th>s3tim,s013x3</th>
<th>s3tim,s02x2,s13x3</th>
</tr>
</thead>
<tbody>
<tr>
<td>XIS0</td>
<td>5x5</td>
<td>3x3</td>
<td>2x2</td>
<td>5x5</td>
<td>3x3</td>
<td>2x2</td>
</tr>
<tr>
<td>XIS1</td>
<td>5x5</td>
<td>3x3</td>
<td>3x3</td>
<td>5x5</td>
<td>3x3</td>
<td>3x3</td>
</tr>
<tr>
<td>XIS2</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>XIS3</td>
<td>5x5</td>
<td>3x3</td>
<td>2x2</td>
<td>timing</td>
<td>timing</td>
<td>timing</td>
</tr>
</tbody>
</table>

* The PPU ratio controls the relative fractional telemetry allocation for the four sensors. The fraction is an integer from 0 to 3. The hexagonal representation is with 8 bits = 2 bits × 4 sensors in the order of XIS0, 1, 2, 3 from the LSB, wherein the 2 bits are used for the PPU ratio value.

5.3.1.4 Lower Event Threshold

The lower event threshold sets the threshold in the PH to be recognized as an event. It practically controls the lowest bandpass of the detector. The default event threshold is shown in Table 5.6. For some XIS calibration observations, the event threshold of the FI is set to 50.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Event threshold (ADU)</th>
<th>Event threshold (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>100</td>
<td>0.365</td>
</tr>
<tr>
<td>BI</td>
<td>20</td>
<td>0.073</td>
</tr>
</tbody>
</table>

5.3.1.5 Area Discrimination

A part of the image can be masked with an area discriminator. Either inside or outside of a single rectangular region can be applied as a mask separately for each sensor. This is useful to suppress telemetry of unwanted bright sources within the field of view of the target source.

Currently, an area discrimination mask is applied permanently to the XIS0 to suppress leaked charges from the area damaged by a micrometeorite hit.
5.3.2 Difficulties in Observations and Mitigation

5.3.2.1 Photon Pile-up

Effects  Photon pile-up is caused when multiple photons arrive at a detection cell within a frame time. If two photons with an energy of $E_1$ and $E_2$ arrive, it is wrongly recognized as a single photon with an energy of $E_1 + E_2$. This causes wrong underestimation of count rate, spectral hardening, PSF distortion, grade migration, and various other effects. The photon pile-up is a concern in observing point-like sources brighter than $\sim 10$ mCrab.

The degree of pile-up effect is measured by the pile-up fraction. Assume the mean count rate of photons landing in a pixel is $\lambda \text{s}^{-1} \text{pixel}^{-1}$. Then, the mean number of counts ($\bar{n}$) in a detection cell ($A_{\text{cell}}$) in a frame time ($t_{\text{frame}}$) is

$$\bar{n} = \lambda A_{\text{cell}} \Delta t_{\text{frame}}. \quad (5.1)$$

The number ($n$) fluctuates around $\bar{n}$ following the Poisson statistics. The probability to have $n = k$ photons in a detection cell in a frame time is

$$P(n = k; \bar{n}) = \frac{\bar{n}^k e^{-\bar{n}}}{k!}. \quad (5.2)$$

The pile-up fraction (PF) is defined as the fraction of pile-up events among all incoming events as

$$\text{PF} (\bar{n}) = \frac{\sum_{k=2}^\infty P(n = k; \bar{n})}{\sum_{k=1}^\infty P(n = k; \bar{n})} = 1 - \frac{1 - \sum_{k=0}^{1} P(n = k; \bar{n})}{1 - \sum_{k=0}^{0} P(n = k; \bar{n})} = 1 - \frac{\bar{n}}{e^{\bar{n}} - 1}. \quad (5.3)$$

Obviously, $\text{PF}(\bar{n}) \to 0$ as $\bar{n} \to 0$ and $\text{PF}(\bar{n}) \to 1$ as $\bar{n} \to \infty$.

$\lambda$ is a function of the position in the PSF $f_{\text{PSF}}(x, y)$ as

$$\lambda(x, y) = N_{\text{total}} f_{\text{PSF}}(x, y) \Delta x \Delta y \quad (5.4)$$

where $N_{\text{total}} \text{s}^{-1}$ is the total count rate of a source and $\Delta x \Delta y$ is the area of a pixel. $\lambda(x, y)$ is the largest at the center $\lambda(x = 0, y = 0)$ and becomes smaller as the distance from the PSF center ($r = \sqrt{x^2 + y^2}$) increases in the outskirts.

Limits  The pile-up limit is defined as the total count rate ($N_{\text{pileup}} \text{s}^{-1}$) at which the PF($\bar{n}$) at the PSF center exceeds 3%. In the XIS, this is roughly 12 $\text{s}^{-1}$, or 10 mCrab. The limit should be recognized as an approximate value as the exact value depends on the spectral shape of the object. The tolerance also depends on scientific goals. For example, if the detection of a weak hard tail is the goal, the pile-up effect should be minimized. If the detection of a line is the goal, some degree of pile-up can be tolerated.

Mitigation  There are two major strategies to mitigate the effect of pile-up. The two can be used in combination.

The one is to raise the pile-up limit by using an option in the Normal clocking mode. The pile-up limit for various options is summarized in Table 5.3 and shown in Fig. 5.6.

The other is to only use events in the outskirt of the PSF, at which the incoming rate per pixel is substantially smaller than at the center. This is called the annulus extraction method and is discussed in detail in Yamada et al. (2011). The tools are available at http://www-utheal.phys.s.

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Figure 5.6: Incident versus observed count rates of a point-like source. The ratio of the two gives the observing efficiency. The thick lines indicate the range below the pile-up limit. The telemetry saturation is applicable only to Normal clocking modes.

Note that the attitude fluctuation of the satellite does not mitigate the photon pile-up as the typical time is much longer than the frame time of 8 s.

5.3.2.2 Telemetry Saturation

Effects The XIS has a quota in the size of telemetry per unit time. The quota depends on the data rates (DR; SH=super high, HI=high, MED=medium, and LOW=low) and whether the observation is conducted on weekends or weekdays (Table 5.8). The satellite is also operated with a weekend allocation for a few days at the end and the beginning of an year.
Table 5.7: Total count rate ($s^{-1}$) to cause the indicated pile-up fraction as a function of PSF radius.

