Amptek Inc.

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DEAD TIME, THROUGHPUT, AND PILE-UP IN THE DP4

Difference between digital and analog systems

- In most analog spectroscopy systems, the “dead time” listed in the specification is only the time to digitize and capture the peak and the “dead time correction” corrects only for pulses lost due to this process. Since this is usually the longest dead time, it is the dominant correction but not the only one.
- In Amptek’s digital processors (DP4, PX4, X123, and GammaRad), there is no dead time due to peak digitization. The dead times correspond to the second order corrections to dead time in analog system, due to overlap of shaped pulses.
- Most analog systems only record the rate of the slow pulses, those in the output spectrum. A faster pulse is used internally, for pile-up rejection, but this is not sent to the MCA and so not recorded. Dead time must be corrected based on the slow channel data. In Amptek’s digital processors, the fast channel rate is always recorded and is known and this is much more accurate, so makes a more accurate correction possible.
- Most analog pulse shaping is asymmetric in the time domain, with a longer tail than rise. The digital systems use true triangular shaping, with a high degree of symmetry. The start and end times of the pulse are very well known, permitting shorter and better known dead time intervals.

The input count rate and the fast channel measurement

- The true rate of interactions in the detector is R_{In}.
- R_{In} can be determined from the DP4’s fast channel rate measurement, R_{Fast}, which has a peaking time of 400 nsec and a non-paralyzable dead time of 800 nsec. R_{Fast} is related to R_{In} by

$$R_{FAST} = \frac{R_{In}}{1 + R_{In}\tau_{Fast}} \quad \Rightarrow \quad R_{In} = \frac{R_{FAST}}{1 - R_{Fast}\tau_{Fast}}$$

  where $\tau_{Fast} = 0.8$ μsec.

- The ADMCA software reports R_{Fast} as the “Total Rate”. The total fast counts recorded in an accumulation interval T is reported as “Input Counts”.
- The factor $1/(1-R\tau)$ makes a 1% correction at $R_{In} = 1.2\times10^{4}$ sec^{-1}. If 1% accuracy in count rate is adequate, then no correction is needed up to 12 kcps. This is independent of peaking time since this is based on the fast channel’s dead time, which is constant.

The slow channel count rate

- The data shown in the main spectrum are processed by the slow channel, which has some peaking time τ_{Peak} and a flat top duration τ_{Flat}. It has an output rate R_{Out}, the total rate of events recorded in the spectrum. This total counts in the spectrum recorded in an accumulation interval T is reported in ADMCA as “Counts”.
- If pile-up rejection is disabled, the slow channel has a paralyzable dead time equal to the sum of the peaking time and the flat top time. In this case, the measured count rate R_{Out} is

$$R_{Out} = R_{In}\left(e^{-R_{In}(\tau_{Peak} + \tau_{Flat})}\right) \qquad \text{Pile-Up Rejection Disabled}$$

- If pile-up rejection is enabled, the equation is the same but the dead time is longer. There is a factor of two arising from the fact that two pulses are rejected and a factor of 19/16, which is the pile-up inspection interval

$$R_{Out} = R_{In}\left(e^{-(2.375)(R_{In})(\tau_{Peak} + \tau_{Flat})}\right) \qquad \text{Pile-Up Rejection Enabled}$$

- The difference between these two is clearly the rate of piled-up events. These occur at a range of time intervals, and given the triangular shaping, for a monoenergetic source these will lead to a flat continuum from the primary peak to twice the primary peak
- The pile-up rejection circuit uses the fast channel, which has a pulse pair resolving time τ_{PUR}=400 nsec. If two pulses occur within 400 nsec, then the pile-up is not detected. This leads to a sum peak. The rate of events in the sum peak is

$$R_{Sum} = R_{In}\left(1\text{-}e^{-(R_{In})(\tau_{PUR})}\right)$$

Correction Factors

- The true input count rate can be determined from the measured fast rate using the equation above:

$$R_{In} = \frac{R_{FAST}}{1 - R_{Fast}\tau_{Fast}}$$

- To determine the true rate at any channel, simply scale using the ratio R_{In}/R_{Out} where R_{In} is computed above and R_{Out} is the ADMCA reported “counts” divided by accumulation time. To be specific, if the system records $Meas_i$ counts in channel i, then the true rate at channel i $True_i$ is

$$True_i = Meas_i\left(\frac{R_{In}}{R_{Out}}\right)$$

- The equation for the sum peak above can be used to remove the sum peaks and add them back to the main peaks, if desired.

