# On the role of the signal processing electronics in x-ray analytical measurements

T. Papp[a,b,c], J.A. Maxwell[b], A. Papp[a], Z. Nejedly[b,d] and J. L. Campbell[b]

[a]Cambridge Scientific, Guelph, Canada N1E 2X5

[b] Guelph-Waterloo Physics Institute, University of Guelph, Guelph, Ontario, Canada N1G 2W1

[c] Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Bem tér 18/c, Pf. 51, H-4001, Hungary

[d]AnZ Solutions, Guelph, Canada N1G 1S6

Abstract: Large differences were observed in the performance of Si(Li) detectors when used with different signal processors. The performance depended on the user-adjustable parameter setup of the given processor. Comparative tests of signal processing electronics were made using four detectors and feeding the preamplifier signal to two signal processors simultaneously. Some of the signal processors produced ghost peaks in the spectra. Differences in the resolution, throughput rate, and pile-up recognition were observed even at moderate input rates. Several examples of how the choice of signal processor can effect the quality of the spectra produced are shown. We conclude that the choice of signal processor does matter to the x-ray spectral analyst.

Keywords: digital signal processor, DSP, throughput rate, resolution, pileup

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## 1. Introduction

PIXE (Particle-Induced X-ray Emission) is a well-established member of the range of IBA methods, providing excellent accuracy and spatial resolution for trace element analysis even in complex matrices. Almost all of PIXE is carried out with Si(Li) X-ray detectors. The observation in Si(Li) X-ray spectra during recent years of various small intrinsically generated artifacts that are attributable to electron transport [1-3] suggests that these detectors are now of very high quality. This encouraging picture, however, is offset to a degree by a number of observations that we have recently made regarding the electronic pulse processors used with Si(Li) detectors; the role of these processors in influencing various spectral features and therefore overall analytical response in PIXE is far from insignificant. Here we present some of these observations, and we demonstrate that use of a fully digital processor can be advantageous.

The work to be discussed was done with various Si(Li) detectors including one that we consider to be a state-of-the-art device made by Oxford Instruments (OI). Various commercial pulse processors were used, including an Oxford Instruments XP3, which we used with the OI detector. In addition a CSX3 digital signal processor from Cambridge Scientific, Canada was tested with the OI detector, by connecting it to the OI preamplifier output in parallel with the XP3 processor. The study includes both PIXE spectra, and spectra from radioactive sources of $^{55}$Fe and $^{241}$Am. We present here a small selection from a wide range of observations that have been made in development of the CSX3 unit.

## 2. Measurements and observations

### 2.1 Electronic noise

Accelerator facilities can be mechanically and electrically “noisy”. Figure 1 shows a PIXE spectrum taken in such an environment, with a single detector and two different processors (analog and the CSX3 digital). The spectra exhibit significant differences due to the different means of electronic noise recognition in the two processors. Because the detector has a beryllium window, the only features that should be expected below 500 eV X-ray energy are the silicon escape peaks. Not only does the analog processor produce events in the low-energy region, its greater peak broadening throughout the spectrum is apparent.

### 2.2 Throughput and spectral quality

The economics of IBA demand the largest possible signal throughput, and quality assurance demands the best possible retention at high throughput of the system’s low-throughput characteristics, viz. resolution, noise, low-energy tailing. Using the OI detector with either the XP3 analog processor or the CSX3 digital processor, we observe very similar spectrum quality at modest input rates; the sole exception is pile-up (see section 2.5 below), where the CSX3 is superior.