<table>
<thead>
<tr>
<th>Radius (pixel)</th>
<th>3%</th>
<th>20%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>~5</td>
<td>13.4</td>
<td>30.0</td>
<td>45.9</td>
</tr>
<tr>
<td>5~10</td>
<td>17.6</td>
<td>43.3</td>
<td>67.7</td>
</tr>
<tr>
<td>10~15</td>
<td>25.6</td>
<td>64.3</td>
<td>101</td>
</tr>
<tr>
<td>15~20</td>
<td>33.8</td>
<td>85.4</td>
<td>134</td>
</tr>
<tr>
<td>20~25</td>
<td>42.6</td>
<td>108</td>
<td>171</td>
</tr>
<tr>
<td>25~30</td>
<td>55.8</td>
<td>142</td>
<td>224</td>
</tr>
<tr>
<td>30~35</td>
<td>70.6</td>
<td>180</td>
<td>285</td>
</tr>
<tr>
<td>35~40</td>
<td>88.2</td>
<td>226</td>
<td>356</td>
</tr>
<tr>
<td>40~45</td>
<td>100</td>
<td>256</td>
<td>404</td>
</tr>
<tr>
<td>45~50</td>
<td>119</td>
<td>304</td>
<td>480</td>
</tr>
<tr>
<td>50~55</td>
<td>141</td>
<td>362</td>
<td>571</td>
</tr>
</tbody>
</table>

The operation team is responsible for deciding the data rates depending on the observing conditions. The schedule is made to avoid bright sources to be observed in weekends, in which the telemetry allocation is small. The excess use of the quota is judged at every 8 s during observations.

Table 5.8: Telemetry allocation for XIS

<table>
<thead>
<tr>
<th>DR</th>
<th>Condition</th>
<th>Date</th>
<th>Rate (kbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH</td>
<td>During contact</td>
<td></td>
<td>144</td>
</tr>
<tr>
<td>HI</td>
<td>Contact passes</td>
<td></td>
<td>144</td>
</tr>
<tr>
<td>MED</td>
<td>Remote passes</td>
<td>weekday</td>
<td>60</td>
</tr>
<tr>
<td>MED</td>
<td>Remote passes</td>
<td>weekend</td>
<td>25</td>
</tr>
<tr>
<td>LOW</td>
<td>Bad conditions$^a$</td>
<td>weekday</td>
<td>15</td>
</tr>
<tr>
<td>LOW</td>
<td>Bad conditions$^a$</td>
<td>weekend</td>
<td>1</td>
</tr>
</tbody>
</table>

$^a$ Bad conditions include SAA passages, low geomagnetic cut-off rigidity, etc.

Beyond the limit, a part of the telemetry is lost. Events in the segments B and C are prioritized than those in the segments A and D.

The telemetry saturation occurs only when observing bright sources. Fortunately, in the XIS, the telemetry saturation is always avoided when users select an appropriate clocking mode to avoid pile-up. In practice, following users need to consider the possibility of telemetry saturation seriously.

- Users planning a very bright extended source.
- Users planning a very bright point-like sources with a strategy of intentional pile-up for annulus extraction.

Limits  The telemetry saturation limit depends on the DR, choice of clocking modes, editing modes, and the PPU ratio.
The resultant telemetry saturation limits are shown in Table 5.9 for the six combinations of the editing mode. A 10% margin for the headers and the background rates of 10 s\(^{-1}\) (FI) and 20 s\(^{-1}\) (BI) are included. The exact limit depends on the choice of the clocking mode. Users can use the XIS limit calculator at \(http://www.astro.isas.jaxa.jp/~tsujimot/limits_xis.ods\).

<table>
<thead>
<tr>
<th>Edit mode</th>
<th>5x5</th>
<th>3x3</th>
<th>f2x2,b3x3</th>
<th>s3tim_s015x5</th>
<th>s3tim_s013x3</th>
<th>s3tim_s02x2</th>
<th>s13x3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH</td>
<td>118.24</td>
<td>271.03</td>
<td>416.55</td>
<td>663.24</td>
<td>1163.81</td>
<td>1309.33</td>
<td></td>
</tr>
<tr>
<td>HI</td>
<td>118.24</td>
<td>271.03</td>
<td>416.55</td>
<td>663.24</td>
<td>1163.81</td>
<td>1309.33</td>
<td></td>
</tr>
<tr>
<td>MED (weekday)</td>
<td>37.6</td>
<td>101.26</td>
<td>161.89</td>
<td>276.17</td>
<td>484.74</td>
<td>545.37</td>
<td></td>
</tr>
<tr>
<td>MED (weekend)</td>
<td>4.00</td>
<td>30.53</td>
<td>55.79</td>
<td>114.89</td>
<td>201.79</td>
<td>227.06</td>
<td></td>
</tr>
<tr>
<td>LOW (weekday)</td>
<td>0.00</td>
<td>10.32</td>
<td>25.47</td>
<td>68.81</td>
<td>120.95</td>
<td>136.11</td>
<td></td>
</tr>
<tr>
<td>LOW (weekend)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.80</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) The lowest limit among the three operating sensors (XIS0, 1, 3) is given. A 10% margin for the headers and the background rates are included. The Normal clocking mode for the same options is assumed for 5x5, 3x3, and f2x2,b3x3, and the P-sum clocking mode (XIS3) and the Normal clocking mode with the 1/4win + 0.5s burst option (XIS0 and 1) is assumed for s3tim_s015x5, s3tim_s013x3, and s3tim_s02x2_s13x3.

**Mitigation**  
The operation team is fully responsible for an appropriate choice of the editing mode combinations among those in Table 5.5. The PPU ratio is optimized for a wide range of use cases. Therefore, not much can be done by users to avoid telemetry saturation.

**5.3.2.3 Out-of-time Events**

**Effects**  
Out-of-time events are those recorded during charge transfer, which spread along the Y direction at a low surface brightness below the source PSF. For accurate photometry, users need to be careful about out-of-time events. It is expected that out-of-time events have the same spectrum with the on-source events.

The effect appears for the Normal clocking mode of any options, but appear differently for those with and without a burst option. For Normal clocking mode without a burst option, the out-of-time events spread uniformly along the Y direction at a surface brightness of 156 ms/(8–0.156) s=2.0% integrated over 1024 pixels.

For Normal clocking mode with a \(b_s\) burst option, the out-of-time events spread uniformly in the upper and lower half of the image with a different strength (Fig. 5.7). This is because the clocking in the \(b_s\) burst options takes several steps: (1) exposure for \(~(8–b)\) s, (2) charge transfer only in the imaging area for flushing, (3) exposure for \(b\) s, (4) charge transfer both in the imaging and storead areas for recording. In (2), the flushing readout is performed with charge injection, and it takes 156 ms. In (4), the recording readout is without charge injection, and it takes 25 ms. The different strength in the upper and lower half of the image is caused by this. The fraction of out-of-time events is \(~25\) ms/\(b/2\) s in the upper part and \(~156\) ms/\(b/2\) s in the lower part. The fraction can be significantly large for short burst options; i.e., for \(0.1\) s burst option, the out-of-time events 12.5% in the upper half and 78% in the lower half.
Mitigation  The contribution of out-of-time events can be estimated in the area far from the center of the image. This is difficult for observations taken with a window mode. In such a case, at least one of the sensors can be operated without a window option so that it can be used for estimating the out-of-time events also for other sensors.

