

OPTIMAL SIGNAL SHAPING IN SOLID STATE DETECTOR SPECTROMETERS

Mikhail A. Mikhailov, Lilianna Panteleev-Simeonova

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Abstract

The performance of the most widely used shapers in solid state detector spectrometers is investigated in respect to noise suppression and count rate ability. Three shaper types have been experimentally checked with two detector types – X-ray Silicon Drift Detector and HPGe gamma detector. The results show small difference in noise line width and negligible difference in obtainable energy resolution while the high count rate performance depends noticeably on shaper type selected. This allows for simultaneous optimization of noise and count rate performance.

Key words: signal shaping, noise line width, energy resolution, high count rate operation

Introduction. The type of the signal shaper used in a contemporary solid state detector spectrometer determines the performance in two aspects – obtainable energy resolution and achievable count rate.

The total energy resolution E_T can be expressed [1] as

$$(1) \quad E_T = (E_n^2 + E_s^2 + E_b^2)^{1/2},$$

where E_n is the noise line FWHM, E_s is the electron–hole pairs generation statistical FWHM (dependent on the incoming photon energy), and E_b is the ballistic deficit FWHM contribution that also depends on photon energy. The shaper affects E_n by filtering out part of the noise, but if the pulse is shaped to have a

flat top of duration longer than the maximum charge carrier's collection time, the shaper would also effectively remove E_b [2].

It is well known that the best possible signal to noise ratio would be achieved if the signal pulses are shaped to the form of infinite cusp. As this is impractical, various approximations are used. Some of them are shown in Fig. 1a. If the infinite cusp signal to noise ratio is 1, the most remote approximation – CR-RC shaper yields 0.736. The 4th order semi-Gaussian shaper's S/N is 0.858 while the triangular shaper (trapezoidal shaper without flat top) has S/N of 0.930 [3]. Thus these shapers give 1.359, 1.166, and 1.075 times wider E_n , respectively, in comparison to the infinite cusp. Of course the comparison is correct for equal peaking times. The closest approximation – finite flat top cusp is realized, for example in [4].

For the count rate performance, the achievable throughput is important. The output count rate in function of the input count rate is expressed by a formula derived by JENKINS et al. [5]. When the analogue to digital conversion adds no dead time (this is the case for all digital shapers and analogue shapers followed by adequately fast ADC), this formula simplifies to:

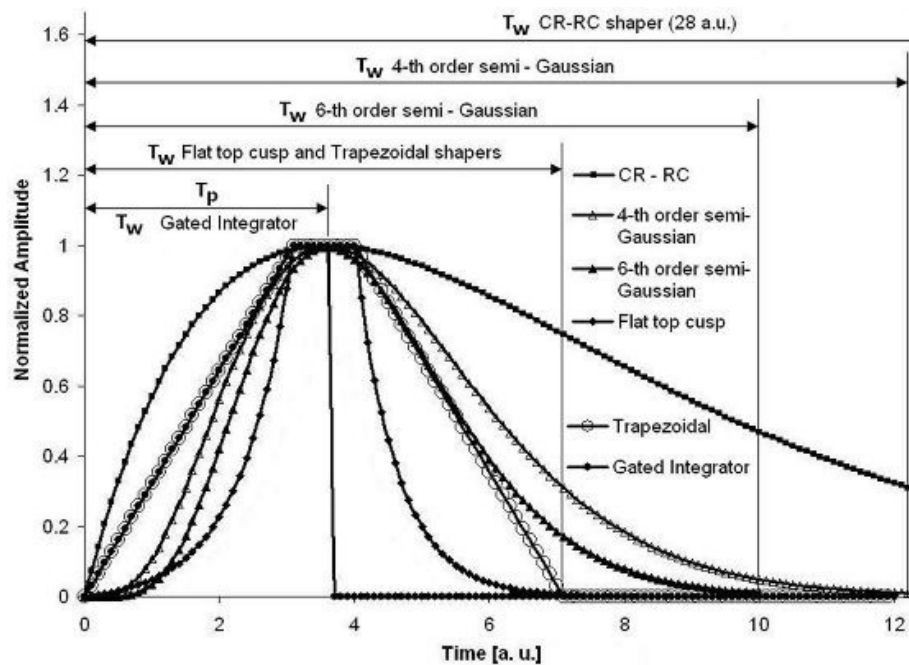
$$(2) \quad R_o = R_i / \exp[R_i(T_w + T_p)],$$

where R_o is the output count rate, R_i is the input count rate, T_w is the shaped pulse width, and T_p is the peaking time. It should be noted that (2) is also valid for the digital implementation of Gated Integrator with digital delay line shaper pre-filter, whose shaped pulse is in Fig. 1. The throughput curves for the shapers in Fig. 1a at equal peaking times are shown in Fig. 1b.

