USING THE DP5 WITH GERMANIUM DETECTORS

The DP5 is a high performance digital pulse processor which can be used with high purity germanium (HPGe) gamma-ray detectors. Figure 1 shows spectra which were obtained using an HPGe detector and a DP5 digital pulse processor [[1]]. Quantitatively, we found better resolution and higher throughput using the DP5 than an analog solution (a Canberra 2025 spectroscopy amplifier with an Amptek MCA8000). The DP5 is far more compact, has much greater configurability, and supports modern networking (Ethernet and USB interfaces). In this application note, we will first show the advantages that we observed with the DP5 system and then will discuss how the DP5 should be configured to obtain the best performance.

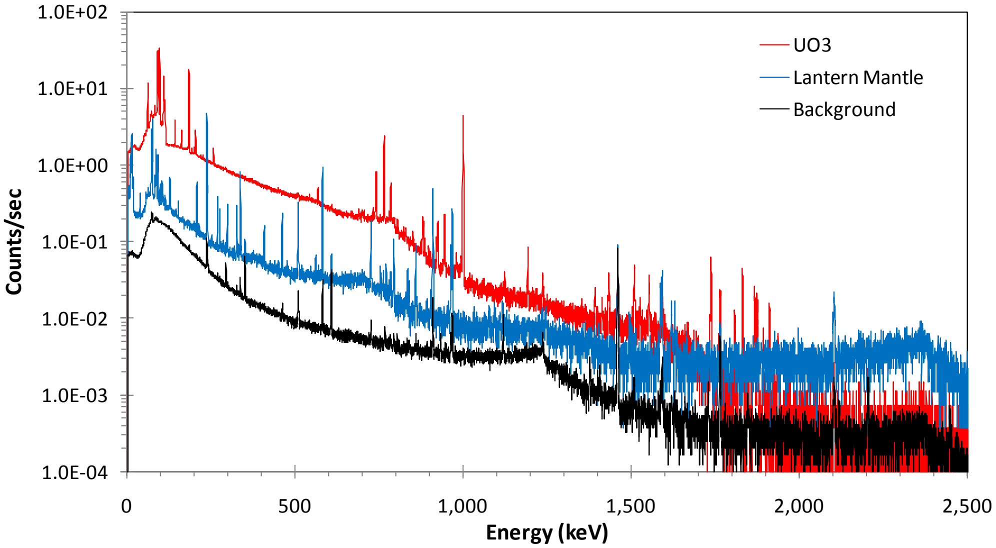

Figure 1. Spectra of low intensity material obtained with an HPGe detector and a DP5 signal processor.

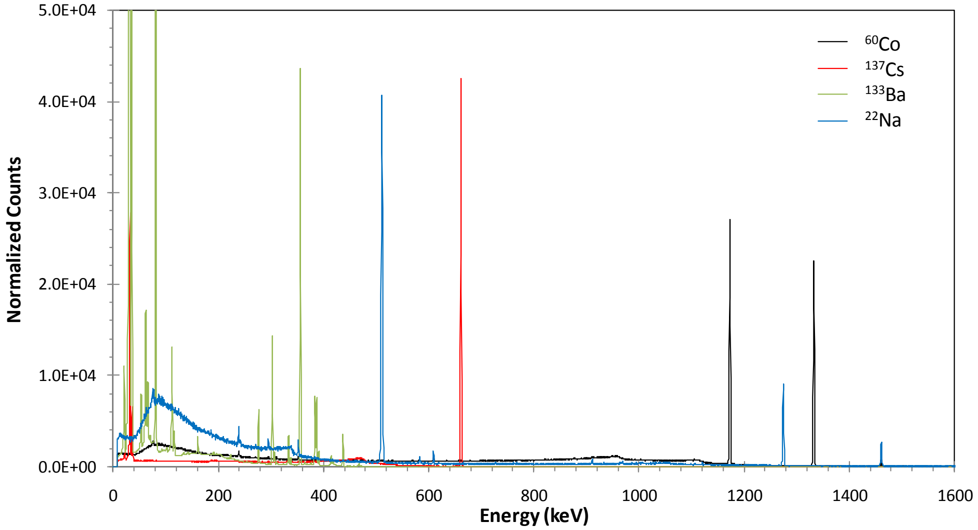

Figure 2. Spectra of laboratory radioisotopes obtained with an HPGe detector and a DP5 signal processor.

