1. Introduction

In CCDs electrons of the signal charge generated by an absorbed X-ray photon are lost during transfer to the readout node by traps in the transfer channel. The number of traps is expected to increase with time due to radiation damage. As the knowledge of the charge loss is essential for extracting quantitative spectral information, the performance of the EPIC pn camera is routinely monitored with an internal calibration source. This source consists of radioactive Fe\(^{55}\) with an Al-target, and irradiates the detector with Al–K\(_\alpha\) and Mn–K\(_\alpha\) emission lines at 1.5 and 5.9 keV. This is usually done for about one hour at the beginning of each 48 hour revolution of XMM–Newton. The line positions determined from these exposures are a sensitive indicator for any change in the energy response.

2. Ground calibration

The importance of the CTI for the energy calibration of the EPIC pn camera was realized long before launch, and a lot of experience was gained during extensive laboratory measurements with different detectors at different temperatures and energies. We developed specific software tools for the CTI analysis of such calibration data, which allow us to determine the charge loss across the 768 readout channels with high spatial resolution. Fig. 1 illustrates the method. Results from laboratory measurements for the detector now onboard XMM–Newton are shown in Figs. 2 and 3. More about the energy calibration before launch can be found in Dennerl et al. (1999). Here we report on recent results obtained from monitoring the CTI in orbit.

3. CTI monitoring in orbit

The number of photons obtained during the ~1 hour calibration measurements in orbit is not sufficient for the determination of the charge loss for individual columns. However, during six revolutions (#23, 80, 125, 172, 242, and 332) long measurements were made with exposures of...
4. RESULTS

The effects of the CTI can be reduced with this method. Charge losses of up to 10% occur, the colour coding which is displayed at top together with a fraction of the charge which arrives at the readout node, in ground calibration at Orsay, where more than 80 million columns (cf. Fig. 1). Fig. 7 illustrates the accuracy which was then analysed in the same way as those of individual events. In the better exposed areas, which are less contaminated by multiplications which are the consequence of charge losses determined from rev. 125, and Fig. 7 in the history for CCDs 1, 2, and 3 quadrants 0, derived from Briel et al. (2002, these proceedings) summarizes the CTI.

The same CTI correction to the measurements which were not caused by CTI changes, but by changes in the short-term drifts of the readout, and in the readout amplifiers. We found that the short-term drifts of the readout, and in the readout amplifiers.

In order to extract the CTI residuals, the different columns, derived from the detector (Figs. 5 and 6), we selected only events from the same CTI correction to the calibration data (Fig. 9).

The same CTI correction to the measurements which were not caused by CTI changes, but by changes in the position. We found that the short-term drifts of the readout, and in the readout amplifiers which were the consequence of charge losses determined from rev. 125, and Fig. 7 in the history for CCDs 1, 2, and 3 quadrants 0, derived from Briel et al. (2002, these proceedings) summarizes the CTI.

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the operating temperature of the EPIC pn camera in orbit (1998):

the charge losses accumulate to the readout node. When shifted along the whole column, apparent line energy as a function of the distance from the charge losses for individual pixels. The curves show the high statistical quality made it possible to determine with the internal calibration source during revolution 125.

quadrant 2 at Mn–K\textsubscript{\alpha}, obtained from a 18 hour exposure with the mean value. The shaded region shows the standard deviation of the CTE values, which is printed to the right together with the mean value.

Figure 4. Charge loss and CTE for individual columns of quadrant 2 at Mn–K\textsubscript{\alpha}, obtained from a 18 hour exposure with the internal calibration source during revolution 125. The high statistical quality made it possible to determine the charge losses for individual pixels. The curves show the apparent line energy as a function of the distance from the readout node. When shifted along the whole column, the charge losses accumulate to \sim 10\%. The first number at the curves identifies the column, while the second number gives the CTE in the form \( (CTE - 0.999) \cdot 10^5 \), i.e. the last two digits xx of 0.999xx. The CTE was obtained by fitting an exponential function to the charge losses. At bottom the CTE values of all columns are summarized. Significant differences between the individual columns are obvious. The shaded region shows the standard deviation of the CTE values, which is printed to the right together with the mean value.