5.3.2.4 Self Charge Filling

Effects  In principle, charge traps can be filled not only by artificially injected charges, but also by charges created by X-ray events. This effect is apparent in observations of some very bright sources (Todoroki et al., 2012). This effect is not included in the calibration. Users may encounter a better energy resolution than the distributed RMF files indicate.
Table 5.10: Routine calibration observations and their usage.

<table>
<thead>
<tr>
<th>Target</th>
<th>Sensor</th>
<th>Mode</th>
<th>Option</th>
<th>Freq (yr(^{-1}))</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>E0102–72(^b)</td>
<td>013</td>
<td>Norm</td>
<td>none</td>
<td>4</td>
<td>Gain &amp; resolution at soft band.</td>
</tr>
<tr>
<td></td>
<td>013</td>
<td></td>
<td></td>
<td></td>
<td>Chemical composition of contamination thickness at XIS center.</td>
</tr>
<tr>
<td></td>
<td>013</td>
<td>Norm</td>
<td>1/4w</td>
<td>2</td>
<td>Gain difference for the 1/4 w mode at soft band.</td>
</tr>
<tr>
<td>RX J1856.5–3754(^b)</td>
<td>013</td>
<td>Norm</td>
<td>none</td>
<td>2</td>
<td>Chemical composition of contamination thickness at XIS center.</td>
</tr>
<tr>
<td>PKS 2155–304(^b)</td>
<td>013</td>
<td>Norm</td>
<td>1/4w</td>
<td>2</td>
<td>Chemical composition of contamination thickness at XIS center.</td>
</tr>
<tr>
<td>N132D(^b)</td>
<td>013</td>
<td>Norm</td>
<td>none</td>
<td>2</td>
<td>Gain &amp; resolution at medium band.</td>
</tr>
<tr>
<td>Perseus cluster</td>
<td>013</td>
<td>Norm</td>
<td>none</td>
<td>2</td>
<td>Gain &amp; resolution at hard band.</td>
</tr>
<tr>
<td>Perseus cluster</td>
<td>013</td>
<td>Norm</td>
<td>1/4w</td>
<td>2</td>
<td>Gain difference for the 1/4 w mode at soft band.</td>
</tr>
<tr>
<td>Lockman hole(^c)</td>
<td>3</td>
<td>P-sum</td>
<td>none</td>
<td>1</td>
<td>Gain &amp; resolution at hard band.</td>
</tr>
<tr>
<td>Cygnus loop(^b)</td>
<td>013</td>
<td>Norm</td>
<td>none</td>
<td>2</td>
<td>Spatial-dependence of contamination thickness.</td>
</tr>
<tr>
<td>Day earth</td>
<td>013</td>
<td>Norm</td>
<td>none</td>
<td>all time</td>
<td>Spatial-dependence of the contamination thickness.</td>
</tr>
<tr>
<td>Night earth</td>
<td>013</td>
<td>Norm</td>
<td>none</td>
<td>all time</td>
<td>NXB.</td>
</tr>
</tbody>
</table>

\(^a\) Additional calibration observations are made upon necessity.  
\(^b\) Targets observed with the event threshold of 50 and 20 ADU for the FI and BI sensors, as opposed to normal observations of 100 and 20, respectively. One ADU corresponds to 3.65 eV.  
\(^c\) Signals from the \(^{55}\)Fe sources are used for calibration.
5.4 Performance & Calibration

5.4.1 Spaced-row Charge Injection (SCI)

X-ray CCD devices are subject to degradation in the orbit. One of the outcomes is the increase of charge traps under constant radiation of cosmic rays in the space environment. This results in the increase in the charge transfer inefficiency (CTI), which leads to the degradation in the energy resolution.

![Frame dump image of XIS2 with the SCI. The bright lines at every 54 rows are rows with injected charges. Other events are mostly due to cosmic rays. The gaps between the segments are due to over-clock sampling.](image)

The XIS has a function to precisely monitor and mitigate this effect. For monitoring, each sensor has $^{55}$Fe calibration sources at two corners in the far-side of the readout.

For mitigation, the spaced-row charge injection (SCI) is implemented. Electrons are injected artificially from one side of the chip and are read out along with charges produced by X-ray events. Artificial charges are injected periodically in space (one in 54 rows; Fig. 5.8), which fill in charge traps sacrificially, and thereby alleviate the increase in CTI for charges by X-ray events (Bautz et al., 2004; Nakajima et al., 2008; Uchiyama et al., 2009; Ozawa et al., 2009). The SCI is not available for the P-sum clocking mode for its continuous clocking nature.

5.4.1.1 Trend

Fig. 5.9 shows the long-term trend of the measured peak energy and width of the Mn I Kα line (5.9 keV) from the calibration sources. The peak decreases and the width increases gradually, which are restored by the SCI operations.

5.4.1.2 Journal of SCI Operations

Start of SCI  The SCI technique was put into routine operation since the middle of 2006 and has brought a drastic improvement. At the start of the SCI operation, it was decided to inject the
amount of charges equal to the amount produced by a 6 keV X-ray photon ("6 keV equivalent") for the FI devices and a smaller amount ("2 keV equivalent") for the BI device. The smaller amount is due to the expected increase in noise in the soft-band end of the spectrum, at which the BI device has an advantage over the FI device.

**Choice of SCI on/off**  The SCI on and off was a user option for nearly one year since the start of SCI. This was because the SCI observations suffer a larger dead area and a larger fraction of out-of-time events as sacrifices of improved spectroscopic performance. The user option was terminated and all observations were made only with the SCI on since the AO4 cycle, as the number of users to choose SCI off decreased substantially.

**CI Increase for XIS1**  The accumulation of the contaminating material on the surface of the CCDs made the soft-band advantage of the BI sensor less prominent (§ 5.4.3). The CTI for the BI device has increased at a faster rate due to the smaller amount of injection charges. As a consequence, the astrophysically important lines of Fe XXV (6.7 keV) and Fe XXVII (7.0 keV) became hardly resolved in 2010. The injection charge amount was changed to 6 keV from 2 keV equivalent for the BI sensor since the dates in Table 5.1. Detailed information can be found in the Suzaku memo 2010-07 available at [http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2010-07v4.pdf](http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2010-07v4.pdf).

### 5.4.1.3 Data Impacts

Uses need to be aware of some drawbacks by the SCI operations.