Figure 1 and Figure 2 show spectra measured with an HPGe detector and a DP5 signal processor. Figure 1 shows spectra of low intensity materials: 0.5 kg of UO_3 at a distance of 10 cm, a lantern mantle containing

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[1] The data taken in this application notes were taken using a coaxial HPGe detector from Canberra, a reverse electrode diode with dimensions of about 4 cm (dia) x 4 cm, cooled to liquid nitrogen temperatures. It included an internal preamplifier with a 50 μs time constant and a gain of 500 mV/MeV. The analog shaping amplifier was a Canberra 2025 spectroscopy amplifier, using quasi-triangular shaping, and an Amptek MCA8000A multichannel analyzer.

thorium, and the laboratory background. Figure 2 shows spectra measured from common laboratory radioisotopes. These figures show the capabilities of an HPGe detector with a DP5.

ADVANTAGES OF DIGITAL PROCESSING

Digital pulse processing has intrinsic advantages over analog processing, which are discussed in detail elsewhere [2,3]. For a comparable pulse width, the digital pulse shape should theoretically simultaneously improve electronic noise, reduce ballistic deficit, permit higher throughput, and reduce pile-up.

- The digital pulse processor (DPP) reduces electronic noise because the truly trapezoidal shape in a DPP is closer to the theoretically ideal shape than can be achieved with conventional analog filters. The table below shows the noise indices for several shapers for the same pulse width (defined as the FWHM).

	Semi-Gaussian	Analog Triangle	Digital Trapezoid
Series Noise	$\frac{2.5}{T_{FW}}$	$\frac{2.0}{T_{FW}}$	$\frac{2.0}{T_{FW}}$
Parallel Noise	$\frac{2}{3}T_{FW}$	$\frac{7}{8}T_{FW}$	$\frac{2}{3}T_P + T_F$

- The flat top in the DPP trapezoid should theoretically eliminate ballistic deficit, which is commonly seen in coaxial HPGe detectors due to variation in risetime with the long charge collection time. The top of the digital pulse is truly flat and can be adjusted independently of peaking time. When the flat top is longer than the maximum charge collection time in the detector, ballistic deficit is eliminated.
- The finite duration of the pulse, and the absence of an exponential tail, should theoretically lead to improved throughput. The difference in the shapes can be seen in Figure 3. Pile-up in the DPP is reduced due to the properties of the triangular shaping in the fast channel, used in pile-up rejection.

