DEAR Technical Note IR-28

Noise level fluctuations and the reduction of periodic noise occurring in CCD x-ray data

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1 Introduction

The DEAR experiment requires a precise absolute energy calibration for an x-ray energy spectrum at around 6 keV with an error of ~ 5 eV. One necessary condition to achieve this high resolution is the understanding of the response functions of the CCD x-ray detectors. CCD data taken during background measurements with colliding beams in the DEAR I.P. were analyzed. In this analysis, specific attention was paid to the noise level (pedestal). This pedestal was found to be unstable. This Note explores the origin of these pedestal fluctuations, and describes how to treat this effect.

Even if a CCD chip does not show any events, the charge contents of the individual pixels have non-zero values due to a set basic voltage. Due to leakage currents during the CCD exposure time, the value of the pedestal shifts away from the set value and forms a

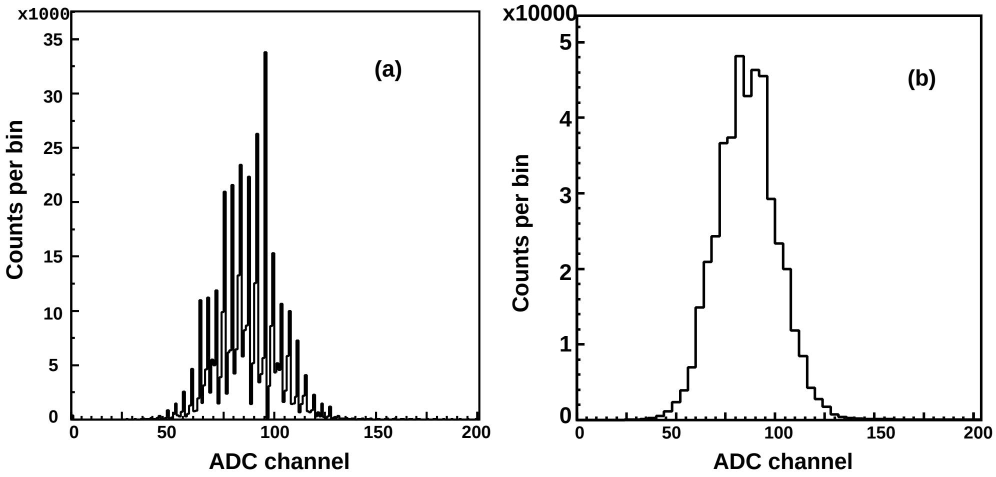

Figure 1: (a) A typical raw spectrum (one channel per bin). Fine structures are visible and the global structure is far from being a Gaussian distribution, since the two less significant bits are sometimes lost in the read-out process [2]. (b) The energy spectrum of the noise peak (four channels per bin). The shape is still not Gaussian.

noise peak. Its width is due to electrical noise, leakage currents and pedestal fluctuations. The shape of the noise peak was expected to be Gaussian [1], but we found that it is not.

The study of the noise peak is of great interest for the analysis of the DEAR experiment, since the x-ray energy is given by the difference between the event pixels positions and the noise peak position. The gain of our read-out system at the present settings is about 4 eV/channel using a 12-bit ADC. Therefore, to achieve the required resolution of 5 eV, we have to determine the noise peak position with an accuracy of one channel.

2 The behaviour of the noise peak

We briefly summarize here below the behaviour of the noise peak.

2.1 The raw spectrum of the noise peak

To check whether a short-term structure exists in the noise, we plotted an energy spectrum from channels 0 to 200, as shown in Fig. 1. This figure shows a snapshot of the shape of the noise peak for a typical exposure time. During the read-out, the two less significant bits are sometimes lost (filled with electrical noise) [2], therefore only 10 bits of the 12-bit ADC are significant, and consequently the data are binned by 4.

2.2 Periodic pedestal level fluctuations

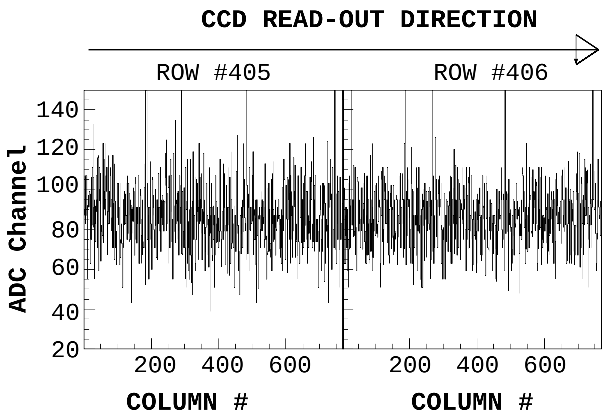

Figure 2: A continuous slow repetitive fluctuation is shown as a function of column number. The two typical rows were connected in the order of the read out.

