# High Order Peak Pileup Correction Algorithm

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*Abstract*— **In the field of room temperature spectroscopic X-ray inspections, such as medical computed tomography or industrial inline analysis, reducing times measurements is increasingly demanded. High-flux conditions allow faster data acquisition but inevitably introduce distortions in the measured spectra because of coincident events. The non-linear behavior of the device is intrinsic because of the finite pulse time width and the electronics deadtime. By using pileup rejectors, spectroscopic performance can be preserved at high flux. However, pileup related features are unavoidably present because of the limited accuracy and efficiency of these algorithms. A different approach is a correction by numerical methods. If the device response as a function of the energies of overlapped pulses and their time separation is known, a post-processing correction can be tentatively implemented. Here, a numerical approach to drastically reduce peak pileup effects is proposed and investigated.**

*Index Terms*— **spectral correction, pileup.**

## I. Introduction

Semiconductor-based X-ray detector behaves non-linearly at increasing flux rate because of the limits of the electronic chain (sampling frequency, finite pulse width, deadtime). Count loss and pulse overlapping are the main effects which characterize high-flux measurements and they produce a change of the energy distribution shape and a worsening of the energy resolution. Thus, quantitative analysis on distorted spectra is compromised. A viable way to prevent spectral degradation are pileup rejection algorithms: by analysing the incoming signal at the single event level, discarding overlapped pulses is possible. However, the accuracy of these algorithms is limited. Furthermore, a considerable fraction of counts does not contribute to the final spectra and the benefit of using high flux in order to decrease times measurement is reduced. A statistical approach to correct acquired spectra by numerical methods is a challenging task because of the intrinsic non-invertibility of the phenomenon but would allow to obtain information using all the collected events, including the overlapped ones. Through suitable approximations, analytic models have been proposed in literature and 1st order pileup distortions have already been successfully corrected (*e.g.* two events in the same deadtime) [1] [2]. Nevertheless, current high-flux conditions are affected by higher pileup order (i.e. the probability of more than two overlapped photons is not negligible). Here, we propose an iterative method to remove peak pileup effects from X-ray spectra for nonparalyzable detectors.

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## II. Model Description

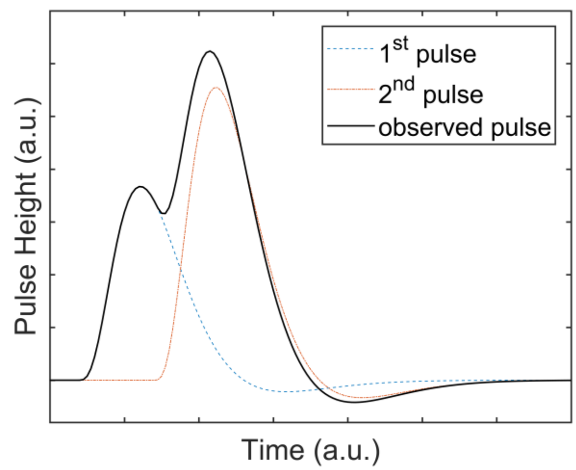


Figure 1. Example of peak pileup effect in the case of two bipolar pulses.

The approach is based on the capability of accurately reproducing the electronic response at different flux rates and using this information to apply a correction. The first step ("forward") consists in the peak pileup simulation. We used the model proposed by Taguchi et al. [3] which considers the statistical distribution of the arrival time of triangular pulses. The model has been extended to arbitrary pulse shapes (Figure 1). The result is a pileup matrix $P_m(E_1, E_2, E_R)$ which consider every possible combinations of pulses in terms of height and time separation. Each matrix element represents the probability that two events of energy $E_1$ and $E_2$ are recorded as a single event of energy $E_R$ for the $m^{th}$ pileup order. Given an arbitrary incident energy distribution and a certain $r\tau$ value, the distorted spectrum can be calculated by means of the matrix $P$. $r\tau$ represents the mean value of events which occur during a time $\tau$, where $r$ represents the incoming rate and $\tau$ is the deadtime. Due to the large amount of calculation involved, for $m \geq 2$ the matrix is calculated recursively as a sum of two pulses where the energy of the first is due to $m$ combined events. The accuracy and the limits of this approximation are reported in [3]. The final distorted energy distribution consists of the weighted sum of these spectra according to the probability density function of time intervals between two events.