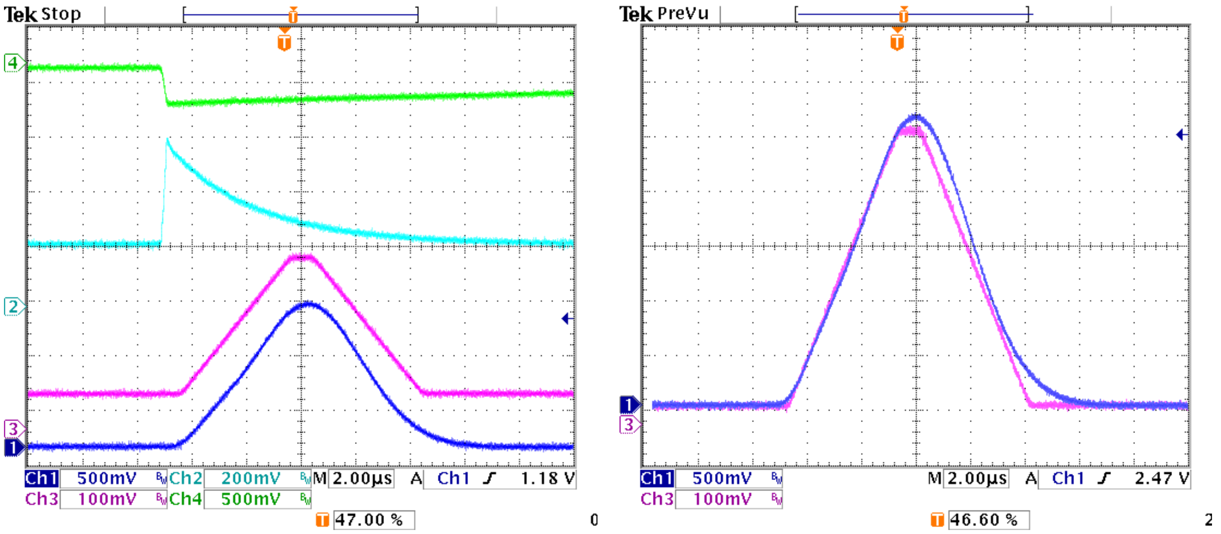

Figure 3. Oscilloscope traces for a 662 keV gamma-ray. The green trace is the preamp output, while the light blue trace is the input to the ADC in the DP5. The pink trace shows the trapezoidal pulse used in the DP5 while the blue trace shows the analog approximation. The plot on the right shows the two pulses overlaid (the gain was adjusted to show the flat top). Note particularly (1) the flat top in the digital pulse and (2) the exponential tail in the analog pulse continuing after the digital pulse has terminated.

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[2] G.F. Knoll, *Radiation detection and measurement*, 4th ed, John Wiley & Sons, 2010, p 669.

[3] R. Redus, "Digital pulse processors: Theory of operation", Amptek application note AN-DPP-001, 2009.

Data were taken with this coaxial HPGe detector, the Canberra 2025 and MC8000, and the DP5 to verify these theoretical advantages. Table 1 shows the energy resolution, in keV FWHM, measured by the two systems at several gamma-ray energies using common isotopes. At low energy, the resolution is dominated by electronic noise and the two systems yield very similar results. At higher energies, the resolution of the DP5 is better than the analog system. This is due to ballistic deficit: with a shorter flat top but fixed peaking time, the DP5 resolution became worse. Extending the flat top beyond 0.8 μs led to no additional resolution improvements. The ability to eliminate ballistic deficit and the near decoupling of peaking time (which determines noise) and flat top is another key advantage of the DPP.

Energy (keV)	**14.4**	**122**	**662**	**1173**	**1333**
DP5	1.24	1.32	1.72	2.05	2.19
Analog	1.25	1.36	1.85	2.18	2.49

Table 1. Chart showing the resolution, in keV FWHM, measured at various gamma-ray energies with the digital and analog systems.

Figure 4 shows spectra taken using the HPGe detector with both the DP5 and the analog signal processor at an incoming count rate (ICR) of 85 kcps, for about a 60% dead time in both systems. The insert is a zoomed view of the sum peak at 1323 keV. The shape of the primary spectrum is very similar in the two systems. But notice the difference in the pile-up spectrum. The digital system has fewer piled up events, between the main and sum peak, particularly at the lower amplitudes. The sum peak has both a lower intensity and is narrower. The DP5 used a 100 ns peak time in the fast channel.

Figure 5 shows throughput, sum peak fraction, and pile-up peak fraction for the two systems. These data were obtained using a 0.5 mCi ^{57}Co source at distances up to 1 meter. The throughput was defined as the total counts divided by the real time for the analog system and the acquisition time for the DP5. The pile-up fraction was defined as the ratio of pile-up counts (gross counts between the 136 keV peak and the sum peak) to the photopeak, while the sum peak fraction is the ratio of counts in the sum peak to the photopeak. The DP5 provides a higher throughput and fewer counts in the sum peak and in the pile-up peak.

