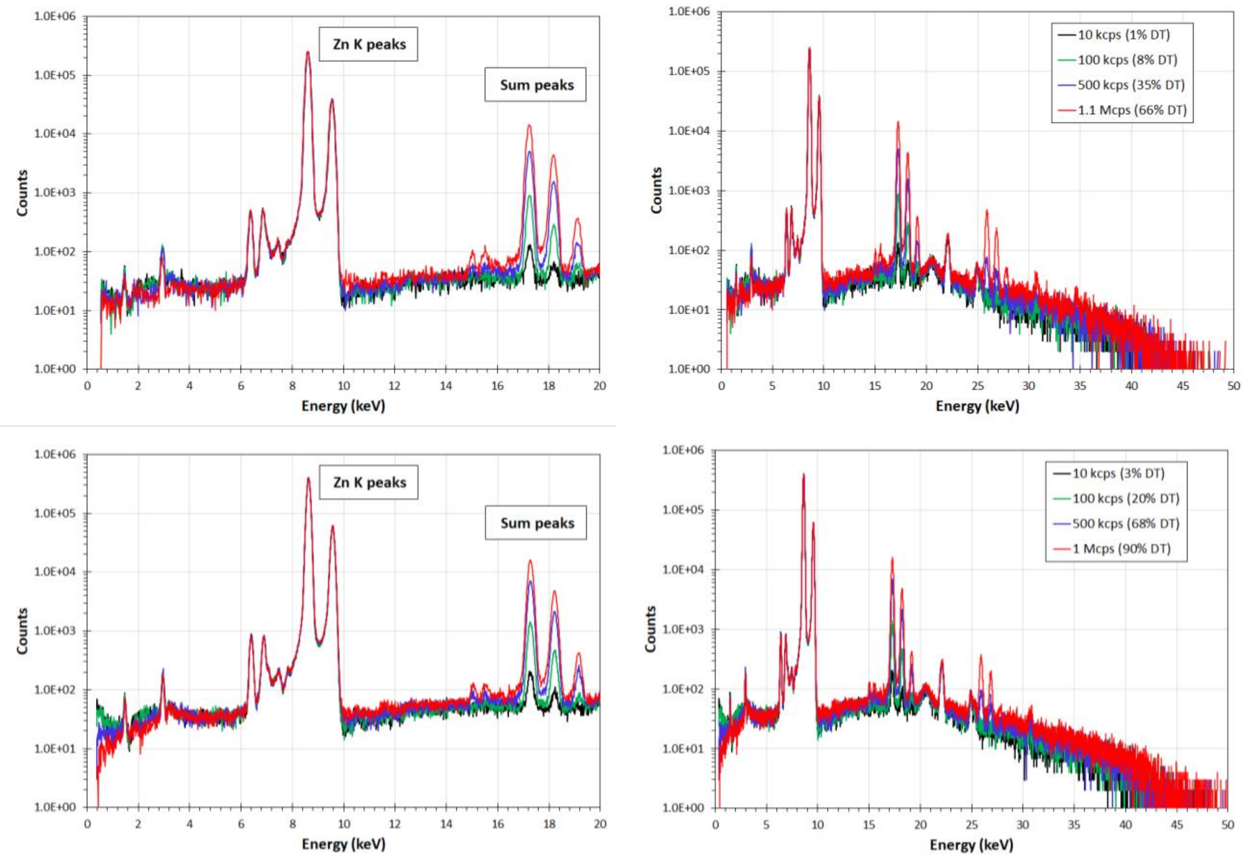
High Rate Performance in Amptek FASTSDD® Detectors

Amptek's FASTSDD® detectors can be used at count rates exceeding 1 Mcps. Operating at such high rates will lead to improved statistical precision or to reduced measurement times, both of which are extremely valuable. As a general rule, operating at high count rates is advantageous[1]. But this is only true if the spectrometer is properly configured, and even when properly configured, there are trade-offs. The primary goal of this application note is to explain (1) what can be expected when operating Amptek's FASTSDD® detectors at high count rates and (2) how to optimize the spectrometer settings for best operation at high count rates.

What is typically observed for the performance of the FASTSDD® at high count rates?