The second step ("backward") is based on the correction method proposed by Wielopolski and Gardner which, however, is limited to first order pileup [4] [5]. Treating higher orders as a combination of two pulses as in the "forward" step, a similar correction can be implemented. In each bin a weighted fraction of the counts is attributed to the $m^{th}$ pileup order and the energy distribution is iteratively corrected. At each iteration the corrected spectrum is convolved with the pileup matrix and this distorted solution is compared to the initial spectrum. In this way a convergence criterion can be established. The algorithm has been implemented in MATLAB.

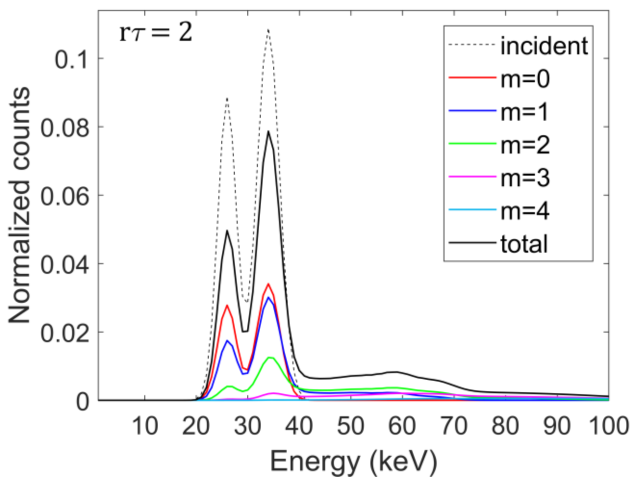


Figure 2. Simulated spectrum distorted by peak pileup effect at high flux ($r\tau = 2$). The dashed line represents the undistorted spectrum. Peak pileup spectra up to $m = 4$ are showed as colored curves.

## III. RESULTS

Different types of energy distributions have been tested at different $r\tau$ (delta-like function, gaussian multiplets, x-ray tube-like distribution). In all cases, counts in the high energy region, where only pileup-related events are present, are drastically reduced. Hence, the shape of the undistorted distribution and the height of the photopeaks are almost completely restored. The correction applied to the spectrum showed in Figure 2 is reported in Figure 3 as example. We stress the fact that no prior hypothesis on the initial energy distribution has been promoted before applying the correction. The algorithm only requires the pileup matrix and the $r\tau$ value.

In conclusion, the simulations suggest that peak pileup effects can be corrected in the ideal case in which the detector response is perfectly reproduced at a given flux. The model has been applied to distorted spectra at $r\tau$ value up to 2. Since the pileup matrix is calculated just once, the correction is fast and can be performed on a standard laptop in ~2 s. It is worth noticing that the algorithm has not been optimized for the computational efficiency. Thus, the implementation with more efficient programming languages and more performing computers would surely decrease the running time. This is interesting in view of its application for inline analysis.

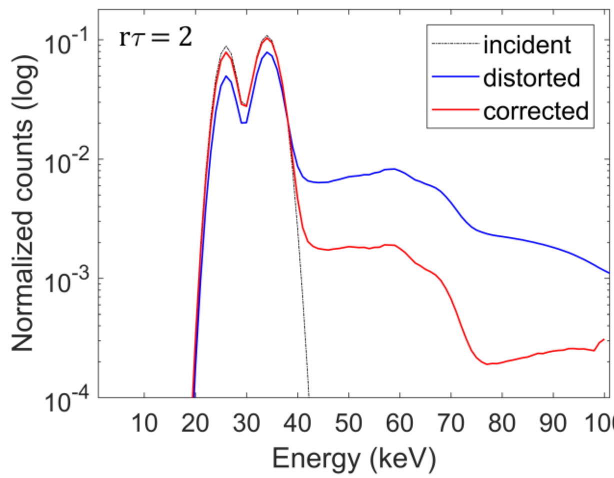


Figure 3. Correction of the distorted spectrum at high flux ($r\tau = 2$) showed in Figure 2. The dashed line represents the undistorted spectrum.

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