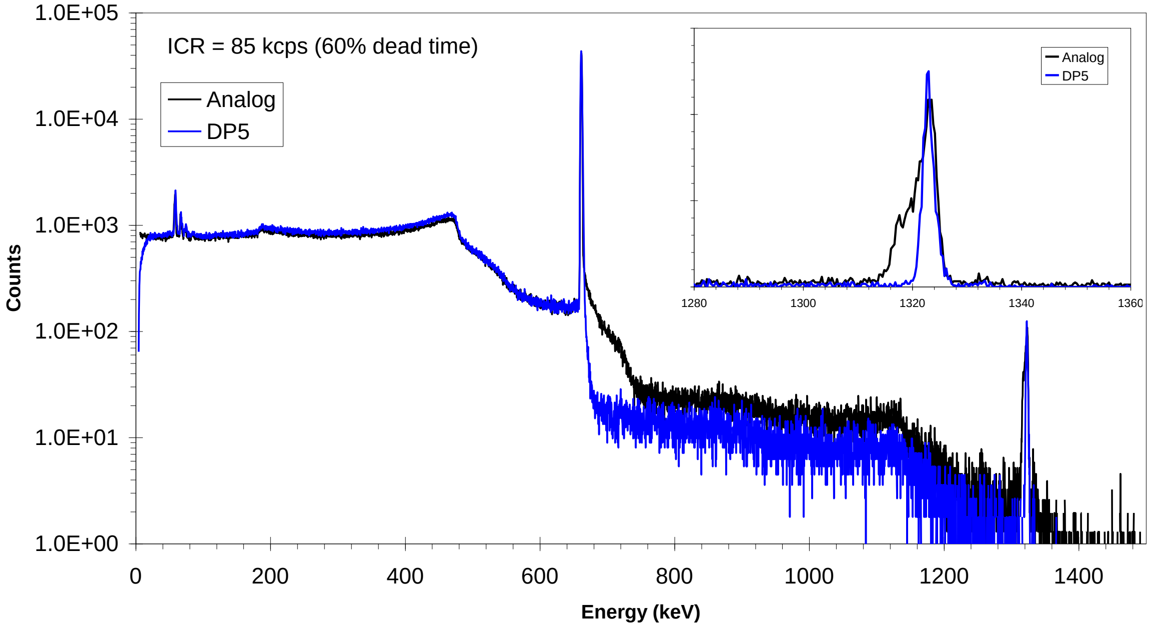

Figure 4. ^{137}Cs spectra measured with the analog and digital systems at 85 kcps (60% dead time), The insert zooms in on the sum peak at 1323 keV.

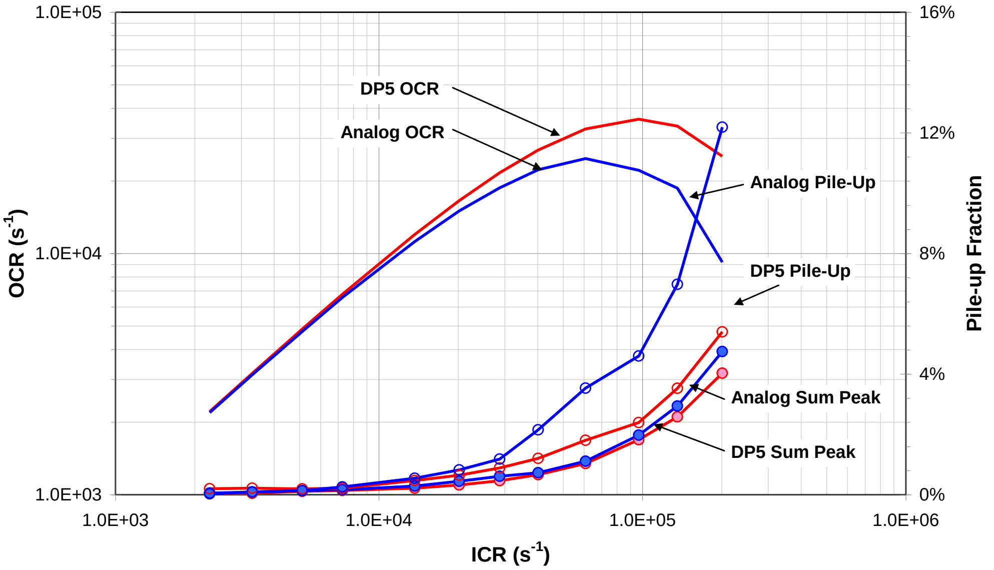

Figure 5. Plot showing the throughput and the fraction of counts in the sum peak and piled up for the analog and digital systems.

