Optimization of Pulse Processing Parameters for HPGe Gamma-ray Spectroscopy Systems Used in Extreme Count Rate Conditions and Wide Count Rate Ranges

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Abstract:

The need to perform gamma-ray spectroscopy measurements at high count rates with HPGE detectors is more common than many believe. Examples exist in safeguards, radiochemistry, nuclear medicine, and neutron activation analysis. In other applications wide dynamic ranges in count rate may be encountered, for example samples taken after a nuclear accident are counted on a system normally used for environmental monitoring. In a real situation, it may not be possible to reduce count-rates by increasing the distance or using collimators. The challenge is to obtain the "best" data possible in the given measurement situation. "Best" is a combination of statistical (number of counts) and spectral quality (peak width and position) considerations over a wide range of count rates. The development of MultiChannel Analyzers (MCA) using Digital Signal Processing (DSP) has made possible a much wider range of values for shaping times as well as the processing of the detector signal in various ways to improve performance with pulse-by-pulse adjustments. The pulse processing time is directly related to the shaping time. The throughput is related to the pulse processing time and the duration of the detector signal. Longer shaping times generally produce better peak resolution. However, the longer shaping times mean larger dead times and lower throughput. The ability to select the best compromise between throughput and resolution is possible with DSP MCAs. In addition, the dead-time-per-pulse can be reduced by changing the digital filter without significant impact on the FWHM. To evaluate the improvements and to suggest an approach to optimization of system performance, a small and a large GEM (P-type) coaxial HPGE detector were selected for measurements to determine the performance at various input count rates and wide range of rise times and flattops in the DSPEC 50 MCA. Results will be presented for the throughput measured at dead times from 30 to 99.9% with and without the use of the ORTEC Enhanced Throughput Mode.

1. Introduction

The use of HPGe detectors is favored in situations where isotope identification is needed because of their excellent resolution. In many situations, it is necessary to perform these gamma-ray spectroscopy measurements in areas of high gamma ray flux which means high counting rates. Examples exist in safeguards, radiochemistry, nuclear medicine, and neutron activation analysis. In other applications wide dynamic ranges in count rate may be encountered, for example, samples taken after a nuclear accident are counted on a system normally used for environmental monitoring. In a laboratory counting situation, the count rate could be lowered by increasing the source-detector distance, collimation or shielding, or reducing the sample size. In a real situation, it may not be possible to reduce count-rates by any of these means. The challenge is to obtain the "best" data possible in the given measurement situation. "Best" is a combination of statistical (number of counts) and spectral quality (peak width and position) considerations over a wide range of count rates.

The development of MultiChannel Analyzers (MCA) using Digital Signal Processing (DSP), where the detector signal is converted from an analog signal to a digital signal directly at the preamplifier output, enables many new ways of processing the signal without most of the approximations and compromises necessary in analog signal processing [1]. It has made possible a much wider range of values for shaping times (termed rise time, fall time, and flattop). In addition, the processing of the detector signal can be done in various ways to improve the resolution or full-width at half-maximum (FWHM) performance, such as, by measuring the preamplifier pulse and then using the measurement to select one of a range of digital filters to do pulse-by-pulse adjustments on the preamplifier pulse.

The FWHM of the spectrum peak (net full energy peak) depends on the shaping time. A short shaping time does not include all of the preamplifier pulse and a long shaping time includes too much signal noise [2]. The best (smallest) FWHM is obtained with the shaping time suited to the detector preamplifier output signal. The total pulse processing time increases directly with the shaping time. The throughput is defined at the ratio of the pulses in the spectrum to the total number of gamma rays entering the detector. The pulse processing time is essentially the dead time or the time that the MCA is unable to collect the next pulse. The throughput is related to the dead time and hence the pulse processing time. Longer shaping times generally produce better peak resolution. However, the longer shaping times mean larger dead times and lower throughput.

In this work, two HPGe detectors (relative efficiency of 20% and 95%) were measured to determine the resolution (FWHM) of a low and high energy peak for the complete range of rise times and flattops available. This range is much wider than previously available on analog systems and covers the range of HPGe detector output signals. The data were collected using the newest ORTEC DSP MCA, the DSPEC 50.

2. Nuclides and Gamma Rays

2.1. Detectors and electronics

The low efficiency HPGe detector was a GEM (p-type) detector of 56 mm diameter and 34 mm length for a relative efficiency of ~20%. The high efficiency HPGe detector was a GEM detector of 79 mm diameter and 77 mm length for a relative efficiency of ~95%. Both were mounted in horizontal cryostats and cooled with liquid nitrogen.