- The injection rows and the rows immediately before and after the injection rows are dead areas, which amounts to 5.6% of the image. The width of the dead rows are much smaller than...
the telescope PSF. Therefore, this does not give significant impact to the imaging analysis.
- For the BI data with 6 keV equivalent charges, events in the second next rows to the charge injection rows may have wrong grading. Details can be found at http://www.astro.isas.jaxa.jp/suzaku/analysis/xis/xis1_ci_6_nxb/.
- The number of out-of-time events increases. It takes a longer time (25 ms for SCI off versus 156 ms for SCI on) to transfer the data in the imaging area due to extra time needed to inject charges. The fraction of the out-of-time events increases from 0.3% to 2.0%.
- The number of hot pixels slightly increases with the SCI, which are removed in the data processing.

5.4.2 Energy Gain and Resolution

The calibration of spectroscopic performance mainly consists of the calibration of energy gain and resolution. For the energy gain, the charge trails and the CTI are corrected.

For the energy resolution, the time-dependence is modeled as

\[ \Delta E(\text{PH}_0, t) = \sqrt{a(t) + b(t)\text{PH}_0 + c(t)\text{PH}_0^2}, \]

where \( \text{PH}_0 \) is the pulse height of the incident X-rays and \( t \) is the time from the launch. The time variable parameters \( a(t), b(t) \) and \( c(t) \) are determined phenomenologically using the \(^{55}\text{Fe} \) calibration sources and the E0102–72 observations.

For the normal clocking modes, data taken with the 3×3 and 5×5 editing modes are merged, as it is known that their difference is negligible.

5.4.2.1 Calibration Results (1) — Normal mode (no option)

The Normal mode with no option is the most calibrated mode of the XIS. The CTI is measured using the observations of the Perseus Cluster (all segments, hard band), 1E0102–72 (segments B and C, soft band), and \(^{55}\text{Fe} \) calibration sources (segments A and D, hard band).

Fig. 5.10 and 5.11 respectively show the gain and energy resolution in the hard band using the \(^{55}\text{Fe} \) calibration sources, while figures 5.12 and 5.13 respectively show the gain and energy resolution in the soft band using the E0102–72 observations.
Figure 5.10: Gain in the hard band for the Normal mode (no option) using the $^{55}$Fe calibration source. The upper panel shows the data before the SCI on and the lower panel shows those after the SCI on. The CTI is corrected.
Figure 5.11: Energy resolution in the hard band for the Normal mode (no option) using the $^{55}$Fe calibration source. The upper panel shows the data before the SCI on and the lower panel shows those after the SCI on. The CTI is corrected. The discontinuity in XIS1 in 2011 is due to the change in the CI amount.
Figure 5.12: Gain in the soft band for the Normal mode (no option) using the E0102−72 observations. The upper panel shows the data before the SCI on and the lower panel shows those after the SCI on. The CTI is corrected.
Figure 5.13: Energy resolution in the soft band for the Normal mode (no option) using the E0102–72 observations. The upper panel shows the data before the SCI on and the lower panel shows those after the SCI on. The CTI is corrected.
5.4.2.2 Calibration Results (2) — Other clocking modes

Normal mode (window option) Because the $^{55}$Fe calibration source is unavailable for observations in the window options, the Perseus Cluster is observed regularly in the 1/4 window option for calibration purposes (Table 5.10). The target is observed in the Normal mode (no option and 1/4 window option) next to each other in time to construct a comparison data set at each epoch. No calibration source is observed in the 1/8 window option.

The pulse height correction for Normal mode with the window options is the same with that for the Normal mode with no option, except that they use different numbers of fast and slow charge transfers. The fast and slow transfers are used for charge transfer in the effective imaging area and non-imaging area, respectively, and have different CTIs. For the window options, the non-imaging area includes the frame stored area as well as the imaging area outside of the window. The CTI in each transfer is calibrated using the calibration observations in the 1/4 window option, which is also applied to the 1/8 window option.

Fig. 5.14, 5.15, and 5.16 shows the resultant gain using the Fe XXV Kα emission line, in which the Normal modes with no option and the 1/4 window option are compared. The gain of the 1/4 window option is consistent with that of the no option within $\sim 5$ eV in the entire energy band along the mission to date.

![Figure 5.14: Comparison of gain in the Normal mode with the 1/4 window option (red) and with no option (black) for five conspicuous emission lines in XIS0. Events in all segments are used.](image)
Figure 5.15: Comparison of gain in the Normal mode with the 1/4 window option (red) and with no option (black) for five conspicuous emission lines in XIS1. Events in all segments are used.

Figure 5.16: Comparison of gain in the Normal mode with the 1/4 window option (red) and with no option (black) for five conspicuous emission lines in XIS3. Events in all segments are used.
**Normal mode (burst option)** The Crab calibration observations for the HXD are utilized as an XIS calibration opportunity of the Normal mode (burst option). The Crab has a featureless spectrum, so the $^{55}$Fe calibration source spectrum is used (Table 5.10).

For the Normal mode (burst options), no correction is made in addition to those for the Normal mode (no option). The calibration observations are used only for confirming of the assumption that there is no change in the instrumental response for the burst options.

Fig. 5.17 shows the $^{55}$Fe calibration source spectrum taken in the 2.0 s burst option during an observation of GX 17+2 and fitted using the RMF for the Normal mode (no option). There is no structure in the residual, indicating that the response is the same for the Normal mode with no option and the 2.0 s burst options.

**P-sum mode** Because of the unavailability of the spaced-row charge injection technique for the P-sum clocking mode (§ 5.4.1), the data taken with the mode suffer a substantially worse energy resolution than those taken with the Normal clocking mode. The P-sum clocking mode is combined only with the timing editing mode (§ 5.3.1.2), which has limited information about the charge distribution around an event. This makes the background level of the P-sum mode much higher than that of the Normal mode.

Fig. 5.18 shows the history of phenomenological gain of the P-sum data. Fig. 5.19 shows the energy resolution of a representative line in the soft and the hard band.
Figure 5.18: History of P-sum gain.
Figure 5.19: History of P-sum energy resolution. The upper panel shows the change of the Ne IX Kα line, whereas the lower panel shows the change of the Mn I Kα line.
5.4.2.3 Calibration Results (3) — Other editing modes

2×2 editing mode The data taken with the 2×2 editing mode have insufficient information to conduct trail correction around each event unlike those taken with the 3×3 or 5×5 editing modes. It is therefore inevitable to have different gains with the other editing modes. In particular, the gain difference between 3×3/5×5 and 2×2 depends on the ACTY position of the imaging area.

Because the 2×2 editing mode is used only for very bright point-like sources for the purpose of saving telemetry, and these observations are made at the XIS nominal position, the 2×2 editing mode data are calibrated so that the gain difference between 3×3/5×5 and 2×2 is the minimum at the image center. Fig. 5.20 shows the difference of the 2×2 and 5×5 editing mode gains in the soft and hard energy bands at several different ACTY positions. At the center (ACTY=512), the difference is within ~3 eV.

