Experiment 1: Digital Signal Processing for Gamma-Ray Spectroscopy in HPGe

Christopher Brand

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1 Introduction

The goal of this report is to explore some of the various techniques used for digital signal processing. This effort utilizes an HPGe detector to explore these techniques through the lens of gamma-ray spectroscopy. A trapezoidal shaping filter is implemented and optimized inorder to achieve a final calibrated energy spectrum. Through this the effect of ballistic deficit and various contributions to electronic noise are studied to learn about the performance of digital signal processing.

2 Methods

2.1 Experimental Setup

A countrate energy spectrum dataset consisting of two sources was gathered with a coaxial high purity germanium detector (HPGE). The two sources used were ^{57}Co and ^{60}Co and were used to calibrate the energy spectrum and optimize the filter parameters. The known energies of the calibration peaks are presented below in Table 2.

Missing the 121 keV line, which is actually higher intensity

Source	Energy (keV)
^{57}Co	136.47
^{60}Co	1173.22, 1332.49

Table 1: Source Isotopes and Corresponding Gamma-ray energies[1]

Additionally, data was collected by generating a pulse from a generator. This simulated data was used to optimize the filter parameter and study noise from the system. All of this data was collected through a digitization system from Struck Innovative Systems (SIS), SIS3302 module. Inorder to gather this data and parse it from the module, custom c++ based software was provided and then modified for our endeavor. The data parsed into the standard .h5 file format.

HDF5 is the format, the extension can change

2.2 Trapizoidal Filter Implimination

A script with a trapizoidal filter was created using python 3.5, based off of the work done by V. Jordanov et. al.[2]. In addition an input spectrum, there are two parameters needed, the rise time, k, of the trapizoid and the gap time,m or the trapizoid. The gap time was found by iterating passing a number of values of m through the script and finding the energy resolution of one of the ^{60}Co peaks. From this a energy resolution vs rise time graph was plotted and a minimized value

Any limitations associated with this approach? Why the high-energy peak - may underpredict gap time!

Digitized preamplifier signal

for m was attempted to be found. An attempt was done to find the rise time, k, in much the same manner, however, the simulated pulse was used in this case so as to be able to evaluate the contributions of the various electronic noise components.

Motivation here a bit off: the noise components are always present, but the test input allows us to isolate them from other contributions to energy resolution, i.e. statistical fluctuations and carrier collection issues

2.3 Energy Calibration

The gamma-ray spectrum is approximated as being composed of a global non-linear background with guassian peaks due to the impingment of high branching ratio gamma-ray lines from radioactive decay.[3] The peaks are fitted by a Gaussian of the form:

$$G(x; A, \mu, \sigma) = A \exp\left(-\frac{(x-\mu)^2}{2\sigma^2} \right) \tag{1}$$

Where x is the data, A is the amplitude, mu is the mean, and sigma is the standard deviation. Additionally, the data was then fit to a linear model as in lab0.

How is this incorporated in your model (doesn't show up in eqn 1)

3 Results

3.1 Trapizod Filter Parameters

The opimization method used as oulined in Section 2, resulted in the following two graphs:

Need more here. I realize you address it in more detail later on, but need some context for the presented result here

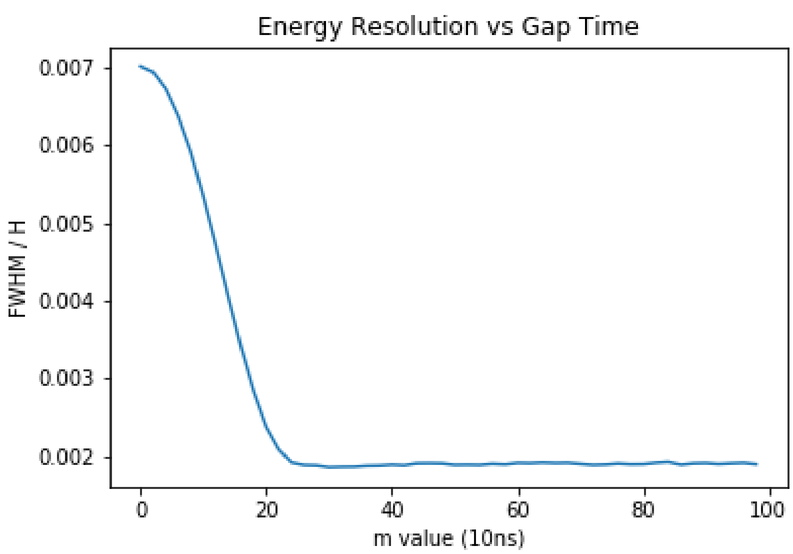

Figure 1: gap time, m, vs Energy Resolution as compared to the 60Co's 1332 keV peak.