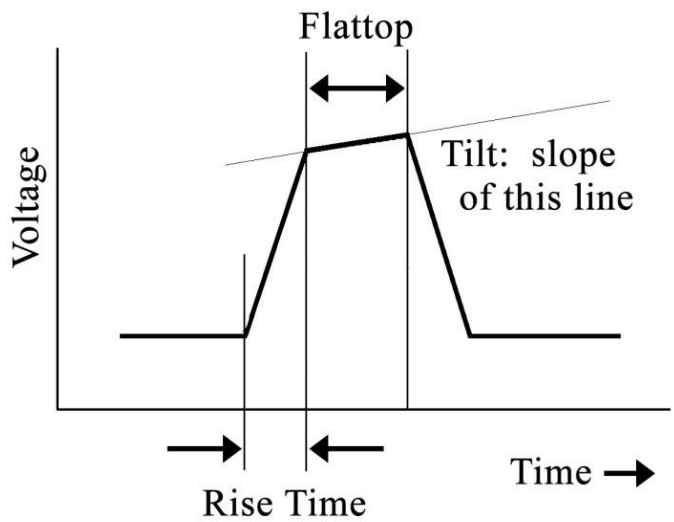

Figure 1 Rise time and Flattop definition

The detectors were measured one at a time on the same DSPEC 50. The DSPEC 50 supplies the high voltage bias, low voltage power, DSP, and spectrum memory. It is connected to the controlling computer by Ethernet.

The rise time has a range of 0.8 to 23.0 µs. The flattop has a range of 0.3 to 2.4 µs. Figure 1 shows the filter with rise time and flattop defined.

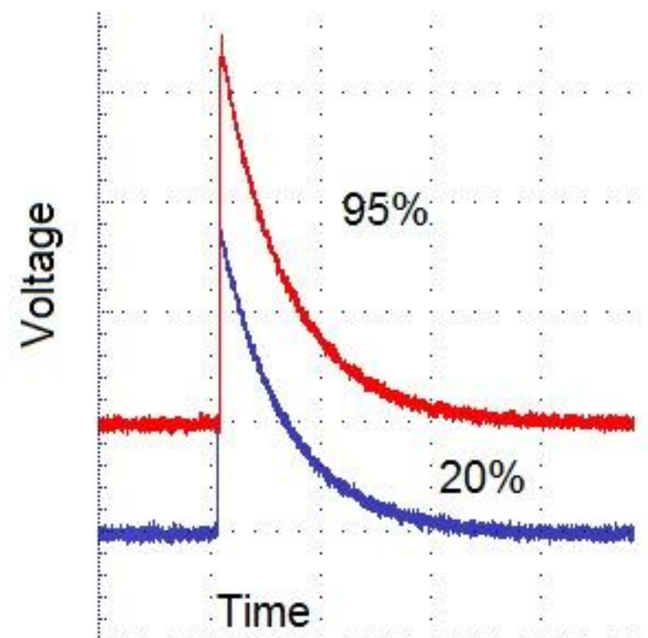

Figure 2 Preamplifier pulses from 20% and 95% HPGe

The preamplifier pulse amplitude is proportional to the gamma ray energy, but the shape, i.e., amplitude vs time, depends on the detector properties. Larger detectors tend to have longer total pulse widths than smaller detectors. The preamplifier output pulses from the two detectors are compared in Fig. 2.

2.2. Sources

The sources used on the small detector were ^{57}Co and ^{60}Co. For the large detector ^{109}Cd and ^{60}Co were used. All are point sources. They were positioned on axis in front of the detector at a distance to obtain reasonable count rate, i.e., in the range of 15 to 25 cm from the front of the endcap. The dead time was approximately 15% for the longest shaping time for each detector. The source-detector geometry remained constant for the entire data collection for each detector.

3. Methods

The data were collected for rise time and flat top times covering the minimum to the maximum allowed for both. In all, 28 rise times and 11 flat tops were used. The data collection was automated using GammaVision. The peak area uncertainty was about 0.4% for the small detector and 0.5% for the large detector. The peak area, FWHM and FW1/25M (full width at one twenty-fifth maximum) for each peak was measured using the IEEE 325 [3] method as implemented in GammaVision [4]. The width of the region for background determination was selected to be relatively wide to reduce any variation of the FWHM with calculation width.