For calibration purposes, 2×2 editing mode data are artificially generated on the ground using the 3×3 or 5×5 editing mode data for the Perseus cluster (table 5.10).

5.4.2.4 User Notes

Users can exploit the calibration results presented above by using the xisrmfgen tool. The remaining issues include the following.

Si K In all the clocking/editing modes, the uncertainties of the gain and energy resolution calibration at the Si K edge remains prominent for the FI devices. Unfortunately, it is currently advised to remove data between 1.8–2.0 keV in the spectral fitting. For the BI device, a workaround was implemented in the latest CALDB to mitigate this uncertainty.

Au M Some uncertainties still remain in the Au M band, which is used for the surface coating in the mirrors. This is visible in very bright sources. Users need to remove data taken in the relevant energy band in the spectral fitting.

Al K Some uncertainties still remain in the Al K band, which is used for the electrodes in the CCD. This is visible in very bright sources. Users need to remove data taken in the relevant energy band in the spectral fitting.

>10 keV The background level is higher than those expected in the energy band above ~10 keV. The cause is not yet identified.
Figure 5.20: Energy gain for $2 \times 2$ and $5 \times 5$ editing modes as a function of ACTY position for the XIS0 and XIS3 in the soft and hard energy band at several different periods: 2008/02 (black), 2009/02 (red), 2010/02 (green), and 2011/02 (blue).
5.4.3 Degradation of Low Energy QE by OBF Contamination

The quantum efficiency below ~2 keV has been decreasing since the launch due to the accumulation of contaminating material on the optical blocking filter (OBF) of each sensor. The OBF is cooler than other parts of the satellite, thus is prone to the accumulation of contamination.

The contaminant consists of several different materials with a time-varying composition. The time-dependence of the thickness and the chemical composition of the contaminant are monitored and calibrated at the XIS nominal position and the spatial-dependence of the thickness across the field of view (Table 5.10).

5.4.3.1 Calibration Results

Time-dependence of the chemical composition  The chemical composition is modeled phenomenologically with time-varying columns of H, C, N and O. Three calibration sources — RX J1856.5–3754 (a super-soft isolated neutron), PKS 2155-304 (a blazar), and 1E0102.2–7219 (a line-dominated supernova remnant) — are used to derive the chemical composition at each epoch of the observations. The spectral models by Burwitz et al. (2003) for RX J1856.5–3754, a simple power-law model for PKS 2155-304, and that by Plucinsky et al. (2008) for 1E0102.2–7219 are used as the standard models. Fig. 5.21 shows the result of XIS1 fitting for RX J1856.5–3754 using the latest contamination model at some selected epochs.

Time-dependence of the contamination thickness  the time-dependence of the contamination thickness is modeled with phenomenological functions of time separately for each composition and for each sensor. Fig. 5.22, 5.23, and 5.24 show the evolution of the thickness for each element, while Fig. 5.25 shows the combined optical thickness and the relative reduction of the effective area. The contamination thickness increased rapidly after the launch for one year, and continues to increase at a moderate pace thereafter. The N component is used only for the XIS1.
Figure 5.21: Results of spectral fitting of the BI spectrum of RX J1856.5–3754 with the current contamination model at the XIS nominal position at several different epochs.
Figure 5.22: Time-dependence of the C thickness at the XIS nominal position for each sensor. The solid curves indicate the trend model.

Figure 5.23: Time-dependence of the N thickness at the XIS nominal position for each sensor. The solid curves indicate the trend model.
Figure 5.24: Time-dependence of the O thickness at the XIS nominal position for each sensor. The solid curves indicate the trend model.
Figure 5.25: Time-dependence of the combined optical depth (top panel) and the relative reduction in the effective area (bottom panel).
Spatial-dependence of the contamination thickness The spatial distribution of the contaminants is monitored and calibrated using regular observations of a part of the Cygnus Loop, a thermal supernova remnant. The atmospheric fluorescent K lines of N I and O I are used, which illuminates the entire field of view when the telescope is oriented toward the day earth.

The model of the spatial dependence assumes the radially symmetric pattern (Koyama et al., 2007). The chemical composition and the thickness at the field center is normalized to the value in Fig. 5.22, 5.23, and 5.24. Different sensors have different radial profiles (Fig. 5.26).

Figure 5.26: Spatial-dependence of the contamination thickness derived from day earth observation data at different epochs. Open circles and filled triangles represent the data points determined by the N and O lines, respectively. The best fit models are shown with solid curves.

5.4.3.2 User Notes

The calibration results are available for use by the ARF generation tool xissimargen (Ishisaki et al., 2007). It is discouraged to use the generic contamination models in the XSPEC package (e.g., xisabs, xiscoabs, xiscoabh, xispcoab).

For proposers, the ARF files are provided with the contamination thickness in the middle of the corresponding AO cycle extrapolated from the current trend.
5.4.4 Non X-Ray Background

The non X-ray background (NXB) has several sources. The most dominant source is the events by the ionization losses of charged particles in the cosmic rays. Others include fluorescence X-rays from materials used in the spacecraft and the $^{55}\text{Fe}$ calibration sources attached to the door of each sensor opened immediately after the launch. Most of the NXB events are discarded onboard as grade 7 events.

The NXB of the XIS is known to be very stable for a time scale of months and thus the NXB spectrum can be constructed using data obtained when the spacecraft is pointed toward the Earth at night. The NXB database is accessible in the CALDB, which is updated biannually in June and December.

5.4.4.1 Calibration Results

Intensity and Spectra  Fig. 5.27 shows the NXB spectrum for each sensor. The background rate in the 0.4–12 keV band is 0.1–0.2 count s$^{-1}$ for the FI CCDs and 0.3–0.6 count s$^{-1}$ for the BI CCD after grade selection. The background rate of XIS1 appears to become smaller after increasing the injection charge amounts from a 2 keV to 6 keV equivalent. The cause of this difference is under investigation now. Table 5.11 shows the current best estimates for the strength of major emission features, along with their 90% confidence errors.

Figure 5.27: Non-X-ray background (NXB) rate for XIS0 (black), XIS1 (red; CI=2 keV), XIS1 (green; CI=6 keV), and XIS3 (blue). The spectra are constructed from night Earth observations.

Cut-off Rigidity Dependence  The total intensity of the NXB depends strongly on the geomagnetic cut-off rigidity (COR), as the dominant source of the background originates from the cosmic rays. Fig. 5.28 shows the NXB count rate as a function of the COR.

The xisnxbgen tool generates the NXB spectra for an observation in such a way that the histogram of the COR is the same between the object and the night Earth observations. The night
Table 5.11: Strength of conspicuous emission lines in the NXB spectrum. The count rates are obtained from the entire CCD chip except for the corners irradiated by the calibration source. The errors are the 90% statistical uncertainties (Tawa et al., 2008).