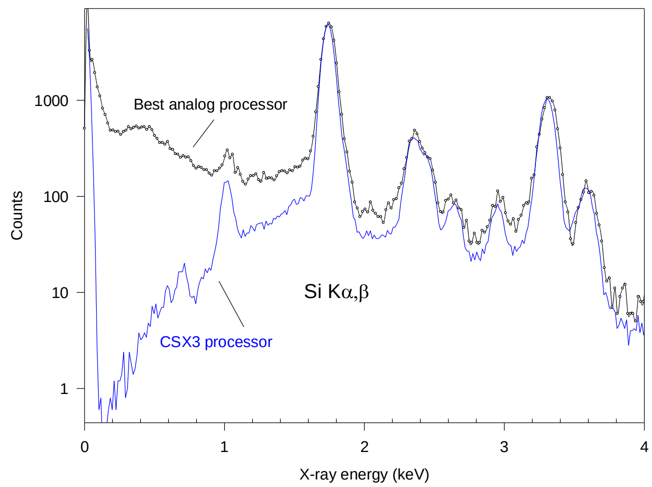


Figure 1 Comparison of PIXE spectra taken by a Si(Li) detector in a "noisy" environment. The spectrum produced by the analog processor (-○-black) shows significant noise below 1 keV as well as peak broadening throughout the spectrum. The CSX3 digital processor (-- blue line ) is much less impacted by the presence of the electrical noise and shows the normal low energy drop off expected with a Be window Si(Li) detector.

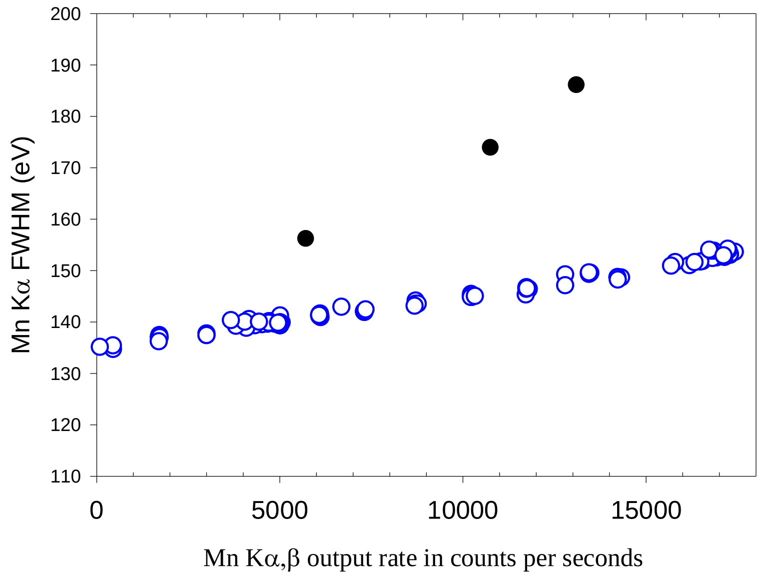


Figure 2 Resolution of the 5.9 keV Mn Kα line vs. signal output rate for an analog processor (● ) and the CSX3 digital processor ( ○) both operated at 30,000 cps input rate. The superior performance of the CSX3 offering higher throughput with smaller resolution penalty is clearly evident.

Figures 2 and 3 show the resolution and pile-up performance of the OI detector operated at 30,000 cps input rate with the OI analog processor and the CSX3 digital processor. For the analog processor, the only adjustable parameters are the input mode (slow or fast) and the processing time $T_p$; our measurements were made in fast mode at the three values of $T_p$ (2.5, 5, 10 μs) that provided meaningful spectra. The digital processor offers more variability: adjustments include peaking time, adaptivity, and separate discrimination levels for rise-time, noise level and pile-up. Of course, the possibility exists that stringent application of these adjustments to optimize on specific parameters may cause a reduction in the intensity of genuine x-ray events. These figures clearly show that the CSX3 digital processor provides superior performance as measured by both peak resolution and pile-up rate at high input rates.