While Figure 1 looks acceptable, Figure 2 has the appearance of being inverted. This is disscused further in Section 4. The optimized m value was 30 +/-2 and the used k value was 740 +/- 20. Additionally, the decay time was found to be 5810.2.

How? Need more info on procedure/analysis

3.2 Data Signals

The following are five examples of signals from the 57Co data set before and after being put through the filter:

Uh oh

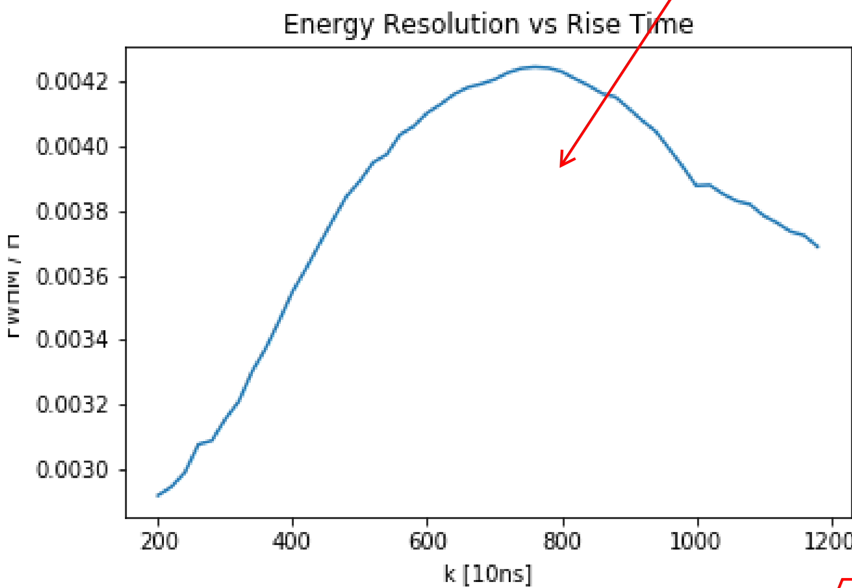

Figure 2: rise time, k, vs Energy Resolution as compared to the simulated pulse peak.

Strange feature

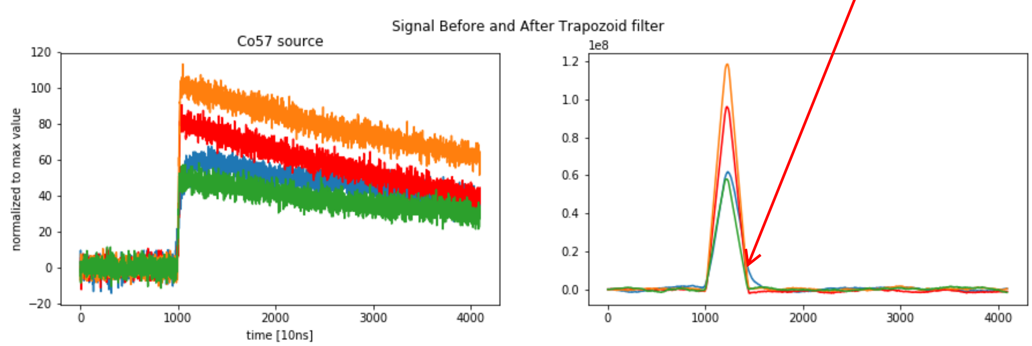

Figure 3: Left: Raw Data signals from the SIS3302. Right: Same signals after going through the optimized trapizoidal filter.

Don't convey the appropriate information - need zoomed views or something in order to see peak shapes and other relevant features

3.3 Energy Spectrum

The following are the final energy spectra with the energy calibration done:

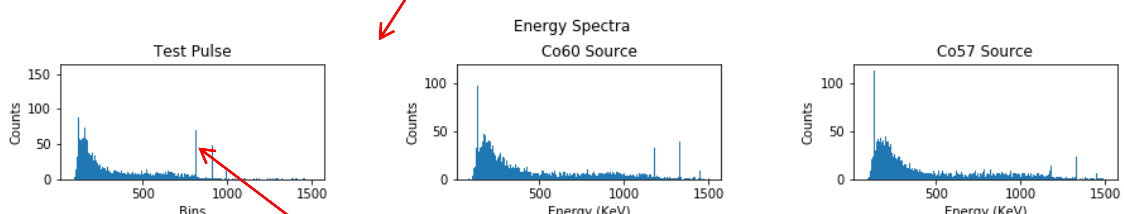

Figure 4: From left to right: Test Pulse Spectrum, Co57 Spectrum, Co60 Spectrum

A discovered issue with these data set was the intense background contribution from other

This spectrum in particular should not have any continua etc. (except from bgnd). The pulser peak is not clearly indicated relative to other spectral features sources. This is discussed further in Section 4.