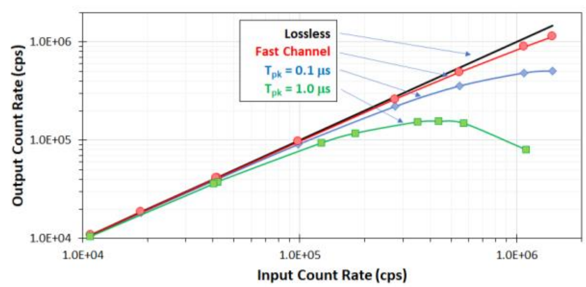
The charts below show results measured at Amptek, using a 25 mm^2 FASTSDD®, an Amptek DP5-X digital pulse processor, with a 50 kV X-ray tube (Ag anode) exciting a 99.9% pure Zn target. Data were taken at T_{pk}=0.1 μs (for the highest rates) and at T_{pk} =1.0 μs (for lower rates but better resolution). Various signal processing parameters in the DP5-X were tuned to optimize the system for high count rates (how to optimize is discussed later in this application note). The tube current was adjusted to give input count rates from 10 kcps to over 1 Mcps; spectra were measured to obtain a fixed number of counts in the photopeak channel.

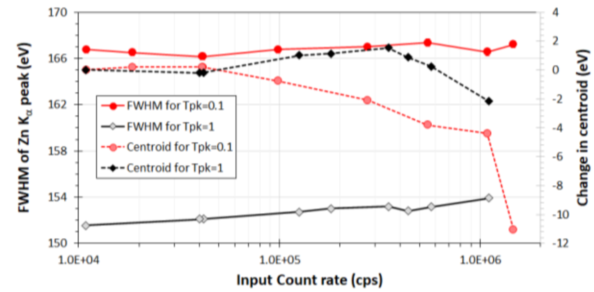
The plots below show spectra measured at T_{pk}=0.1 μs (top two) and at T_{pk}=1.0 μs (bottom two), at input count rates of 10 kcps, 100 kcps, 500 kcps, and 1 Mcps . The plot on the left shows that the Zn photopeaks are unchanged: the resolution of the Zn K_α peak is 167 eV FWHM at T_{pk}=0.1 μs and 152 eV FWHM at T_{pk}=1.0 μs. Notice that the peak to background and secondary peaks are unchanged even at the highest rates. There are sum peaks; the sum peak rates are as expected, they are Gaussian, and their FWHM is as expected and does not change with rate. The plots on the right shows that the spectra are as expected: at the highest rate, the higher order sum peaks and the sum continuum are seen.



[1] Redus, R.H., Huber, A., "*Figure of merit for spectrometers for EDXRF*," X-Ray Spectrom (2012)

The plots below show the throughput (left) and change in photopeak FWHM and centroid (right) in the spectra shown above.

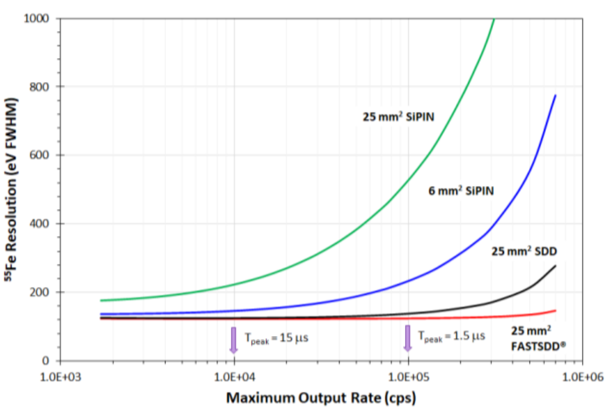


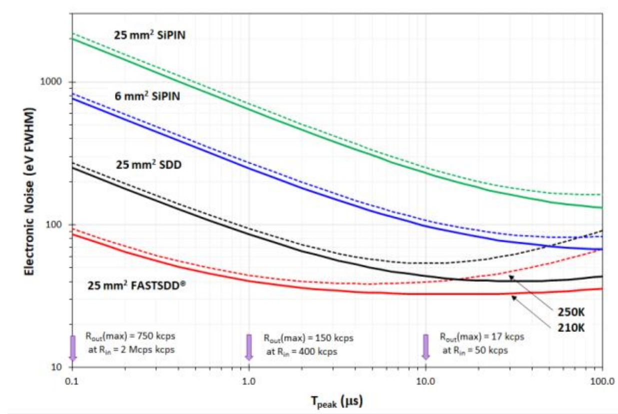


What are the intrinsic limitations to operation at high count rate?