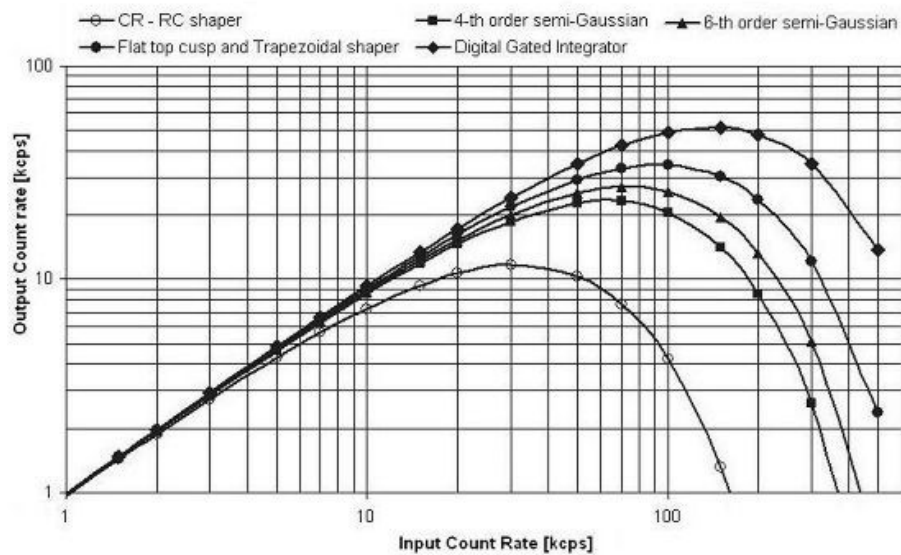
Experimental. From noise suppression point of view, shapers implementing closer approximation to finite cusp perform better. From count rate point of view the Gated Integrator works best. The obtainable energy resolution, however, depends on three components (1). Therefore it would be useful to estimate the improvement of real detector's noise line E_n and energy resolution FWHM by selection of a shaper representing closer approximation to infinite cusp. As measurements of all possible shapers is practically impossible, the presented investigation was limited to three shaper types – home-made analogue CR-RC shaper, triangular shaper (ORTEC 672), and digital Gated Integrator (SENSOTRON GDPP-8k). Two solid state detectors were used – a KETEK X-ray Silicon Drift Detector with integrated FET useful for noise line width E_n estimation and an ORTEC HPGe detector of 15% relative efficiency to check the performance at higher energies where ballistic deficit takes place.

The noise line width was measured on each calibrated spectrometer with the appropriate shaper by means of ORTEC 448 Research Pulser. For the digital gated integrator, the measurements have been repeated with the built – into the GDPP – 8k digital pulser; however, the results obtained show no difference.

The results are shown in Fig. 2.



a



b

Fig. 1. Calculated pulse shape of different shapers having equal peaking time (a) and the corresponding to the different pulse widths count rate performance (b)