Caveats

- These equations are very simple and accurate but apply as long as R_{In} and R_{Fast} , and R_{Out} represent the rate of all real interactions. The digital processors record the total rate of events above thresholds, with separate thresholds for the fast and slow channels.
- These equations apply very accurately for a monoenergetic source with thresholds set well above the noise and well below the source.
- A common difficulty arises from noise. The fast threshold is often set low enough for noise counts to be recorded at a low rate, say 3 sec^{-1}, while the slow threshold is set a little higher, with no noise counts. If there are few counts from the source, say 3 sec^{-1}, then the equations above imply a 50% dead time! One solution is to measure the count rates with no source and then subtract from the measured rates to get the signal rates. A second solution is to make no correction for count rates below some threshold.
- Another common situation is to have a wide distribution of energies rather than monoenergetic peaks. The fast channel has more noise than the slow, due to its faster shaping time constant, and so its threshold is higher. This means that more signal counts are recorded in the slow channel.

SAMPLE RESULTS

The plots below show typical results. These are a series of spectra, recorded using an X123 with a 13mm^2 Si-PIN detector. Peaking time was set to 32.0 μsec. A 0.5 mCi 55Fe source was the stimulus source, at distances from 0.5 to 7".

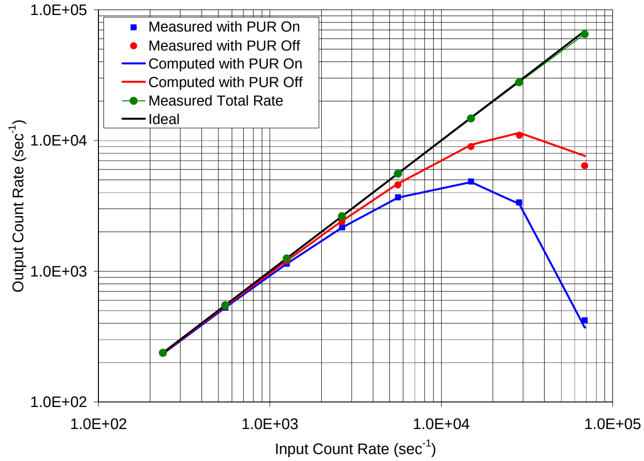

Figure 1. This plot shows the input and output count rate. The fast rate was corrected, using the equations above, to derive the input rate. The correction was generally small, 5% at the highest input rate where the dead time of the slow channel was 99.6%. The colored curves and dots compare measured values with those computed using the equations on pages 1 and 2.

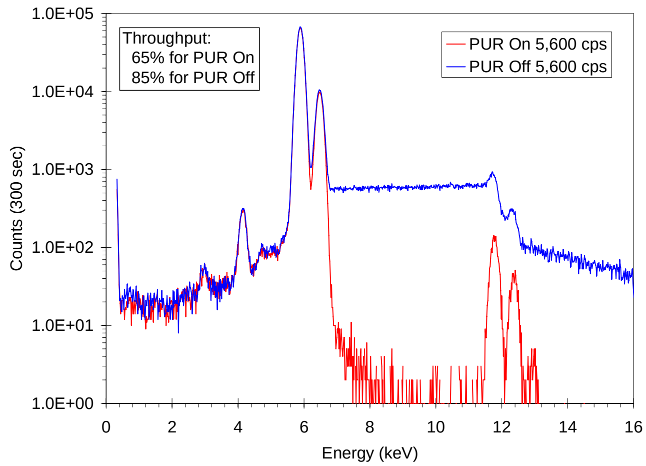

Figure 2. This plot shows the spectra with PUR on and off at an input count rate of about 5,600 sec^{-1}. With PUR on, the primary peaks are seen and the sum peaks. The rate of these sum peaks was measured to be 10 sec-1, while the equation above predicts 12 sec-1. With pile-up reject, the flat shelf up to the sum peak is visible, along with a tail towards higher order sums.