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Al Kα</td>
<td>1.486</td>
<td>1.45 ± 0.11</td>
<td>1.84 ± 0.14</td>
<td>1.41 ± 0.10</td>
<td>1.41 ± 0.10</td>
</tr>
<tr>
<td>Si Kα</td>
<td>1.740</td>
<td>0.479 ± 0.081</td>
<td>2.27 ± 0.15</td>
<td>0.476 ± 0.080</td>
<td>0.497 ± 0.082</td>
</tr>
<tr>
<td>Au Mα</td>
<td>2.123</td>
<td>0.63 ± 0.093</td>
<td>1.10 ± 0.13</td>
<td>0.776 ± 0.097</td>
<td>0.619 ± 0.092</td>
</tr>
<tr>
<td>Mn Kα</td>
<td>5.895</td>
<td>6.92 ± 0.19</td>
<td>0.43 ± 0.14</td>
<td>1.19 ± 0.13</td>
<td>0.76 ± 0.11</td>
</tr>
<tr>
<td>Mn Kβ</td>
<td>6.490</td>
<td>1.10 ± 0.11</td>
<td>0.26 ± 0.13</td>
<td>0.40 ± 0.11</td>
<td>0.253 ± 0.094</td>
</tr>
<tr>
<td>Ni Kα</td>
<td>7.470</td>
<td>7.12 ± 0.19</td>
<td>7.06 ± 0.37</td>
<td>8.01 ± 0.20</td>
<td>7.50 ± 0.20</td>
</tr>
<tr>
<td>Ni Kβ</td>
<td>8.265</td>
<td>0.96 ± 0.10</td>
<td>0.75 ± 0.22</td>
<td>1.16 ± 0.11</td>
<td>1.18 ± 0.11</td>
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<tr>
<td>Au Lα</td>
<td>9.671</td>
<td>3.42 ± 0.15</td>
<td>4.15 ± 0.49</td>
<td>3.45 ± 0.15</td>
<td>3.30 ± 0.15</td>
</tr>
<tr>
<td>Au Lβ</td>
<td>11.51</td>
<td>2.04 ± 0.14</td>
<td>1.93 ± 0.48</td>
<td>1.97 ± 0.14</td>
<td>1.83 ± 0.14</td>
</tr>
</tbody>
</table>

Earth data are retrieved from ±150 days of the observation by default.

The count rate of the PIN upper discriminator (PIN-UD) in the HXD is also useful as a proxy for the COR, and thus the XIS NXB level. Tawa et al. (2008) shows that the PIN-UD provides a slightly better reproducibility of the XIS NXB than COR. The reproducibility of the NXB in the 5–12 keV band is evaluated to be 3–4% of the NXB, when the PIN-UD is used as the NXB sorting parameter.

Spatial Dependence Users need to be aware that the NXB is not uniform over the chip. It is stronger toward larger ACTY positions (Fig. 5.29). This is because some fraction of the NXB is produced in the frame-store region. The fraction can be different between the fluorescent lines and the continuum.

Time Dependence The NXB level changes both continuously and discontinuously. The continuous changes are seen only in the low energy band for the BI sensor, in which a gradual increase in the NXB level is observed (figure 5.30), although the NXB level once discontinuously decreased at the time that the injection charge was increased. The level is stable for the high energy band for the BI and the total band for the FI sensors.

5.4.4.2 User Notes

Change by the XIS0 anomaly A putative micro-meteorite hit occurred for XIS0 in 2009-06-23. Since then, the XIS0 has been operated with an area discrimination masking the damaged area. In the masked area, the NXB level is zero, which causes an apparent discontinuous change in the NXB database. Users generating their own NXB spectrum using the xisnxbgen need to be aware that they are mixing the NXB data before and after the event if their observations are within ±150 days of the event (between January 24, 2009 and June 27, 2009). A recipe for mitigating this is described in http://www.astro.isas.jaxa.jp/suzaku/analysis/xis/xis0_area_discrimination/.
Figure 5.28: Cut-off rigidity dependence of the NXB (average intensity for 5–10 keV) for each sensor. The NXB flux varies by a factor of ~2 depending on the cut-off rigidity.

**Change by the XIS1 CI increase** The CI level was increased from 2 to 6 keV in 2010. Due to the increased amount of charges, the NXB level has increased discontinuously. The increase is only seen in the second trailing row, which is the rows next next to the rows with charge injection. Users can achieve the same level of NXB for the CI=2 keV by masking the events in the second trailing rows. The details can be found in [http://www.astro.isas.jaxa.jp/suzaku/analysis/xis/xis1_ci_6_nxb/](http://www.astro.isas.jaxa.jp/suzaku/analysis/xis/xis1_ci_6_nxb/).

**Day Earth Contamination** When the XIS field of view is close to the day Earth (i.e., Sun-lit Earth), fluorescent lines from the atmosphere contaminate the low-energy part of the XIS data, especially in the BI chip. Most prominent are the O and N lines. Although the standard event screening criterion (the elevation angle from the day Earth >20 degrees) is sufficient to remove these features, some emission may remain due to the variable nature of the Earth X-ray albedo. In such a case, the event screening at a higher elevation angle is recommended.
Figure 5.29: ACTY dependence of the NXB for XIS0, XIS1, and XIS3. Black lines indicate the continuum component (2.5–5.5 keV), while the red lines indicate the Ni Kα line component (7.2–7.8 keV). The NXB flux tends to be higher at larger ACTY, because some fraction of the NXB is produced in the frame store region.
Figure 5.30: NXB spectrum of XIS1 integrated over one year for CI=2 keV (top) and CI=6 keV (bottom). For the CI=6 keV data, the second trailing rows are removed.
5.4.5 Quantum Efficiency

The stability of the relative normalization among the three XIS sensors is shown in Fig. 5.31. No significant time change is found. The relative normalization remains constant. The mean and standard deviation are summarized in Table 5.12 separately for the XIS and HXD nominal positions.

![Figure 5.31: Relative normalization among different sensors. The ratio of the best-fit normalization values are compared between two sensors at the XIS and the HXD nominal positions. Observations of a power-law source in the Normal clocking mode were used. The best-fit constant values are shown with solid lines.](image)

Table 5.12: Relative normalization among different sensors.