Mn–K\textsubscript{\alpha} we measure a long-term trend of

\[
\frac{dCTI}{dt} = + (1.5 \pm 0.1) \cdot 10^{-5} \text{ yr}^{-1}.
\]

Before launch, laboratory measurements, taken at \(-90^\circ \text{ C}\), the operating temperature of the EPIC pn camera in orbit, showed the following response of the CTE to a 10 MeV proton equivalent flux \( F_{\text{rad}} \) for Mn–K\textsubscript{\alpha} (Meidinger et al. 1998):

\[
\frac{dCTI}{dt} = 4 \cdot 10^{-13} \text{ cm}^2 \cdot F_{\text{rad}}
\]

For \( F_{\text{rad}} \), an average value of \( 5 \cdot 10^7 \text{ cm}^{-2} \text{ yr}^{-1} \) was expected, yielding

\[
\frac{dCTI}{dt} = + 2 \cdot 10^{-5} \text{ yr}^{-1}
\]

at Mn–K\textsubscript{\alpha}. Thus, the measured value is even somewhat lower than this estimate.

The additional noise created by the small relative increase of the CTE is almost negligible and should not have measurable consequences for the energy resolution. In fact, no significant increase of the width of the Mn–K\textsubscript{\alpha} line was observed over the first two years (Fig. 10).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4}
\caption{Irradiation at Al–K\textsubscript{\alpha} and corresponding mask.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5}
\caption{Irradiation at Mn–K\textsubscript{\alpha} and corresponding mask.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure6}
\caption{Irradiation at Mn–K\textsubscript{\alpha} and corresponding mask.}
\end{figure}

\section{5. Summary and Conclusions}

From routine measurements with the internal calibration source, the CTE of the EPIC pn camera was found to increase by \( + (1.4 \pm 0.4) \cdot 10^{-5} \text{ yr}^{-1} \) at Al–K\textsubscript{\alpha}, and by \( + (1.5 \pm 0.1) \cdot 10^{-5} \text{ yr}^{-1} \) at Mn–K\textsubscript{\alpha}.

This corresponds to a relative increase of the CTE by \sim 4\% for Al–K\textsubscript{\alpha} and by \sim 7\% for Mn–K\textsubscript{\alpha} during the first two years in orbit, with no measurable effect on the energy resolution. If this trend continued, then it would take more than 25 years until the CTE at Mn–K\textsubscript{\alpha} would have doubled. At Al–K\textsubscript{\alpha}, the CTI would then have increased by about half of its present value.
Figure 7. Charge loss and CTI for individual CCDs, and for quadrant 0. This plot is similar to Fig. 4. Here, however, photons from several columns were combined (after having been corrected for individual gain variations) to increase the statistical quality and to extend the CTI analysis to shorter exposures. The data were taken from a 2-hour exposure with the internal calibration source during revolution 285. The curves refer to CCDs 1–12, and to quadrant 0, for Al–K\(_\alpha\) (top) and Mn–K\(_\alpha\) (bottom). Gaps are caused by poorly exposed regions (cf. Fig. 5, 6). The CTI values, determined from exponential fits, are listed to the right of each curve.

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Figure 8. Results of the CTI determination from internal calibration measurements in orbit, for quadrant 0 at Al–K\(_\alpha\) (top) and Mn–K\(_\alpha\) (bottom). Both energies show a consistent slope, which is significantly different from zero in both cases.
Figure 9. Mn–Kα line position, not corrected for CTI history. In the first months after the launch of XMM–Newton, short–term drops of the peak position on time scale of days showed up, caused by temperature variations in the electronic boxes, while brief, sudden rises were found to be related to episodes of very high background. In addition to these short–term changes there are indications for a long–term decrease of the line position (dashed red line), which is caused by a CTI increase. The green line marks the nominal value of Mn–Kα for an amplification of 5 eV/adu.

Figure 10. Energy resolution for Mn–Kα. The FWHM of 31 adu corresponds to 155 eV. During the first two years in orbit, no change in the energy resolution was observed.