Peaking Time, Count Rate, and Resolution

The most important factor determining both count rate and energy resolution is the peaking time. As the two charts below show, to operate at high count rates, the system must be configured for a short peaking time, and this necessarily worsens the resolution. The user needs to understand what is best for each particular application and adjust the peaking time appropriately.





Dead Time, Throughput, and Sum Peaks

Because it takes some time to process each X-ray, (a.k.a. the dead time per pulse, roughly equal to T_{peak}+T_{flat}) and the X-rays interact at random time, there is always some probability that pulses will overlap in time. This means that some pulses will not be counted, reducing the throughput.

When pulses overlap, the result (called "pile-up") is a pulse with distorted pulse height. Amptek's signal processors include pileup reject (PUR) logic to eliminate the vast majority of these pulses. The PUR logic does require a minimum time between the pulses (the "pulse pair resolving time"); two pulses occurring within this interval will (a) yield a single pulse with height equal to the sum of the two pulses and (b) not be rejected. The result is a "sum peak".

The fact that there is a dead time per pulse, that it limits throughput, and the existence of a sum peak are intrinsic to any pulse counting radiation detection system. Please refer to Amptek's application notes to understand how to accurately determine the true, input count rate with Amptek's digital pulse processor[2]. For background information on dead time, sum peaks, and so on, there are excellent textbooks available[3].

[2] See Amtptek's application note "*Understanding acquisition time and live time in Amptek DPPs*"

[3] G.F. Knoll, *Radiation detection and measurement*, 4th ed, John Wiley & Sons, p 92, 2010

Are there any anomalies at high count rates?

If the system is configured correctly, there should be no "anomalies." We expect sum peaks (and sum continuum); we expect dead time, as shown above. We expect small changes in FWHM and centroid, as shown above.

If the system is not configured correctly, then many types of anomalies are indeed possible. Larger dead times, larger shifts in centroid or FWHM, are possible. Various distortions of the photopeak shape, e.g. tails on the upper or lower end, excess low amplitude counts, are all possible.

If a customer sees "anomalies" at high count rates, please contact Amptek technical support. Please save a .MCA file (from the DPPMCA application) at low count rate and another .MCA file taken at high count rate and send these to Amptek. Seeing the complete file is quite important, so Amptek support has the raw data and can view all the configuration settings.

What is the maximum count rate for the Amptek FASTSDD®?

It depends on the requirements for spectral quality and purity. With the shortest peaking time (50 ns) and flat top (12.5 ns), the system can operate at over 4 Mcps input rate. But the resolution will be quite poor (due to both noise and ballistic deficit) and the resolution and centroids will shift. For some applications, which involve counting strong peaks in a wide ROI, this may be adequate.

For applications requiring good quality spectra, input count rates of 1 Mcps are quite achievable, as shown above. With careful tuning and certain applications, input rates can go higher, even to 2 Mcps.

Is Amptek's default configuration the best for high count rate?

No! By default, when Amptek tests a system at the factory, it is configured for the best energy resolution at the ^{55}Fe photopeak. It uses a relatively long peaking time, so clearly T_{peak} needs to be shortened. As shown below, other parameters will likely need to be changed as well.

What configuration do you recommend for high rates?

The table below shows the key parameters which should be adjusted, for Amptek's digital pulse processors. The first column shows settings from Amptek's default configuration, used in the factory to measure ^{55}Fe resolution. The second and third columns show the configuration settings used for the spectra shown above. The second column used T_{peak}=1.0 µs and is appropriate for count rates up to 50 to 300 kcps. The third column used T_{peak}=0.1 µs and is recommended for count rates of 300 kcps to 1 Mcps or above.