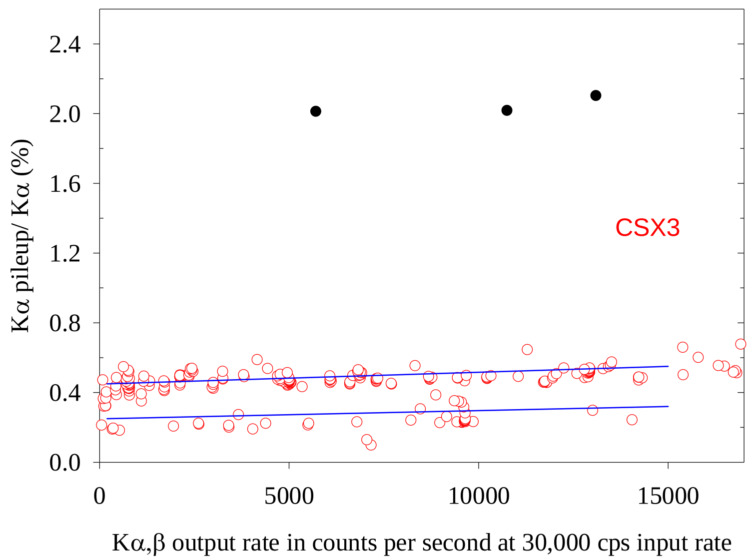


Figure 3 The per cent Mn Kα peak pile-up vs. signal output for the analog processor (● ) and CSX3 digital processor ( ○) operating at 30,000 cps input rate. The two groups of points for the CSX3 (as indicated by the lines) represent two different rise time discrimination values, with a resultant 5 to 10 times improvement over the analog processor.

## 2.3 Background reduction

The rise-time discrimination mentioned in the previous section enables the CSX3 to reject a small portion of continuous background. As an example, we show in Fig. 4 a portion of the spectrum of $^{241}$Am, a standard radionuclide that is widely used to determine X-ray detector efficiency. The background underlying the L X-ray peaks is mainly due to Compton electrons from scatter of high-energy gamma rays from this source. The background reduction afforded by the CSX3 enables a more accurate extraction of the intensity of the Ll and Lα peaks. The long rise times associated with the removed events presumably mean that they occurred in peripheral weak-field regions of the Si(Li) detector.

## 2.4 Spurious peaks

Figure 5 shows an $^{55}$Fe spectrum from a particular Si(Li) detector, using the manufacturer's suggested third party digital processor and the CSX3 processor. The CSX3 offers a large reduction in degraded background in the 0 -5 keV region. The absence in the CSX3 spectrum of the peaks seen in the upper spectrum at 0.6 and 2.8keV suggests that these are electronic artifacts.

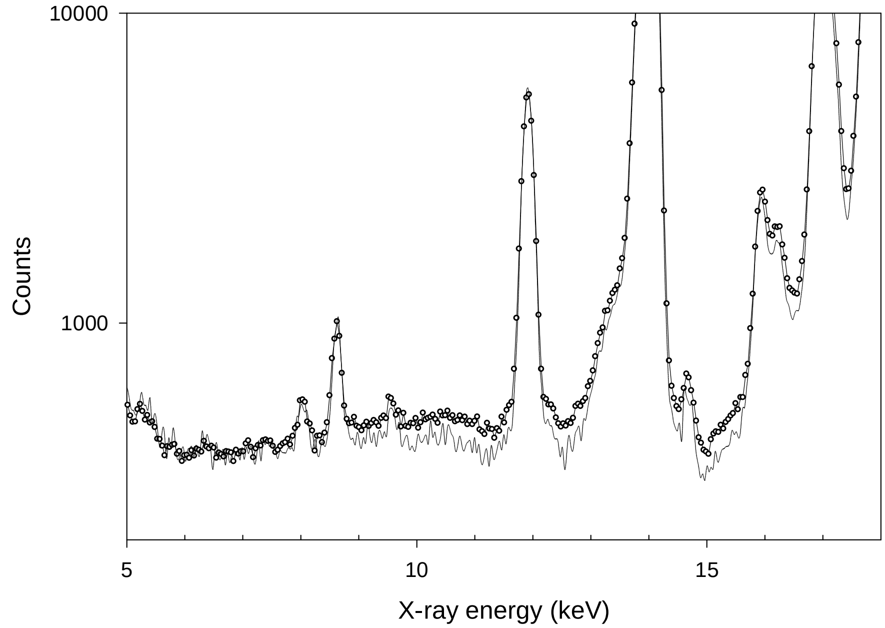


Figure 4 Shown here is a portion of $^{241}$Am spectra processed by the analog system (-○-) and the digital CSX3 (--). The background in this region is mainly due to Compton electrons scattered in the detector by gamma rays from the source. The reduction of this unwanted spectral interference feature by the CSX3 is readily visible and makes the peak evaluation more reliable.