Live Time Correction

The "live time correction" in the DP5 works slightly differently than in conventional analog systems [4]. In the analog system, there is a free-running real time clock. The live time clock is obtained by gating off the real time when the incoming pulse is above threshold. To get the "true" rate of photopeak counts, the measured counts are divided by the live time rather than the real time.

In the DP5, the "real time" is replaced by the "acquisition time". Data acquisition must be stopped in the DP5 when data are read out from memory (and during preamplifier resets, with a reset-style preamp). The acquisition time is a real time clock which is gated off when the system is not acquiring data. It is not gated off by pulses so does not correct for count rate or pile-up. It represents the actual duration of data acquisition. In the DP5, the fast channel is used to directly measure the incoming count rate (ICR): the ICR is the number of counts measured in the fast channel divided by the acquisition time. The output count rate (OCR) is the total number of counts in the spectrum (after counts are eliminated due to pile-up, etc) divided by acquisition time. The ratio OCR/ICR is the live time fraction. To obtain the true photopeak count rate, the number of counts in the photopeak is multiplied by this fraction:

$$R_{corr} = R_{meas}\left(\frac{ICR}{OCR}\right) = R_{meas}\left(\frac{N_{fast}}{N_{tot}}\right) \qquad [1]$$

where R_{meas} is the measured photopeak counts, N_{fast} is the number of counts in the fast channel (input counts), N_{tot} is the total number of counts in the spectrum, ICR is the incoming count rate (N_{fast}/T_{acq}), OCR is the output count rate (N_{tot}/T_{acq}), and T_{acq} is the acquisition time. A second order improvement can be obtained by correcting the ICR measured by the fast channel for dead time in the fast channel:

$$N_{fast\_corr} = \frac{N_{fast}}{1-\left(\frac{N_{fast}}{T_{acq}}\right)\tau_{FAST}} \qquad [2]$$

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[4] Redus, R.H., A.C. Huber, D.J. Sperry, "Dead time correction in the DP5 digital pulse processor", IEEE Nucl. Sci. Symp. Conf. Rec., Oct 2008, pp 3416 - 3420 (2009).

where τ_{FAST} is the fast channel peaking time. This method requires the fast and slow channels to measure the same pulses so the thresholds must be the same.

The plot below shows data taken using a ^{57}Co source to validate this approach. Spectra were taken at source distances between 4 and 42 inches. The black curve shows the expected count rate. This was computed for a point source and a detector with circular apertures [5], normalized to the farthest measurement. As the source is moved closer, the photopeak count rate should increase according to this curve. The dashed red line shows the uncorrected photopeak count rate in the DP5, that is, the net counts in the photopeak divided by the accumulation time. The solid red line shows the result of applying Eq. [1] and [2], and the resulting corrected photopeak count rate is in excellent agreement with the data. Data were also taken using the analog system with 0.5 and 2 μs shaping time constants. The analog system is in good agreement at the shorter shaping time.

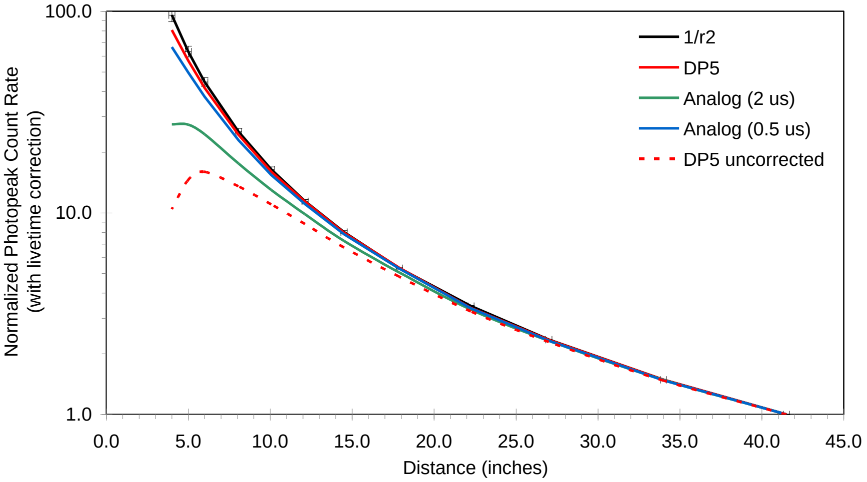

Figure 6. Plot demonstrating live time correction in the digital and analog systems.