Figure 3 compares the 122 keV peak from the small detector for different rise times and flat tops. The low amplitude peak is for a rise time of 0.8 µs and flat top of 0.3 µs, the shortest times possible. The higher peak sitting on the base line is for a rise time of 5.0 µs and flat top of 1.0 µs, the low end of the uniform resolution region. The middle peak is for a rise time of 23.0 µs and a flat top of 2.4 µs, the maximum possible values for each.

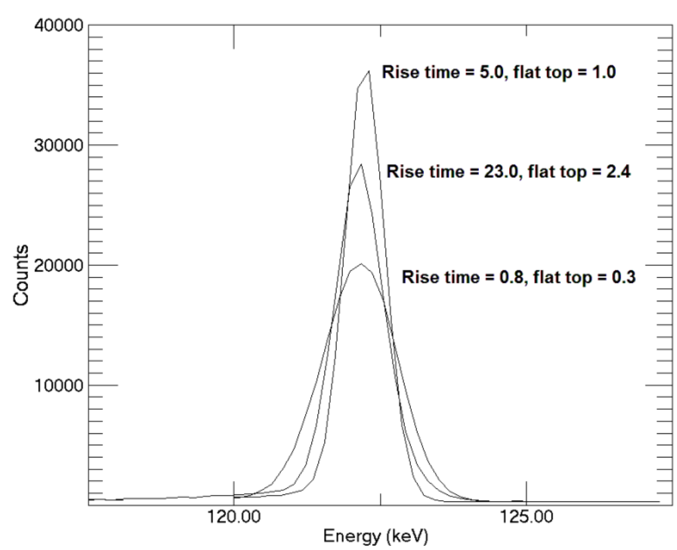

Figure 3 Comparison of spectrum peak shapes for different shaping times

4. Results

4.1. Resolution

The FWHM and FW1/25M of the 122 keV peak are shown in Fig. 4 for the 20% detector. The shape of both curves follow the predictions in Ref [2], where the longer shaping times are shown to include a greater fraction of noise. The 122 keV gamma rays will have only a single interaction in the crystal, meaning the charge pulse is short. The FWHM shows only a slight (~20%) increase, while the FW1/25M shows a larger increase (~35%), indicating that the parallel noise added is small in amplitude.

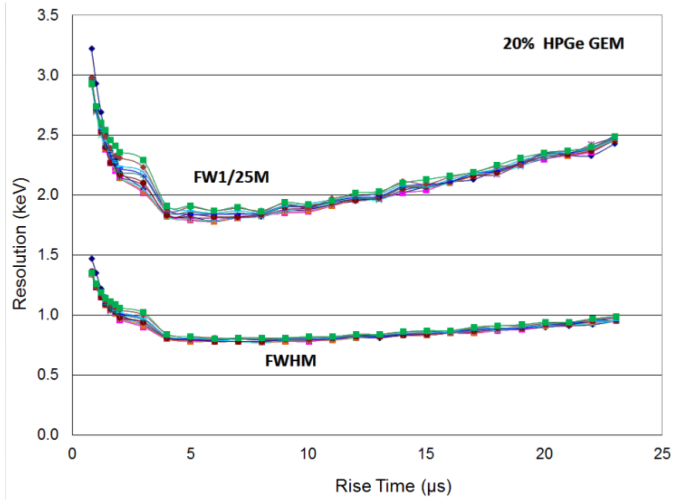

Figure 4 Resolution at 122 keV vs rise time for many flat top times (FWHM and FW1/25M) for 20% HPGe

Figure 5 shows the same data for the 95% detector at 88 keV. The general dependence of shape on time is the same as the smaller detector but with the minima occurring at higher times, which is consistent with the longer charge collection time in larger crystals. The short flattop of the 95% detector is too short for the low amplitude (low-energy gamma ray) detector pulse, which is masked by the longer rise times.