Default	Up to 300 kcps	Up to 1 Mcps	Parameter	Comments
CLCK=80	CLCK=80	CLCK=80	20MHz/80MHz	
TPEA=4.000	**TPEA=1.000**	**TPEA=0.100**	**Peaking Time**	**Most important parameter for high rates**
GAIF=1.1001	GAIF=1.4970	GAIF=0.9977	Fine Gain	
GAIN=25.000	**GAIN=6.000**	**GAIN=3.999**	**Total Gain (Analog * Fine)**	**Gain should be low for higher rates**
RESL=50	**RESL=15**	**RESL=15**	**Detector Reset Lockout**	**Reset lockut of 15 us is fine for FASTSD**
TFLA=0.200	**TFLA=0.175**	**TFLA=0.175**	**Flat Top**	
TPFA=100	TPFA=100	TPFA=100	Fast Channel Peaking Time	
PURE=ON	PURE=ON	PURE=ON	Pileup Reject On/Off	
RTDE=OFF	RTDE=OFF	RTDE=OFF	RTD On/Off	
MCAC=2048	MCAC=4096	MCAC=4096	MCA/MCS Channels	
SOFF=OFF	SOFF=OFF	SOFF=OFF	Set Spectrum Offset	
AINP=POS	AINP=POS	AINP=POS	Analog Input Pos/Neg	
INOF=DEF	INOF=DEF	INOF=DEF	Input Offset	
	PURS=100	**PURS=100**	**Secondary PUR**	**Need latest FW to use this feature.**
THSL=1.708	THSL=0.756	THSL=0.756	Slow Threshold	**Adjust thresholds after changing Tpeak, gain, and BLR mode**
TLLD=OFF	TLLD=OFF	TLLD=OFF	LLD Threshold	
THFA=39.00	THFA=3.00	THFA=3.00	Fast Threshold	
RTDS=139.8	RTDS=139.8	RTDS=139.8	RTD Sensitivity	
RTDT=1.56	RTDT=0.97	RTDT=0.97	RTD Threshold	
BLRM=1	**BLRM=3**	**BLRM=3**	**BLR Mode**	**Need latest FW to use this feature.**
BLRD=3	BLRD=3	BLRD=3	BLR Down Correction	If using BLR mode 1, you may improve centroid stabiity by empirally adjusting these
BLRU=0	BLRU=0	BLRU=0	BLR Up Correction	
HVSE=-135	HVSE=-135	HVSE=-135	HV Set	
TECS=200	TECS=226	TECS=226	TEC Set	

What factors are important, if I want to optimize the configuration for myself?

T_{peak}, T_{flat}, T_{fast}

As noted above, T_{peak} is the most important parameter in determining the maximum count rate. A short peaking time allows operation at higher count rates but leads to degraded resolution (the noise bandwidth of the filtering electronics is greater). The maximum output count rate is found at a dead time of 68%, but in general, we recommend limiting the dead time to 50% or lower. A higher dead time implies a larger correction and this can degrade accuracy.

For SDDs and FASTSDDs, we recommend a T_{fast} of 0.1 μs. You can make it shorter, but since this gets convolved with the charge collection time in the SDD, you don't gain much in the ability to resolve closely space pulses which the noise in the fast channel increases significantly. For the lowest energy applications, e.g. EDS, where T_{peak} is long for the best resolution, you can increase T_{fast} to reduce the noise threshold in the fast channel.

For most peaking times, a T_{flat} of 0.2 μs is recommended. For the shortest peaking times, this can be reduced, but if it is made too small, an effect called "ballistic deficit" will make the FWHM worse and the photopeak shape will be non-Gaussian, with a tail towards lower amplitudes. A T_{flat} shorter than 0.15 μs may give ballistic deficit. Note that T_{flat} should always be longer than T_{fast}; if it is shorter, the shape of the sum peak is distorted.

Gain

The gain of the digital processor should always be set so that the full spectrum is observed on the screen: off range pulses lead to distortions. At high rates, the gain should be reduced further: there can be tail pileup at the ADC input, and when this occurs, there will be anomalies in the spectrum. There is no "hard and fast" rule since it depends on both the rate and the spectrum, but as a general rule, lower gain is important to support high rates.

BLR and PURS

In early 2019, Amptek introduced a new version of firmware for the DP5 and DP5X processors, which included a new and improved baseline restoration algorithm (mode 3) and a "secondary" pileup rejection algorithm. This secondary pileup reject can detect and reject many events which were not rejected in the older, primary algorithm, so it reduces the sum peak intensities by typically half. These are described in a separate application note; please refer to Amptek's application notes "Secondary Pileup Rejection" and "Baseline Restorer Mode 3".

Reset lockout

For high rates, we recommend a reset lockout interval of 15 μs for the FASTSDD. Every time the preamp resets, the pulse shaping is distorted; data acquisition is stopped for the lockout interval, to avoid distortions. If the interval is shorter than 15 μs, then some distortions can be seen in the spectrum (typically a tail on the photopeaks). If the interval is much longer, then the difference between acquisition time and real time becomes quite long and the effective measurement time increases.

Thresholds

After the other key parameters are adjusted (T_{peak}, T_{flat}, T_{fast}, gain) then it is important to adjust the fast and slow thresholds. This is discussed in the DPPMCA Help file.