Pileup Inspection and Deadtime in the DXP-4C

Q: How is pileup inspection implemented in the DXP-4C ?

A. Two separate pileup inspections are implemented in the DXP-4C: slow channel pileup inspection and fast channel pileup inspection. The implementation of these inspections is illustrated in Figure 1, below. X-rays are detected using a fast trapezoidal shaping filter whose risetime (FASTLENGTH) and flat-top (FASTGAP) are typically in of order 200 ns and 0 ns, respectively. The output of this filter is examined using a threshold discriminator (THRESHOLD). For an x-ray not to pileup in the slow trapezoidal digital filter used to determine its energy, it must be separated from both the previous x-ray and subsequent x-ray by the sum of the slow filter's risetime and gap (SLOWLENGTH) + SLOWGAP. This test value (PEAKINT) is thus the minimum allowed interval between successive fast filter crossing of THRESHOLD. If the slow filter output is valid (not piled-up) then it is sampled and latched for output after an appropriate delay (PKSAMP) following the x-ray's detection in the fast filter. Figure 1 shows these relationships for x-ray #1, which is well isolated from its neighbors. X-rays

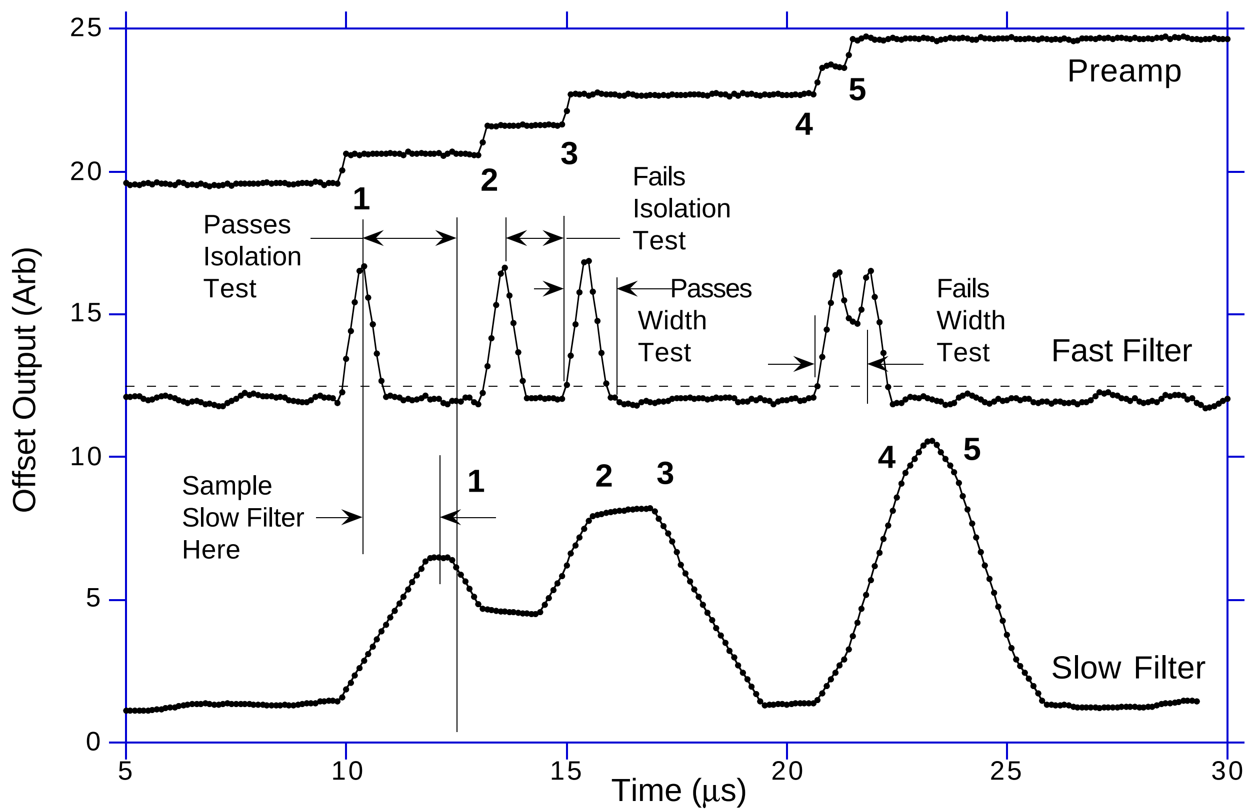

Figure 1: Schematic representation of the DXP-4C's digital filtering functions. The top trace is the digitized preamplifier output with numbered x-ray steps. The middle and bottom traces are the corresponding fast and slow filter outputs. X-ray 1 is adequately isolated, so the slow filter latches its output as indicated. Pulses 2 and 3 are resolved by the fast filter but pileup in the slow filter. Pulses 4 and 5 pileup in the fast filter, but are rejected on the basis of fast filter pulse width.