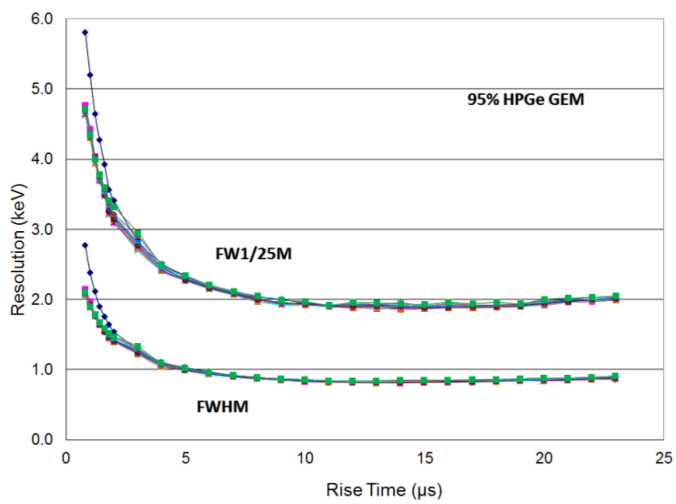

Figure 5 Resolution at 88 keV vs rise time for many flat top times (FWHM and FW1/25M) for 95% HPGe

Figure 6 shows the resolution data for the 1.33 MeV peak for the 20% detector. The 1.33 MeV gamma rays will have multiple interactions in the crystal to deposit all of the energy, giving rise to longer charge collection time. The FWHM shows some increase at short times, especially the shortest flat top. The FW1/25M shows more of an increase at the shorter times. Above a flat top of 1.0 μs, there is little improvement in either the FWHM or the FW1/25M. The rise time has minimal impact on the FWHM above ~ 4 µs. The FW1/25M also has the best values at ~4 to 5 µs, but shows a small and steady increase starting at a rise time of ~ 13 µs.

The same data for the 95% detector is shown in Fig. 7. The FWHM data for the shorter rise time and flat top combinations are not shown, but they show the same trends as the FW1/25M data in this region. For this detector, with longer charge collection times, the FWHM and FW1/25M are large for short flat top times (below ~1 µs). Above a flat top time of 1 µs, the resolution depends on the rise time. From 4 µs to 23 µs, the FWHM changes less than 6%. From 5 µs to 23 µs, the FW1/25M changes less than 7.5%. The use of the rise time and flat top time at the lower end of the acceptable resolution region will reduce the processing time per pulse. The reduced dead time will increase the throughput and reduce the signal loss from pileup or random summing. This indicates that the shorter shaping times can be used in nearly all counting situations as the resulting peak shapes are nearly the same.

4.2. Throughput

The throughput of the DSPEC 50 was measured for the “traditional” timing and for several values of protection time in the throughput enhancer mode for the shortest

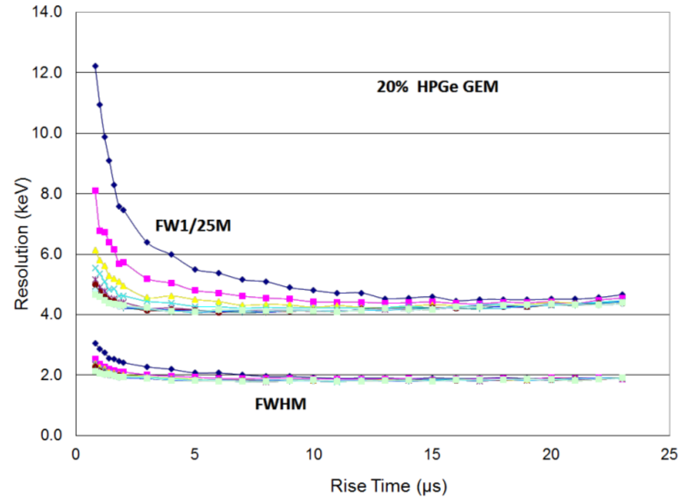

Figure 7 Resolution at 1.33 MeV vs rise time for many flat top times (FWHM and FW1/25M) for 20% HPGe

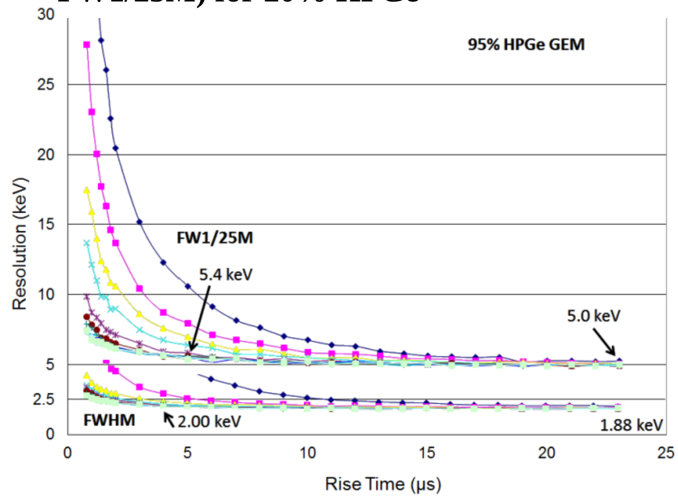

Figure 6 Resolution at 1.33 MeV vs rise time for many flat top times (FWHM and FW1/25M) for 95% HPGe