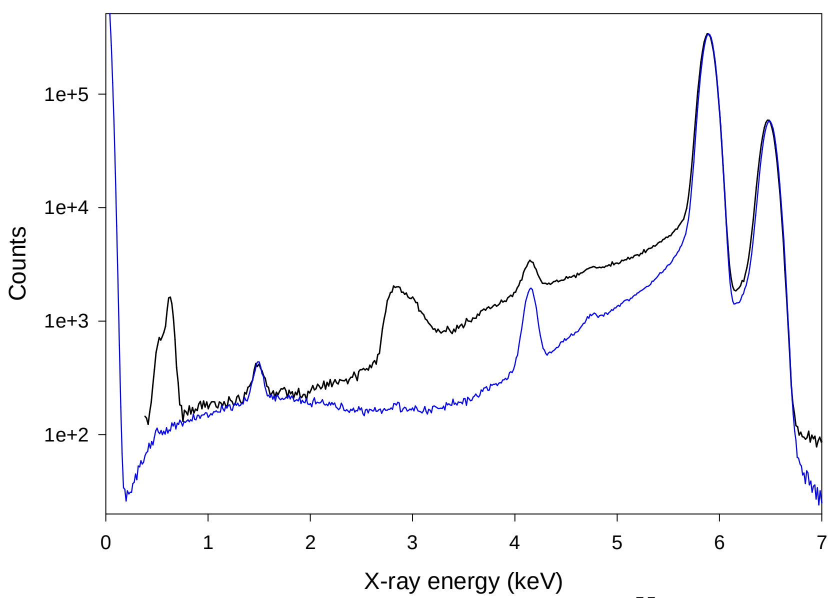


Figure 5 . Electronic artifacts are visible in this $^{55}$Fe spectrum taken with a Si(Li) detector and the manufacturer's recommended third party digital processor (black ), while they are absent in the spectrum of the CSX3 processor (blue). These spectra were measured in parallel and in vacuum so no argon peak should be visible. In addition, the CSX3 greatly reduces the low energy peak tailing.

2.5 Pile-up

Figure 6 is taken with the OI detector that we regard as having excellent lineshape, at an input counting rate of 4500 cps. The upper spectrum was taken with the OI XP3 analog processor set at 80 μs processing time to attain optimum resolution and pile-up recognition. The lower spectrum taken simultaneously with the CSX3 processor shows significantly reduced pile-up.

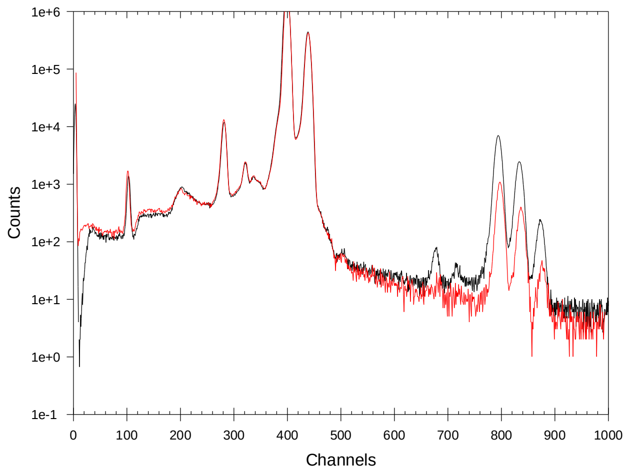


Figure 6 Two $^{55}Fe$ spectra obtained simultaneously with the analog processor (black) and the CSX3 digital processor (red) at a moderate input rate of 4500 cps. The analog processor was operated at 80 us processing time to obtain optimal resolution and pile-up recognition. The CSX3 unit produces an equivalent quality spectrum in the region of the Mn K lines but much reduced pile-up peak intensities.