This measurement shows the validity of using the fast channel count rate, the ICR, to correct for dead time in the DP5. It also shows that the results of the DP5 are in better agreement than the analog system.

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[5] N. Tsoulfanidis, Measurement and Detection of Radiation, Hemisphere Publishing, 1983, p 251

HOW TO CONFIGURE THE DP5 FOR HPGE

To configure the DP5 for an HPGe detector, the first step is adding components to implement a pole-zero circuit. The second step is to tune the software adjustable signal processing parameters.

POLE ZERO CANCELLATION

Most HPGe detectors use preamps with resistive feedback, producing a tail pulse, while the DP5 is configured from the factory for a reset type preamplifier. To use the DP5 with a tail pulse input, the pole in the preamp response must be zeroed, which requires changing the front end circuit slightly. Section 7.3 of the DP5 User's Manual discusses this in general, for any tail pulse input. In this section, we will show a specific example, changing the circuit for a 50 μs preamp tail.

The first step is to add a pot at R102 to cancel the input pole. The DP5 manual says to estimate a value from R102 = τ/6.8 nF, where τ is the preamp pole. For τ=50 μs, this gives R102=7.35 kΩ. We placed a 10 kΩ pot for R102 to give some adjustment. The second step is to estimate a value for R103 (R26 will be removed). The requirement is that the parallel combination of R102, with the series combination of R23 and R103, should be 470Ω, as shown in Eq. 3. For this example, we compute R102=142Ω. We removed R26 and placed a 250Ω pot for R103.

$$\frac{1}{\frac{1}{R103}+\frac{1}{R102+R23}}=\frac{1}{470} \quad \Rightarrow \quad R102=\frac{1}{\frac{1}{470}-\frac{1}{R103}}-R23 \qquad [3]$$

The third step is to adjust these pots. In the software, set the flat top duration to the longest available for your chosen peaking time (the long flat top makes adjustment easy). Connect an oscilloscope to the DAC output, J8 (pin 1 is the signal, pin 2 is ground). You will see a pulse shape like that in Figure 8 (left), with a long tail and a visible slope to the flat top. Adjust R102 until the long tail vanishes, as shown in the middle trace. There will still be a slope on the top and a small tail at the return to baseline. Now adjust R103 until the top is flat and the pulse returns smoothly to baseline, as shown on the right. When this shape is seen, the pots are adjusted properly. The circuit can be used with the pots, or they can be removed and fixed resistors of equal value installed, if you prefer.