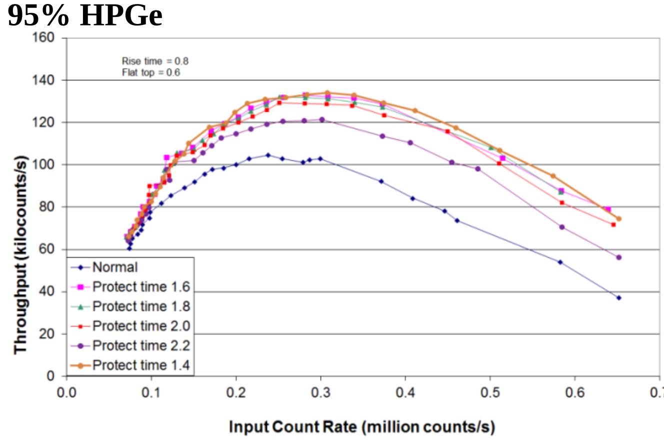

Figure 8 Throughput for different protection times as a function of dead time with Rise Time = 0.8 and Flat top = 0.6 µs.

shaping time possible (rise time of 0.8 µs and flattop of 0.6 µs) and for the shaping time at the low end of the acceptable range (rise time of 6.0 µs and flattop of 1.0 µs).

The throughput vs input count rate for the shortest times is shown in Fig. 8. Note the improvement with shorter protection times. Figure 9 shows the resolution for the same set of parameters. Also the FWHM does not vary with count rate or protection time over a wide range of dead times.

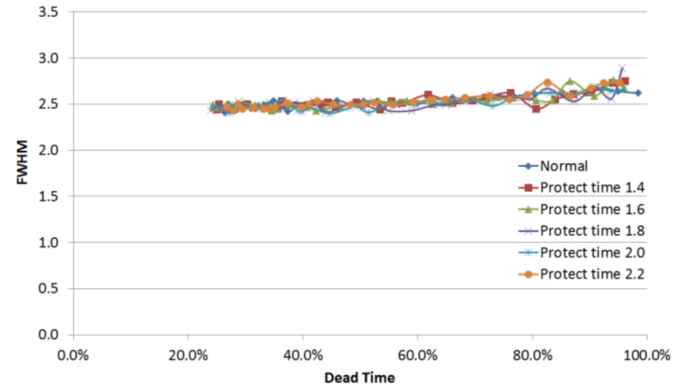

Figure 9 Resolution at 1.33 MeV for different dead times and protection times

The throughput and resolution is of more interest at the rise time and flat top values at the low end of the acceptable range (rise time of 6.0 µs and flattop of 1.0 µs). Figure 10 shows the throughput as a function of input count rate. Note the maximum throughput peaks at input count rates of about 40 kcps for traditional timing and 80 kcps for the minimum protection time. This is an increase of ~1.6 in throughput.

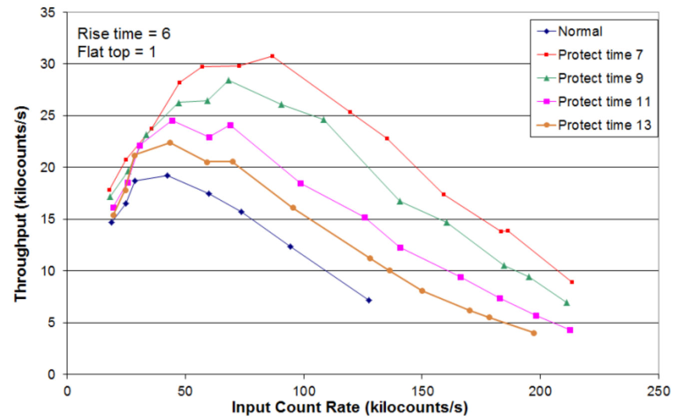

Figure 10 Throughput vs ICR

Figure 11 shows the resolution (FWHM and FW1/25M) for several pulse processing times from minimum to maximum. Both FWHM and FW1/25M are not impacted by the protection time. The FWHM does not start to increase until the dead time reaches 95%. The FW1/25M begins to increase at about 80%.