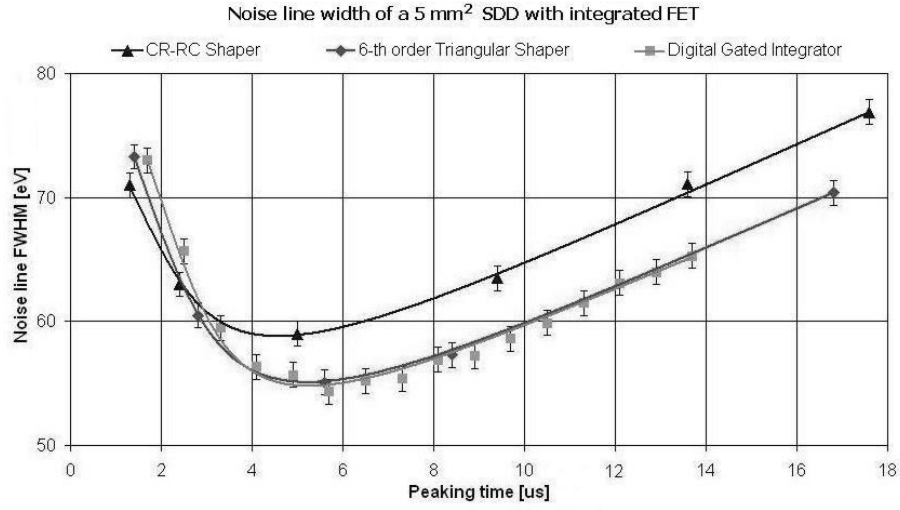


Fig. 2. Noise line width obtained with three different shapers

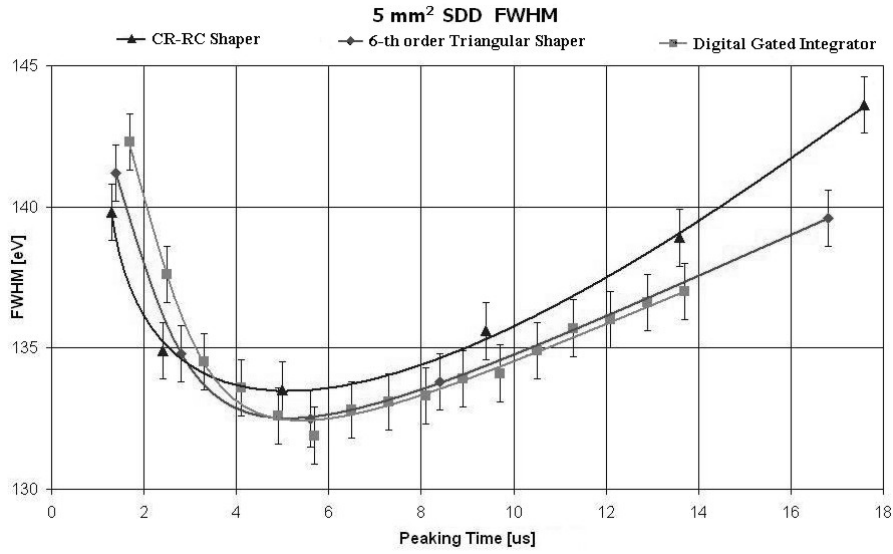


Fig. 3. Measured energy resolution at 5.9 keV for the same three shapers

As expected, the CR-RC shaper exhibits the worst noise line width while E_n is practically the same for the triangular shaper and the digital gated integrator. The optimal peaking time of some 5 μ s is equal for all shapers.

Interesting is the somewhat better E_n obtained with the CR-RC shaper at peaking times below 3 μ s. This might be due to the shaper simplicity.

Next, to estimate the influence on the energy resolution, the FWHM of the 5.9 keV ^{55}Fe line for the same detector and shapers was measured. At such low

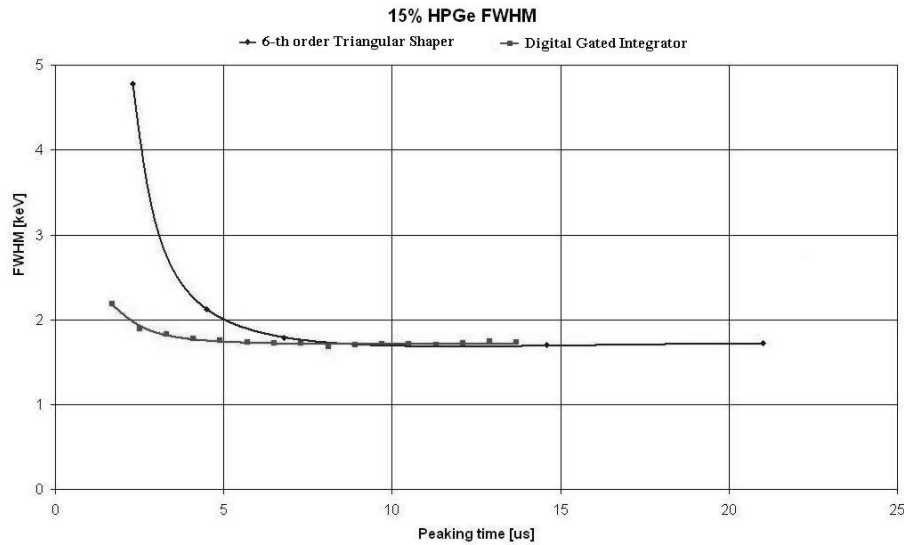


Fig. 4. Energy resolution at 1332.5 keV with triangular shaper and Gated Integrator

energies the ballistic deficit does not contribute to the total energy resolution E_T . Yet the electron-hole pairs generation statistical FWHM E_s remains. For this reason the results shown in Fig. 3 exhibit smaller difference in the obtained energy resolution in accordance with (1).

The influence on the energy resolution was also measured with 15% relative efficiency HPGe p-type detector for the triangular shaper and the digital gated integrator. The FWHM is measured at 1332.5 keV ^{60}Co line. The results are shown in Fig. 4. The significant decrease of resolution at short peaking times for the triangular shaper is due to ballistic deficit.

Discussion. It has been shown that the selection of shapers representing closer approximations to infinite cusp leads to decreasingly smaller improvement in the obtainable noise line width. As the energy resolution is composed of three quadratically added components, the noise line width improvement leads to negligible FWHM improvement. On the other hand, as it is well known, the flat top of the shaped pulses is a must for the cases where ballistic deficit is pronounced.

It can be concluded that shapers having signal to noise ratio similar or better than triangular shall perform practically without differences in obtainable energy resolution.

Then, among them, the shaper having shortest shaped pulse width should be selected from the high count rate performance point of view. The digital gated integrator, though superior to its analogue predecessor (because of the digital delay line pre-filter and easy and fast reset), still exhibits sensitivity to low frequency noise and should be used at not very long peaking times.

The above consideration does not apply to spectrometers with detectors exhibiting, for example, dominant $1/f$ noise or some other untypical noise.

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*Institute for Nuclear Research and Nuclear Energy
Bulgarian Academy of Sciences
72 Tsarigradsko shosse Blvd
1784 Sofia, Bulgaria
e-mail: fish1970@abv.bg*