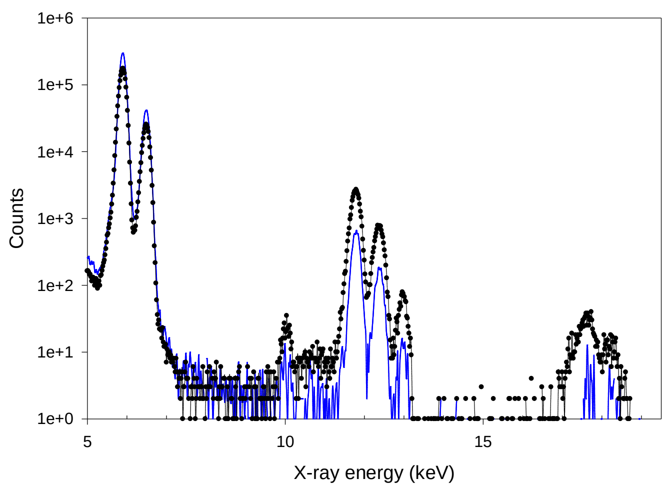


Figure 7 . Relative peak pile-up intensity and distortion is shown in these $^{55}Fe$ spectra taken at an input rate of 30,000 cps using the analog processor (black ) and the digital CSX3 processor (blue). The CSX3 not only produces less pile-up intensity, it apparently reduces the pile-up peak distortion making analysis of peaks in this spectral region much easier.

In PIXE analysis it is important to fit the pile-up features in the spectrum with high accuracy, and available PIXE programs such as GUPIX [4] and GEO-PIXE [5] offer the opportunity to fit pile-up to the third order. Figure 7 offers a comparison of the analog (processing time 10 μs) and the CSX3 digital processors on the OI detector, using a 30,000 cps input rate of manganese K X-rays from $^{55}$Fe. It appears that the CSX3 unit results in less distortion of the pile-up complex. This comparison was carried to an extreme situation through use of a 200,000 cps input rate: it is remarkable that the CSX3 spectrum shown in Fig. 8 appears to be distortion-free to the eighth order.

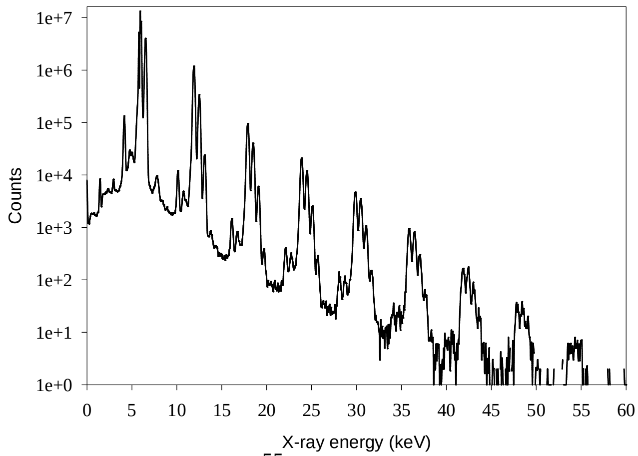


Figure 8. A CSX3 $^{55}$Fe spectrum taken at 200,000 cps input rate. It shows no apparent pile-up peak distortion out to eight orders.

2.6 Efficiency at low energies

A fall-off in observed Si(Li) efficiency is sometimes seen at low energies, relative to what is expected from the physical characteristics and lineshape of the detector [6]. Little attention has been paid to the issue of electronic efficiency and its measurement. Figure 9 gives an elegant illustration of this issue, based upon observation of the L escape peaks of zirconium in the spectrum of Zr L X-rays excited in a Zr foil by $^{55}$Fe radiation. The spectra taken with the XP3 and CSX3 processors differ little except in the enhanced background reduction at low energies afforded by the CSX3. Here the escape peaks are essentially equal in intensity and they offer a chance to quantify electronic efficiency in the low energy region of the spectrum through measurement of escape peak intensity ratios to their parent lines and comparison to theoretical values based upon absorption coefficients.