<table>
<thead>
<tr>
<th>Position</th>
<th>Ratio</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>XIS-norm</td>
<td>XIS1/XIS0</td>
<td>1.026</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>XIS3/XIS0</td>
<td>1.014</td>
<td>0.017</td>
</tr>
<tr>
<td>HXD-norm</td>
<td>XIS1/XIS0</td>
<td>1.004</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>XIS3/XIS0</td>
<td>0.980</td>
<td>0.022</td>
</tr>
</tbody>
</table>

5.4.6 Putative Micro-Meteorite Hits

The XIS experienced sudden anomalies caused putatively by micro-meteorite hits for XIS0, XIS1, and XIS2. The entire XIS2 was lost in 2006. A part of the XIS0 is lost in 2009, which is masked by area discrimination since then. Very small holes were created in the optical blocking filter, but the sensor remains intact.
Event on 2006-11-09 for XIS2  The anomaly of XIS2 suddenly occurred on Nov. 9, 2006, 1:03 UT. About 2/3 of the image was flooded with a large amount of charge, which had leaked somewhere in the imaging region. When the anomaly occurred, the satellite was out of the SAA and the XIS sensors were conducting observations in the Normal mode (SCI on, without any options).

Various tests were carried out to check the condition of XIS2, and found that (1) the four readout nodes of the CCD and the corresponding analog chain were all working fine, (2) the charge injection was not directly related to the anomaly, but may have helped to spread the leaked charge. When the clock voltages was changed in the imaging region, the amount of leaked charge changed. This indicates a short between the electrodes and the buried channel.

Possible mechanisms to cause the short include the micro-meteoroid impact on the CCD, as seen, e.g., on XMM-Newton and Swift. Although there is no direct evidence to indicate the micro-meteoroid impact, the phenomenon observed in XIS2 is not very different from that expected from the micro-meteoroid impact. The low-earth orbit and the low-grazing-angle mirrors of Suzaku may have enhanced the probability of a micro-meteoroid impact.

It was tried to reduce the leaked charge by changing the clock pattern and voltages in the imaging region. However, the attempt was not successful. Therefore it was decided to stop operating the sensor. It is unlikely that operation of the XIS2 will be resumed in the future. More details can be found at http://www.astro.isas.jaxa.jp/suzaku/doc/suzakumemo/suzakumemo-2007-08.pdf.

Event on 2009-06-23 for XIS0  The XIS0 suddenly showed an anomaly on June 23, 2:00 UT. During a Normal clocking operation, a part of the segment A of the XIS0 was flooded with a large amount of charges, which caused saturation of the analogue electronics. The anomaly was very similar to that occurred in the XIS2 in 2007. It is therefore suspected that both anomalies have the same origin, possibly a micro-meteorite impact.

In the Normal clocking mode, the effect is almost localized to a 1/8 area of the XIS0. The XIS team continues to operate the XIS0 in this mode. Users need to be aware of several remaining artifacts after the event. In the Psum clocking mode, the effect spreads to the entire XIS0 with severe degradation of the data. The XIS team discontinues the use of Psum clocking mode for the XIS0. More details can be found at http://www.astro.isas.jaxa.jp/suzaku/doc/suzakumemo/suzakumemo-2010-01.pdf.

Event on 2009-12-18 for XIS1  The XIS1 suddenly showed an anomaly some time between Dec 18, 2009 12:50 UT and 14:10 UT. A bright and persistent spot suddenly appeared at an end of the segment C in all images taken during day-earth observations, while none was found during night-earth observations. It is speculated that the anomaly stems from optical light leaked from a hole of a size of ~7.5 μm in the optical blocking filter created by a micro-meteorite hit.

From the diagnostic observations, it was concluded that scientific impact by this anomaly is minimum. The XIS1 has been and will be operated in the same way as before the anomaly. More details can be found at http://www.astro.isas.jaxa.jp/suzaku/doc/suzakumemo/suzakumemo-2010-03v2.pdf.

Other Events found in July 2013  We obtained some frame dump images of the day Earth in July 16, 2013 and found a total of 10 new bright spots in the XIS1 and XIS3. We speculate that they are caused by OBF holes for their similarities with the event in 2009 December for
XIS1. The size of the OBF holes are estimated to be very small of 0.3 pixel, so they are expected to have no effect in X-ray data unless an optically bright source coincidently falls in one of the holes. More details can be found at http://www.astro.isas.jaxa.jp/suzaku/doc/suzakumemo/suzaku_memo_2013-01.pdf.
5.5 Onboard Processing

5.5.1 Pulse Height Determination & Hot Pixel Rejection

When a CCD pixel absorbs an X-ray photon, the X-ray is converted to an electric charge, which in turn produces a voltage at the analog output of the CCD. This voltage ("pulse height") is proportional to the energy of the incident X-ray. In order to determine the true pulse height corresponding to the input X-ray energy, it is necessary to subtract the dark levels and correct possible optical light leaks.

Dark levels are non-zero pixel pulse heights caused by leakage currents in the CCD. In addition, optical and UV light might enter the sensor due to imperfect shielding ("light leak"), producing pulse heights that are not related to X-rays. The analysis of the ASCA SIS data, which utilized the X-ray CCD in photon-counting mode for the first time, showed that the dark levels were different from pixel to pixel, and the distribution of the dark level did not necessarily follow a Gaussian function. On the other hand, light leaks are considered to be rather uniform over the CCD.

For the Suzaku XIS, the dark levels and the light leaks are calculated separately in the normal mode. The dark levels are defined for each pixel and are expected to be constant for a given observation. The PPU calculates the dark levels in the Dark Initial operation; those are stored in the Dark Level RAM. The average dark level is determined for each pixel, and if the dark level is higher than the hot-pixel threshold, this pixel is labeled as a hot pixel. The dark levels can be updated by the Dark Update operation, and sent to the telemetry by the Dark Frame mode. The analysis of the ASCA data showed that the dark levels tend to change mostly during the SAA passage of the satellite. The Dark Update operation is conducted after every SAA passages unless the telescope is pointed toward the day Earth.

Hot pixels are pixels which always output pulse heights larger than the hot-pixel threshold even without input signals. Hot pixels are not usable for observations, and their outputs have to be disregarded during scientific analysis. The XIS detects hot pixels on-board by the Dark Initial/Update mode, and their positions are registered in the Dark Level RAM. Thus, hot pixels can be recognized on-board, and they are excluded from the event detection processes. It is also possible to specify the hot pixels manually. However, some pixels output pulse heights larger than the threshold intermittently. Such pixels are called flickering pixels. It is difficult to identify and remove the flickering pixels on board. They are inevitably included in the telemetry and need to be removed in scientific analysis, for example by using the FTOOLS sisclean. Flickering pixels sometimes cluster around specific columns, which makes them relatively easy to identify.

The light leaks are calculated on board with the pulse height data after subtraction of the dark levels. A truncated average is calculated for $256 \times 114$ pixels (this size was $64 \times 64$ before January 18, 2006) in every exposure and its running average produces the light leak. In spite of the name, light leaks do not represent in reality optical/UV light leaks to the CCD. They mostly represent fluctuation of the CCD output correlated to the variations of the satellite bus voltage. The XIS has little optical/UV light leak, which is negligible unless the bright earth comes close to the XIS field of view.