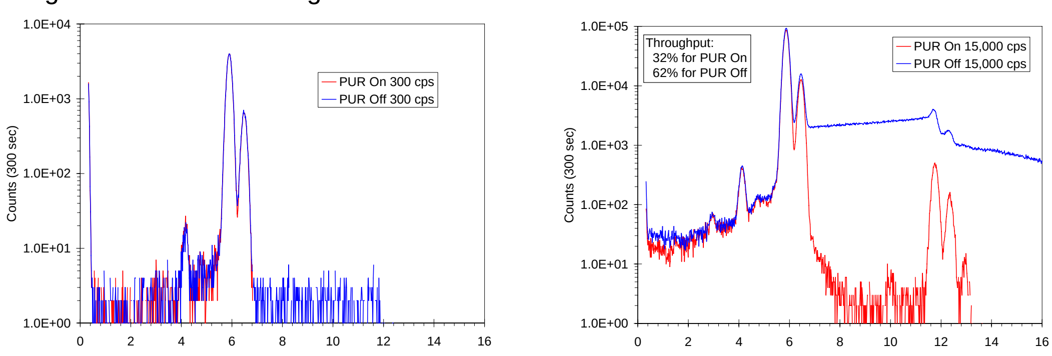

Figure 3. These are similar results but at 300 cps and at 15 kcps, where throughput is only 32% for PUR On.

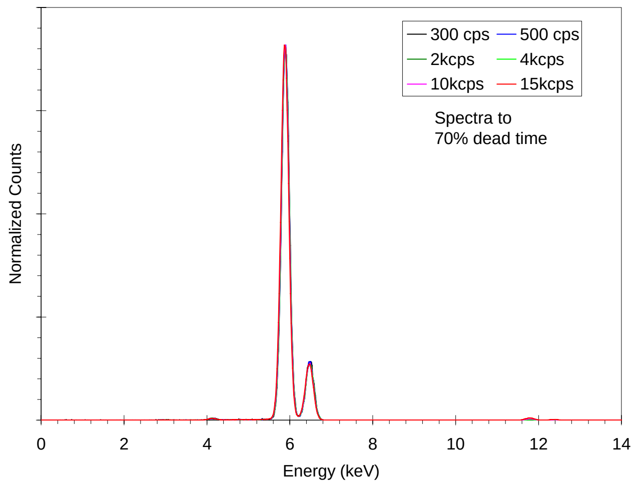

Figure 4. Plot showing spectra taken up to 70% dead time, with pile-up reject enabled. On the linear plot and at this scale, there is essentially no change in the spectrum over this range.

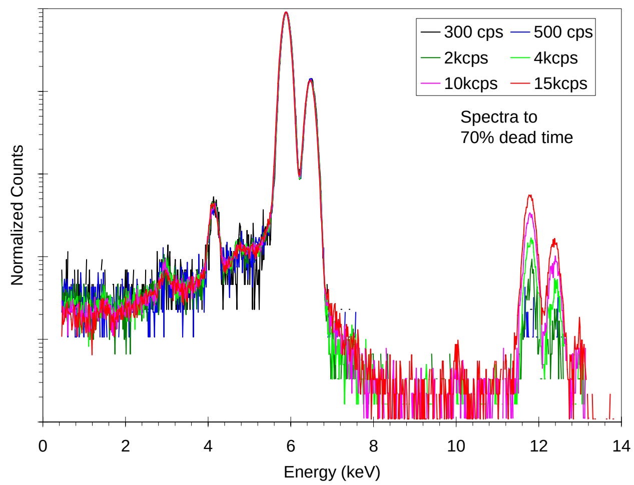

Figure 5. Same data but on a log plot. The sum peak due to pile-up is visible, along with a few other pile-up counts just above the photopeak.

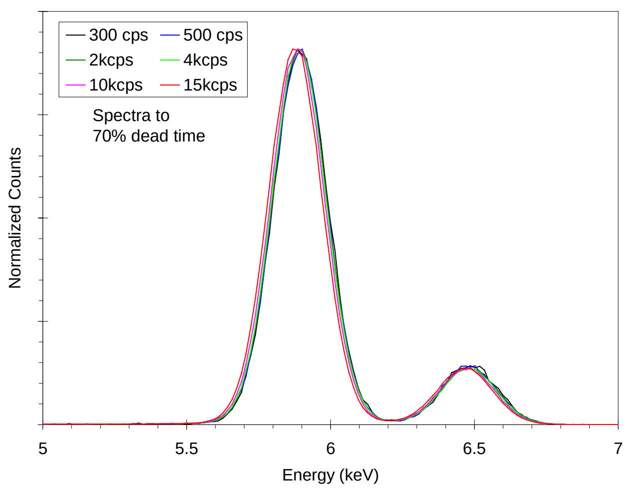

Figure 6. Same data as in the previous two plots, but on an expanded linear scale. There is a slight baseline shift, of about 4 eV, with no change in resolution. This demonstrates the stability of the system.