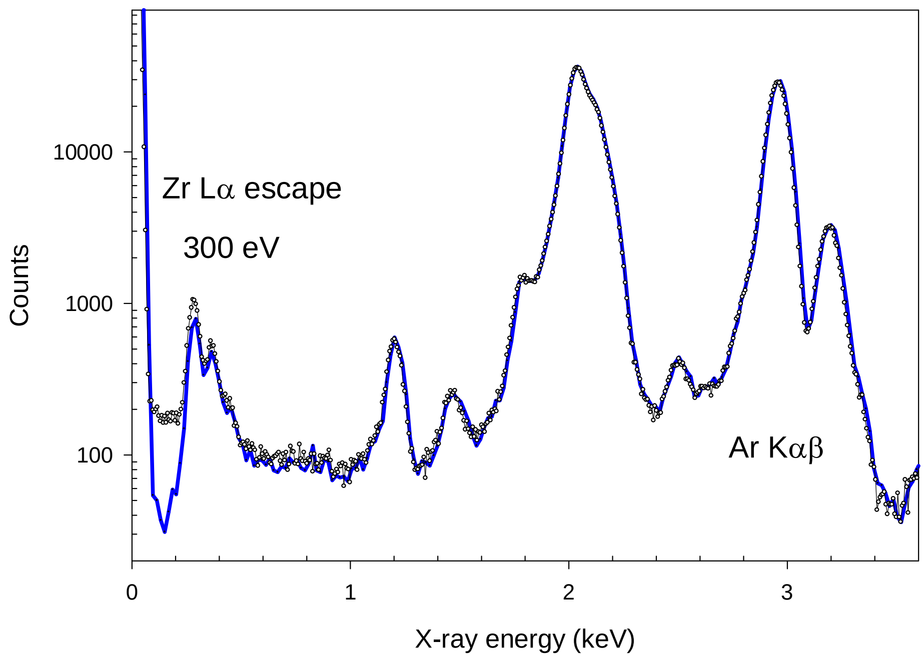


**Figure 9** Here we show low energy spectra of the analog (black) and CSX3 (blue) processors that are useful for illustrating a technique for potentially measuring the electronic efficiency of signal processors. It depends on measuring the escape to parent peak ratios and using the attenuation coefficients of the X-rays in the detector material to arrive at an efficiency value. These are Si(Li) spectra of Zr L X-rays and Ar K X-rays excited by an $^{55}$Fe source producing escape peaks from about 300 eV to 1.5 keV.

## 3. **Conclusions**

Probably the most important message we would like to leave with the reader is that the peak processing electronics system does matter. It is important for the analyst to be aware of and understand the capabilities of their system as well as its capacity to effect the spectral quality and thus the quantitative analysis of their spectra.

Some purely digital pulse processors, such as the Cambridge Scientific CSX3 used in the work described here, can offer the analyst improved performance and greatly reduced spectral distortion thus reducing potential sources of error in the quantitative analysis of spectra. In particular, with the CSX3 digital processor the analyst can increase throughput with little penalty in terms of performance, reduce pile-up and pile-up peak distortion, decrease "noise" in the spectrum, reduce some background components and provide an overall increase in spectral quality. It is worth noting that even under ideal conditions where many processors function well, the CSX3 generally provides improved pile-up recognition and spectral quality. However, it is under the non-ideal conditions that often apply in daily measurements that the CSX3 really makes a difference, greatly reducing spectral distortion and maintaining spectral quality.

In addition, the CSX3 digital processor with its large parameter set, provides the analyst with the opportunity to fine tune the setup to a particular application or to delve into the details of their detector system in order to better understand its response to stimuli and the spectrum features.

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