The dark levels and the light leaks are merged in the Parallel-sum (P-Sum) mode, so the Dark Update mode is not available in the P-Sum mode. The dark levels, which are defined for each pixel as the case of the normal mode, are updated every exposure. It may be considered that the light leak is defined for each pixel in the P-Sum mode.
5.5.2 On-Board Event Analysis

The main purpose of the on-board processing of the CCD data is to reduce the total amount of data transmitted to the ground. For this purpose, the PPU searches for a characteristic pattern of the charge distribution (called an event) in the pre-processed (post-dark level and light leak subtraction) frame data. When an X-ray photon is absorbed in a pixel, the photo-ionized electrons can spread into at most four adjacent pixels.

An event is recognized when a pixel has a pulse height which is between the lower and the upper event thresholds and is larger than those of eight adjacent pixels (e.g., it is the peak value in the $3 \times 3$ pixel grid). In the P-Sum mode, only the horizontally adjacent pixels are considered. The copied and the dummy pixels ensure that the event search is enabled on the pixels at the edges of each segment. The RAW XY coordinates of the central pixel are considered the location of the event. Pulse-height data for the adjacent $5 \times 5$ square pixels (or three horizontal pixels in the P-Sum mode) are sent to the Event RAM as well as the pixel location.

The MPU reads the Event RAM and edits the data to the telemetry format. The amount of information sent to the telemetry depends on the editing mode of the XIS. All the editing modes are designed to send the pulse heights of at least four pixels of an event to the telemetry, because the charge cloud produced by an X-ray photon can spread into at most four pixels. Information of the surrounding pixels may or may not be output to the telemetry depending on the editing mode. The $5 \times 5$ mode outputs the most detailed information to the telemetry, i.e., all 25 pulse-heights from the $5 \times 5$ pixels containing the event. The size of the telemetry data per event is reduced by a factor of two in the $3 \times 3$ mode, and another factor of two in the $2 \times 2$ mode. Details of the pulse height information sent to the telemetry are described in the next section.

5.5.3 Discriminators

Three kinds of discriminators, the area, the grade and the class discriminators, can be applied during the on-board processing. The grade discriminator is available only in the Timing mode. The class discriminator was implemented after the launch of Suzaku and was used since January, 2006. In most cases, guest observers need not to change the default setting of these discriminators.

The class discriminator classifies the events into two classes, “X-rays” and “others,” and outputs only the “X-ray” class to the telemetry when it is enabled. This class discriminator is always enabled to reduce the telemetry usage of non-X-ray events. The “other” class is close to, but slightly different from the ASCA grade 7. When the XIS points to a blank sky, more than 90% of the detected events are particle events (mostly the ASCA grade 7). If we reject these particle events on board, we can make a substantial saving in the telemetry usage. This is especially useful when the data rate is medium or low. The class discriminator realizes such a function in a simple manner.

We show in Fig. 5.5 the pixel pattern whose pulse height or 1-bit information is sent to the telemetry. We do not assign grades to an event on board in the Normal Clock mode. This means that a dark frame error, if present, can be corrected accurately during the ground processing even in the $2 \times 2$ mode. The definition of the grades in the P-Sum mode is shown in Fig. 5.5.
Serial transfer (RAWX →)

Grade 0: single Grade 1: leading split Grade 2: trailing split Grade 3: others

Center pixel of the event.

Pulse height of the pixel is equal to or larger than the (inner) split threshold. This pulse height is added to the total pulse height.

Figure 5.32: Definition of the grades in the P-Sum/Timing mode. Total pulse height and the grade of the event are output to the telemetry. Note that the grades are defined referring to the direction of the serial transfer, so the central pixel of the grade 1 event has the larger RAW-X value than the second pixel, while the opposite is true for the grade 2 event.

5.6 Operation

5.6.1 Uploading μ-codes

The μ-code for the window and burst options are uploaded every time that they are used. They are stored in the following PRAM space.
Table 5.13: μ-code list

<table>
<thead>
<tr>
<th>PRAM</th>
<th>RAMSub ID</th>
<th>Sensor</th>
<th>Usage</th>
<th>Version a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>65</td>
<td>0, 3</td>
<td>Normal (burst)</td>
<td>2 (0.1s), 3 (2.0s)</td>
</tr>
<tr>
<td>1</td>
<td>66</td>
<td>1</td>
<td>Normal (burst)</td>
<td>6 (0.1s), 7 (0.5s), 8 (0.62s)</td>
</tr>
<tr>
<td>2</td>
<td>67</td>
<td>3</td>
<td>P-sum</td>
<td>1 [fixed]</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
<td>3</td>
<td>Normal (win)</td>
<td>13 (1/4w), 16 (1/8w)</td>
</tr>
<tr>
<td>4</td>
<td>69</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>70</td>
<td>1</td>
<td>Normal (win)</td>
<td>27 (1/4w), 23 (1/8w)</td>
</tr>
<tr>
<td>6</td>
<td>71</td>
<td>0</td>
<td>Normal (win+burst)</td>
<td>23 (1/4w+0.1s), 24 (1/4w+0.3s), 22 (1/4w+0.5s), 21 (1/4w+1.0s), 25 (1/8w+0.5s)</td>
</tr>
<tr>
<td>7</td>
<td>72</td>
<td>0, 3</td>
<td>Normal (none)</td>
<td>3 [fixed]</td>
</tr>
<tr>
<td>8</td>
<td>73</td>
<td>1</td>
<td>Normal (none)</td>
<td>6 [fixed]</td>
</tr>
<tr>
<td>9</td>
<td>74</td>
<td>0</td>
<td>Normal (win)</td>
<td>8 (1/4w), 11 (1/8w)</td>
</tr>
<tr>
<td>A</td>
<td>75</td>
<td>1</td>
<td>Normal (win+burst)</td>
<td>19 (1/4w+0.1s), 20 (1/4w+0.3s), 21 (1/4w+0.5s), 22 (1/4w+1.0s)</td>
</tr>
<tr>
<td>B</td>
<td>76</td>
<td>3</td>
<td>Normal (win+burst)</td>
<td>19 (1/4w+0.1s), 20 (1/4w+0.3s), 18 (1/4w+0.5s), 17 (1/4w+1.0s), 21 (1/8w+0.5s)</td>
</tr>
</tbody>
</table>

a All the window and window+burst codes are at the XIS nominal position. All the XIS1 codes are for the CI=6 keV.
5.6.2 User Notes
A heterogeneous clocking mode observation cannot follow a P-sum observation.

5.7 References
Bibliography


Nakajima, H., et al. 2008, PASJ, 60, 1


Yamada, S., et al. 2011, PASJ, 64, 53