#2 and #3 are too close together and pileup in the slow channel filter (see how the slow filter output does not have two discrete peaks). They fail the slow channel isolation (PEAKINT) test and so neither is sampled or latched for output. The fact that two x-rays were detected, however, is noted by the ICR (Input Count Rate) counter, which counts all THRESHOLD crossing in the fast filter channel.

Because the fast filter has a finite time width, there will also be x-ray events which it cannot resolve and which will therefore appear to be "single" events, when they are, in fact, piled-up "doubles". The DXP-4C tests for such events using a fast filter width (MAXWIDTH) test. Because of the nature of digital filtering, pulse widths are substantially independent of pulse amplitudes (excluding only preamplifier settling effects). Therefore the "width" of fast filter peaks is a relatively well defined quantity and can be tested. As shown in Figure 1, when two x-rays (#4 and #5) fall so close together that they are not resolved in the fast channel (the signal does not fall below THRESHOLD between them), they result in a "wide" peak, which then fails the MAXWIDTH test. While the slow filter output may approximate the output from a single x-ray, the fast channel test has detected its corruption and it is not sampled or latched for output.

Q: How do I do deadtime corrections using the DXP-4C?

Because the DXP system digitizes the preamplifier signal and is pipelined, there are no deadtime penalties incurred for performing the spectral analysis. The captured slow filter estimate of x-ray energy (e.g. the peak for x-ray #1) is already a digital value. "Binning" this value simply means adding 1 to the memory location referred to by the value (that is, the value acts as a digital bin address). This one reason why the DXP typically has even faster throughput than analog systems outfitted with single channel analyzers (SCA's) because SCAs typically introduce some additional deadtime as part of their peak detection circuitry.

The DXP-4C reports the following numbers: (1) the spectrum of output counts (number per energy bin) from the slow filter channel; (2) their sum, the slow filter Total Output Counts (TOC_s); (3) the total number of x-rays detected in its fast channel (TOC_f); and (4) total livetime, t_L, as measured by its internal system clock. The "Livetime" is the time during which the DXP is actually available to capture x-ray peak values from the digital filter. For example, times when the preamplifier is resetting are not counted as part of the live time.

To first order (valid when the product of twice the fast channel peaking time and the true Input Count Rate (ICR) is << unity) Output Count Rates (OCR) from both fast and slow channels can be described in the paralyzable deadtime approximation by equations of the form

$$OCR_{s(f)} = ICR \exp(- ICR\ \tau_{ds(f)}), \qquad (1)$$

where τ_{ds} and τ_{df} are the slow and fast dead times, respectively. It is important to note that, while the fast channel OCR_f is commonly reported as "ICR", it too will suffer from deadtime effects and must be corrected if the highest accuracy is to be obtained. This issue is often overlooked or ignored when using conventional analog electronics. It should also be noted that the maximum slow filter output couting rate value OCR_s will occur at $ICR_{max} = 1/\tau_{ds}$, at which point $OCR_s = ICR_{max}/e = 1/(e\ \tau_{ds})$.

Given an accurate value for τ_{df} (note, surprizingly, that τ_{ds} is not required in the correction procedure), producing spectra which have been corrected for all deadtime and livetime effects to order ($ICR\ \tau_{df}$)then proceeds according to the following recipe:

First, for each experimental point, obtain values for OCR_f and OCR_s and the rates in the individual spectrum bins by dividing TOC_f, TOC_s, and the counts in the spectrum bins by t_L.

Second, taking OCR_f and τ_{df}, numerically invert Eqn. 1 to obtain the true value of ICR.

Third, form the scaling constant $K = ICR/OCR_s$, which is the inverse of the ratio between the corrected estimate of the total number of counts that actually impinged on the detector and the number that were actually spectrally binned by the DXP

Fourth: rescale the spectrum by multipling the rate in each bin by K. The spectrum is now corrected for both all deadtime and livetime effects. Note that if error bars are required for the spectrum, the square roots of the original counts in the bins should be divided by t_L and then rescaled by K.

Q: OK, so how do I determine the fast and slow filters' deadtimes?

A: The best way is to measure throughput curves (output values) as a function of some well defined series of input rates. For a laboratory source, this would mean measuring both fast and slow channel OCR's vs tube current. Remember to take a reasonable number of measurements at low current, since these will determine the proportionality constant between current and true ICR. For a synchrotron source, do a table scan so the entrance slits are scanned across the input beam defined by the monochromator slits. Set up a strongly fluorescing target and be sure to include an input ion chamber between the table slits and the target. Then, as the table scans, you can record OCR values from the detectors viewing the target as a function of ion chamber current. Again, the values at low ion chamber current will define the proportionality constant between ion current and true ICR. The resultant data should appear as in Figure 2 below.