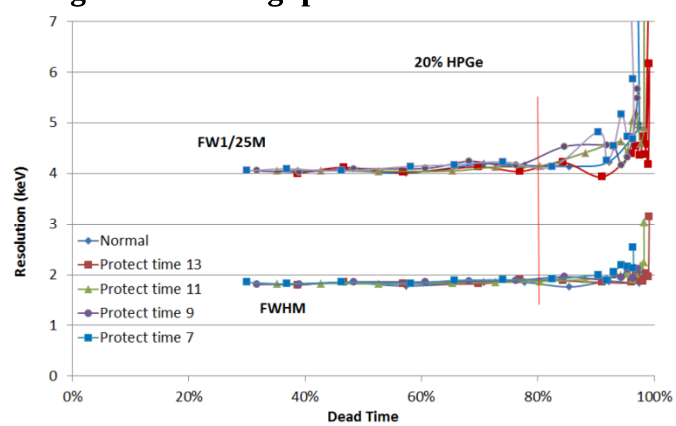

Figure 11 Resolution vs dead time for various protection times

Figure 12 shows the dead time vs input count rate. Comparing the results show in Fig. 10 & 11 with Fig. 12, the maximum throughput at the shortest protection time is within the limits for the good resolution at both FWHM and FW1/25M.

5. Conclusion

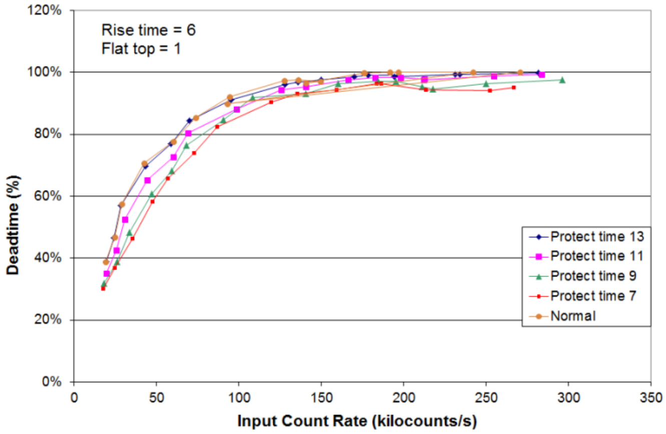

Figure 12 Dead time vs input count rate for various protection times

The IEEE 325 standard specifies the HPGe resolution to be measured at the 1.33 MeV peak of ^{60}Co with an analog shaping time of 6 µs and low count rates (equivalent in digital pulse processing results using a 12 µs digital filter).

The standard was first published in 1971 and was dependent on the technology of the time. While this specification is a valid measure of the performance of the detector under the test conditions, it is not sufficient to predict the performance in other operating conditions, and the 6 µs analog shaping time specification may be sub-optimal for any application of the current detectors and MCAs. To obtain the best system for a specific application, it is necessary to specify performance parameters at values relevant to the application, which may be different than those specified in standards.

The resolution data show that in DSP MCAs there is a lower limit of pulse shaping times (rise time and flat top time) dependent on the size of the detector and the energy of the gamma rays at which is it possible to obtain good quality peak shapes. In contrast to previous analog systems, this may be accurately determined. Longer shaping times on small detectors can increase peak width and on big detectors do little to improve low rate performance, but reduce system maximum throughput at high count rates. Minimizing the shaping time which provides acceptable low count rate resolution increases the dynamic range of count rate achievable, and maximum throughput can be improved further by the use of throughput enhancement techniques.

The data also show that DSP MCAs have superior performance (good resolution and throughput) over a wide range of shaping times and pulse processing times. This means that DSP MCAs can be configured to operate at both low and high count rates without changing any adjustments and without a reduction in data collection or resolution performance at any count rate.

6. References

[1] Ronald Keyser, Timothy Twomey, and Russell Bingham, “Improved Performance in Germanium Detector Gamma Spectrometers based on Digital Signal Processing,” Proceedings of the ANS Fall meeting, Washington, D.C., November, 2004.
[2] Ron Jenkins, R. W. Gould, and Dale Gedcke, “Quantitative X-ray Spectrometry”, p 147, 1995, Marcel Dekker, Inc., New York
[3] IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors Used in Digital Signal Processing Systems, The Institute of Electrical and Electronics Engineers, Inc., New York, NY 10017-2394
[4] GammaVision Operators Manual, ORTEC, Oak Ridge, TN