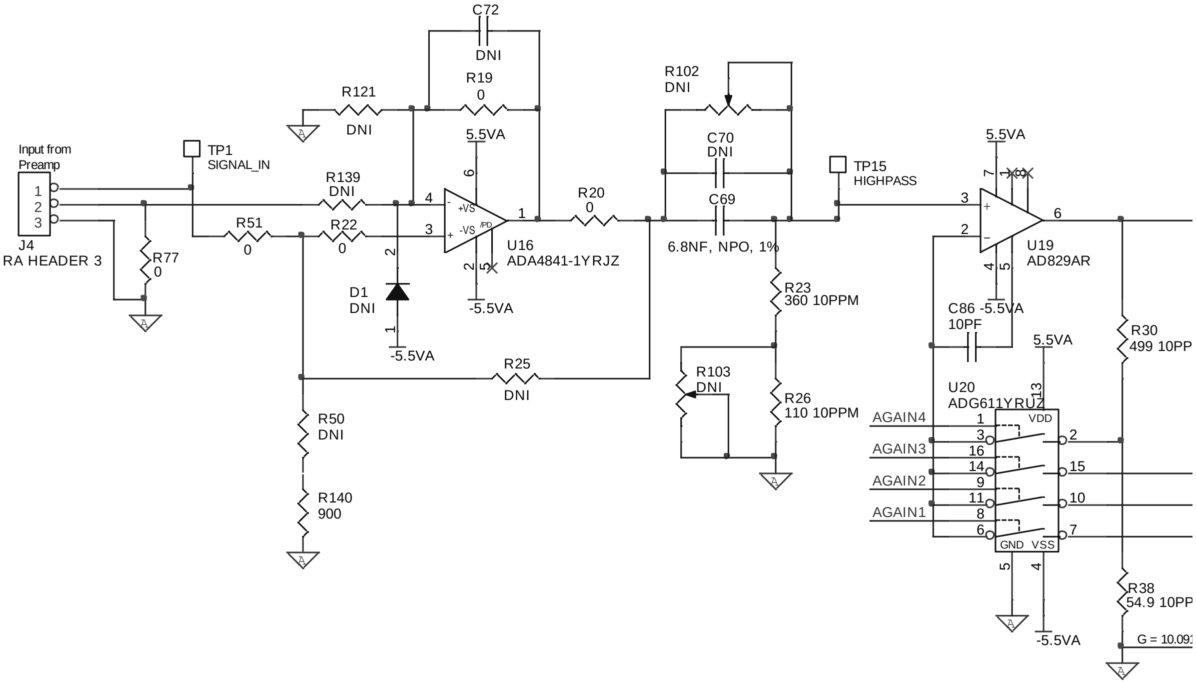

Figure 7. Schematic of the first stage in the DP5 analog prefilter circuit. A more complete schematic is in Figure 7-4 of the DP5 User Manual.

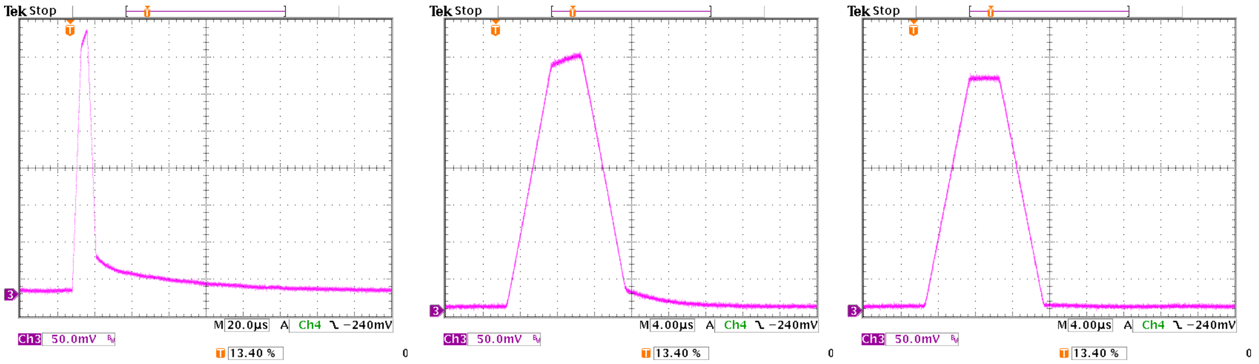

Figure 8. Scope traces illustrating the pole-zero adjustment.

GAIN RANGE CHANGE

A full scale signal on the MCA corresponds to a pulse into the ADC of about 1.0V, and at the DP5's minimum gain of 0.75, this is 1.3V. With a preamplifier gain of 500 mV/MeV, this means that the maximum full scale signal is 2.6 MeV. To increase the maximum full scale signal, the input network to U16 can be used to attenuate the signal. For example, if the preamp has a 93Ω output resistor and a 0Ω resistor is installed in R50, the signal is attenuated by about 10%, increasing the maximum signal commensurately. By selecting appropriate resistors in R50 and R51, the maximum scale can be adjusted. But the preamp output resistor must be included in the calculation because it becomes part of the divider.

CONFIGURING THE SIGNAL PROCESSING PARAMETERS

Figure 3 shows typical oscilloscope traces. It is convenient to connect an oscilloscope to the DP5, to see these pulses as the parameters are adjusted. For this figure, the scope was connected to the AMP3OUT test point (this shows the ADC input) and to the DAC output (J8, pin 1 is signal) to see the shaped pulse. The fast channel pulse can also be displayed by the DAC.

Key Parameters

Input Polarity: NEGATIVE (for the preamp configuration here).

Input Offset: DEFAULT was used here.

Reset Lockout: Set to OFF for a tail pulse preamp.