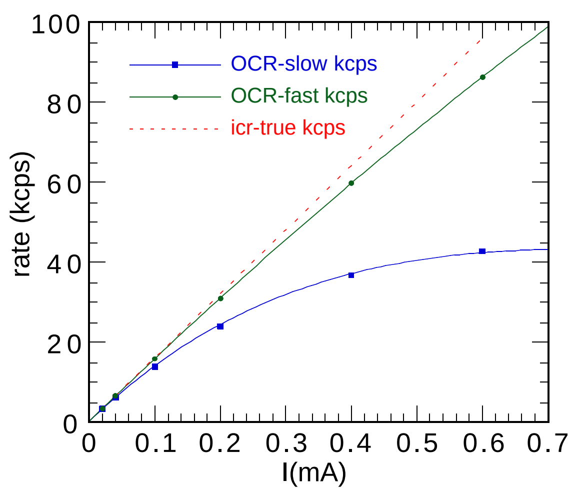

Fig. 2: Showing throughput curves of OCR_f and OCR_s versus tube current in a laboratory measurement of τ_{df} and τ_{ds}. The solid curves are fits to the data using Eqn. 2.

Both fast and slow channel OCR values can be fit using an equation of the form:

$$OCR_{f(s)} = K\, I \exp(- K\, I\, \tau_{df(ds)}) \qquad (2)$$

to determine both slow and fast channel dead times τ_{ds} and τ_{df}, although only τ_{df} is required for a complete deadtime correction. In Eqn. 2, I is either the tube current or ion chamber current, as appropriate, and K is the proportionality constant to true ICR (i.e. true ICR = K I). Thus, in Fig. 2, we find τ_{df} = 450 ns and τ_{ds} = 8.6 µs. These values can be expected to depend upon the fast and slow filter parameters, including MAXWIDTH, so if these values are changed, then τ_{df} and τ_{ds} should be remeasured.

Q: What kind of accuracy can I expect from making these corrections?

A: We experimentally investigated the accuracy with which these corrections may be carried out using a conventional XRF analysis machine. Figure 3, below, shows the accuracy with which the area of a Mn K_α peak can be recovered as a function of ICR for a 4 μs slow filter peaking time. Two cases are shown, one where the sample consisted of pure MnO_2, and one with the identical MnO_2 sample plus the addition of a pure Ag sample which produced approximately three times as many counts in the detector. Figure 2 shows both OCR_f and OCR_s versus tube current in the MnO_2 plus Ag case. Figure 3 shows how the ratio of the area of the Mn K_α peak in the pure MnO_2 case to the area of the Mn K_α peak in the MnO_2 +Ag varies as a function of tube current. The ICR may be found from Fig.2. As may be seen, the peak area can typically be recovered to better than 0.5% accuracy over a very wide range of ICR values (e.g. from 0 to 100 Kcps in the MnO_2 plus Ag case, where ICR_{max} = 116 Kcps.). We believe that the slight average offset of the ratio from unity is due to secondary MnO_2 fluorescence, excited by Ag K_α radiation from the nearby Ag target in the MnO_2 +Ag case, which raises the Mn K_α yield slightly in the mixed target case.

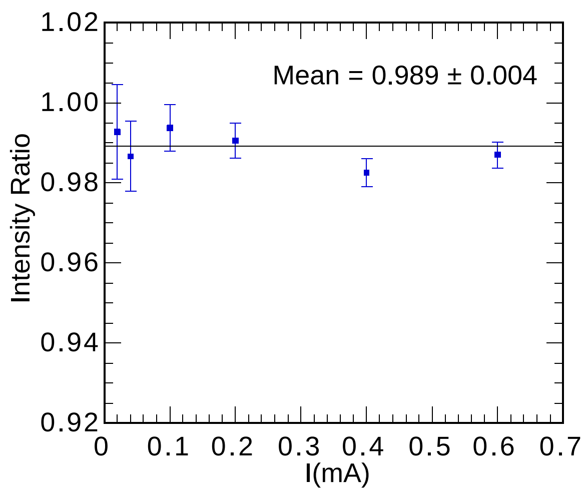

Fig. 3: Experimental investigation of the accuracy of deadtime correction techniques. **a)** Fast and slow channel OCR values as a function of tube current for the MnO_2 plus Ag case, showing the range of ICR values explored. **b)** Extracted Mn K_α peak area deviations versus tube current in the two cases.