As shown in Fig. 1, the shape of the noise peak is not an ideal Gaussian. To study this, we plotted the data as a function of column number, as shown in Fig. 2. The sharp spikes in the figure are due to x-ray hits. The two considered rows are read out in sequential order. A continuous slow repetitive fluctuation can be seen through the column readout. The origin of this fluctuation might be a noise pick-up somewhere in the electronic circuit.

2.3 Subtraction of the slow repetitive fluctuation by a Fourier transformation

In principle, to improve the quality of the data, the observed slow repetitive fluctuation could be minimized by improving the electronics. However, one can also minimize this fluctuation by subtracting the repetitive components using a Fourier transformation.

2.3.1 Noise analysis of the x-ray data

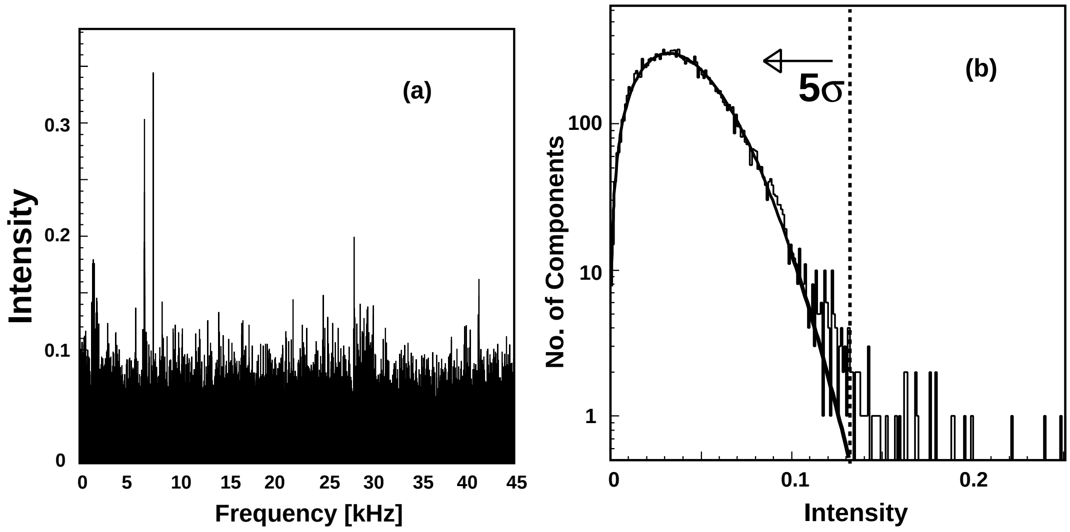

Figure 3: (a) The power spectrum of each frequency in the data. The slow repetitive fluctuations are seen as spikes in this figure. (b) The intensity distribution of the number of components in the power spectrum. The small intensity region (below 5 σ) is fitted with the function (2) (solid line). This region is consistent with a Gaussian distribution.

We adjusted the mean value of the noise peak to zero and applied a Fourier transformation. The region of the noise peak is set to 4.5 standard deviations of the width of the noise peak. Figure 3(a) shows the power spectrum obtained for the x-ray data. The horizontal axis gives the frequency. The vertical axis gives the intensity I of each frequency component, which is given by:

$$I(\omega) = \sqrt{\mathrm{Re}\ F^2 + \mathrm{Im}\ F^2}, \tag{1}$$

where F is a complex number of the Fourier transformed data.

As shown in Fig. 3(a), there are many spikes in the data. This suggests that more than just a Gaussian fluctuation exists. These spikes are components of the slow repetitive fluctuation of the ground level. Figure 3(b) shows the intensity dependence of the number of components in the Fourier analysis. If the data contain only white noise which is Gaussian, this histogram can be fitted with the function:

$$A \cdot \exp(-\frac{I^2}{2\sigma^2}) I \; dI \; d\phi, \qquad (2)$$

where $I \; dI \; d\phi$ is the phase space of the complex plane, A is the amplitude and σ is the width of the Gaussian distribution. We fitted this distribution with the function (2) over a range up to 5 standard deviations. As shown in Fig. 3(b), the dominant component in the phase space is a Gaussian distribution, ending at about 5 standard deviations. Some components above 5 σ are visible. By cutting off such components, we can clearly separate those periodic components which contaminated the ground level.

One should take considerable care not to "over-kill" the Fourier components. A cut-off smaller than 5 σ ("over-kill") could cut off real components of the background and destroy the quality of the data, since this could be one source of a systematic error. Therefore, we decided to set the cut-off parameter relatively high (5 σ), in order to avoid this possibility. We applied the reverse Fourier transformation to the corrected data and subtracted the slow repetitive fluctuations from the original data, including x-ray hit pixels. After this Fourier method was used, the noise peak became Gaussian, as shown in Fig. 4.