Gain: This obviously depends on the energy range to be measured. It was set to 0.75 for the measurements here, with 2.6 MeV full scale.

Pile-up rejection: We usually take spectra with pile-up rejection enabled. However, it is often helpful to turn this off initially: if the software is not configured correctly, it may reject all pulses, leading to much confusion. Once everything is adjusted right, then turn on pile-up rejection.

Risetime discrimination: We recommend disabling this discrimination initially. Once the system is working properly, RTD can be used to reject slowly rising pulses, if this is desired.

Shaping Time Parameters

There are three different parameters related to pulse shaping: peaking time, flat top, and fast channel peaking time. Their selection impacts performance quite a bit and differs from analog shaping:

Flat Top: The flat top duration is quite important in large coaxial HPGe detectors. The charge collection time can be quite long (see Figure 9), and if it is longer than the duration of the flat top, resolution is degraded (an effect called ballistic deficit). The digital processor has two advantages over the analog system: (1) if the flat top is set longer than collection time, there is zero ballistic deficit, and (2) the flat top can be adjust separately from the peaking time.

Peaking Time: The peaking time largely determines the rms electronic noise and the pulse duration, hence throughput and pile-up. A digital processor with peaking time T_{peak} has characteristics similar to, and slightly better than, that of an analog shaper with time constant 2.4 T_{peak}.

Fast Channel Peaking Time: The fast channel resolves pulses which overlap in the slow channel. It is used in the pile-up reject logic (PUR) and to estimate the incoming count rate (ICR). The fast channel peaking can be set to 50, 100 or 400 nsec (200, 400, 1600) for an 80 (20 MHz) ADC clock. Setting this to a short value will generally help the circuits to distinguish closely spaced peaks. However, there are a few disadvantages to setting it too short: (1) Electronic noise increases, so the noise threshold is higher, so both PUR and ICR circuits fail to detect small events. (2) The fast channel pulse duration becomes a strong function of the charge collection time so varies significantly from one event to the next. This can make understanding the throughput and pile-up more difficult.

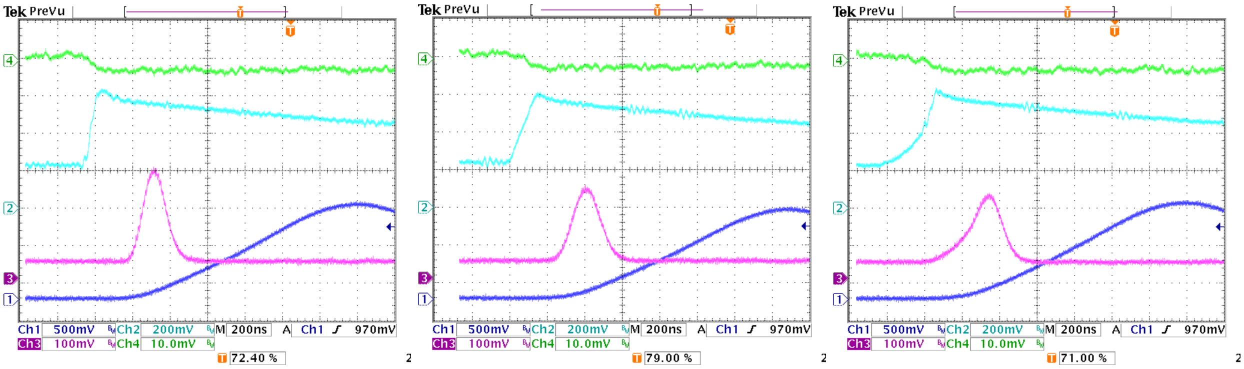

Figure 9. Plot showing risetime variability with an HPGe detector. The green trace is the preamp output. The light blue trace is the ADC input. The pink trace is the "fast channel" of the DP5, set to 100 nse peaking time. The dark blue trace is the output of a Canberra 2025 with 0.5 μs shaping time constant. The trace on the left shows a fast preamp risetime (<50 ns). In the middle trace, the risetime is 200 ns, which leads to a smaller and wider fast channel pulse. The trace on the right has a 350 ns risetime and a curved edge, leading to distorted fast channel pulse.