3 The instability of the noise peak and its correction with Fourier analysis

To check the stability of the noise peak position, we plotted the center position of the noise peak before Fourier analysis as a function of the run number in Fig. 5(a), and the noise peak widths with/without Fourier analysis in Fig. 5(b).

As shown in the figure, the noise peak position is not stable. One should pay attention to long-term drifts. The noise peak position does not fluctuate symmetrically around the

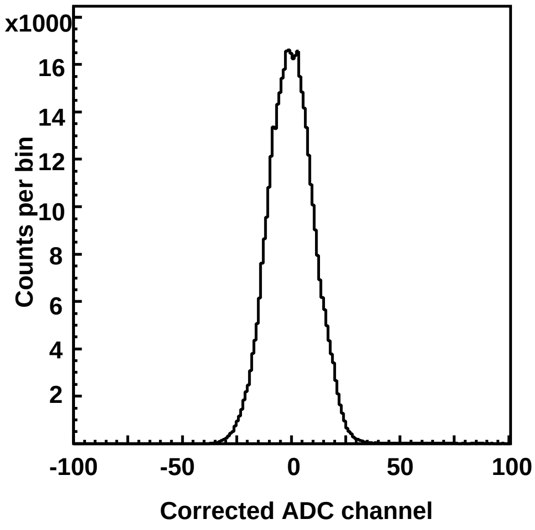

Figure 4: Noise peak spectrum after subtracting the slow repetitive fluctuating components. The center position is adjusted to zero. The shape of the noise peak becomes Gaussian.

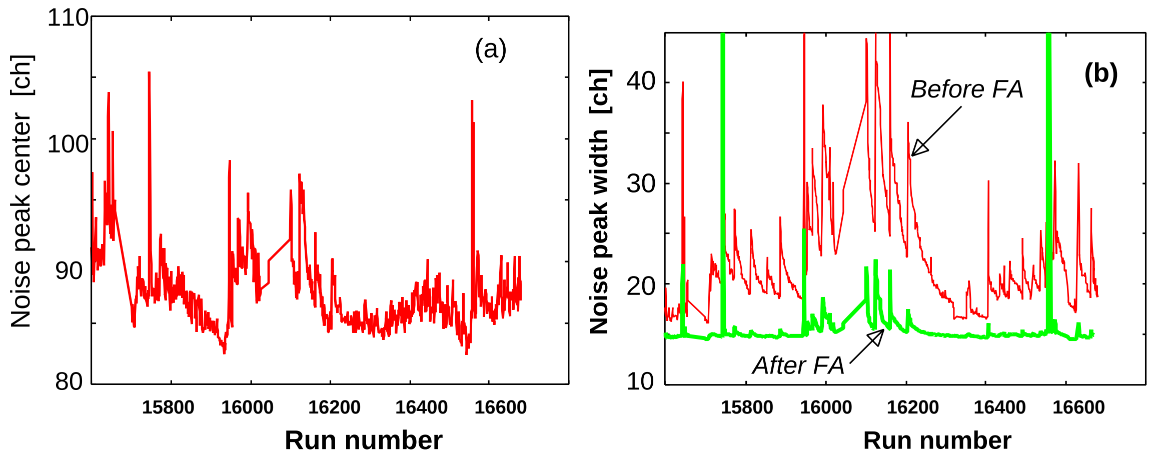

Figure 5: (a) The position of the noise peak center as a function of the run number. These positions are not stable. After applying Fourier analysis (*FA*), these positions are adjusted to zero. (b) The noise peak width before/after subtracting the slow repetitive fluctuation as a function of the run number. The noise peak widths are clearly reduced after Fourier analysis.

stable position as assumed in the DEAR Technical Note IR-1 [3]. However, the noise peak position can be adjusted to zero after application of Fourier analysis and subtraction of the slow repetitive fluctuations. As shown in Fig. 5(b), noise peak widths are clearly reduced by Fourier analysis.

4 Summary

Two observations can be drawn after applying to CCD x-ray data the analysis method based on a Fourier transformation, described in this Note:

1. Long-term drift: There are noise level drifts occurring during the data taking period. These drifts can give an asymmetric deviation to the noise peak shape, which could produce a systematic error. The noise peak does not fluctuate symmetrically around a stable position, as expected [3].

2. Short-term drift: The pedestal level is contaminated with periodic noise during the CCD read-out. This may be due to pick-up noise.

After Fourier analysis of the CCD data, the drifts in the noise peak positions are corrected and the noise widths are reduced. Therefore, we conclude that Fourier analysis is one of the best methods to study how to improve the quality of the CCD data.

References

[1] D. Sigg, Nucl. Instr. Methods A **292** (1994) 107.

[2] M. Iliescu, private communication.

[3] T. M. Ito, *"The relation between the long-term detector response measurement and the periodical stability check"*, DEAR Technical Note IR-1, (December 2nd, 1997).