The peak selection and fitting procedure outlined in Section 2, resulted in a linear energy calibration of the form

$$E = 0.1731 * Bin + 82.76 \tag{2}$$

Units? (rel. or keV)

The energy resolution of the 3 peaks are as follows:

Peaks	**Energy Resolution**
136.47	0.27
1173.22	0.0104
1332.49	0.0078

Table 2: Energy Resolution for one 57Co peak and two 60Co peaks

This statement is much more strongly supported if you show a representative peak shape

Good, would be even better with explicit quantitation

4 Discussion

A major concern with digital processing of signals is ballistic deficit. ballistic deficit is the different in amplitude between the shaped pulse (after it leaves the amplifier) and the original pulse. This difference arises when the rise time of the original pulse is on the order of the shaping time in the amplifier, meaning that pulses will have smaller amplitudes, providing us with the incorrect energy information. These pulses can be corrected to an extent by sending the pulse through a trapizoidal filter as seen in Figure 3 of Section 3. The flat top of the trapizoid, also known as the gap time, m, stabalizes the amplitudes so that they do not suffer from ballisti deficit. This can be seen in Figure 1 of Section 3, where a number of m where compared to the energy resolution of a single peak. At low gap time (a triangle filter), the peak has low energy resolution and the peak has been broadend due to ballistic deficit. However, as we increase the gap time, the peak becomes more precise, because of the reduction of the ballistic deficit until it bottems out at 300 +/-20 [ns]. After this, the gap time is no long able to reduce the ballistic deficit and so greater gap times are not useful. It should be noted that in this case, the error is entirly due to the large step size choosen to minimize the gap time (steps of 20ns). This was done merely to save on time as the code takes time to run. Other sources of error, such as electronic noise and fit errors are negligible compared to the uncertainty due to the step size.

In order to study the contributions of the various electronic noise components, the rise time,k, of the trapizoid was varied while looking at a simulated pulse from a pulse generator. Doing this assures us that a majority of the noise that is seen comes from the internal electronics rather then from background or other sources. The results are shown in Figure 2 from Section 3. This plot is not correct. Unfortuantly I was unable to figure out the problem in my code, however, inverting this graph produces a graph that looks like what I am suppose to get. I am going to assume that the inverse of this graph is correct for the purposes of discussing the various contributions to noise. This figure is shaped like a parabola because of the large contributions due to series (voltage) noise and parallel (current) noise. Low rise times results in high contributions from series noise such as thermal (electron velocity changes that create voltage noise) and Johnson (noise from resistors changing the voltage effects. At high rise times the noise again increases due to larger and larger contributions from parallel noise such as shot noise (flucuations of the current due to changes in kinetic energy of the electrons). The supposed graph would indicate that for all k series and parallel noise are the primary contribitor since any 1/f noise would result in a flat (ish) line. 1/f or flicker noise is the fundimental alterations that exsit in all thing in nature. The optimal k found is 7400 +/-

Close

Okay. This is something to continue devoting time to moving forward as noise analysis and filter parameter optimization is a critical component of nearly all the subsequent labs

Quantify the uncertainty related to peak fitting - probably doesn't explain the issues you see with the noise analysis

200 [ns]. It should be noted that the error is entirly due to the large step size choosen to minimize the gap time (steps of 20ns). This was done merely to save on time as the code takes time to run.

One draw back to this filtering method is that it breaks down at higher count rates. So it is recommended that this method be used only for low count rates. That being said, I would recommend taking more data then I took for this lab. The lack of counts I had in my spectrum made it difficult to find peaks. Additionally, greater care should have been taken in isolating the sources from background. After analysing the data it can be seen in Figure 4 Section 3, that additional peaks from other sources appear. This made the analysis more uncertain, as there is uncertainty to what excalty these peaks were. Additionally, the lower energy peaks in the 57Co could not be seen.

You have general access to the lab - don't be shy about taking more/new datasets whenever you need to

References

[1] M. R. Bhat. *Nuclear Data Sheets 85*. NNDC, 1998.

[2] Valentin T Jordanov and Glenn F Knoll. Digital synthesis of pulse shapes in real time for high resolution radiation spectroscopy. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 345(2):337–345, 1994.

[3] Glenn Knoll. *Radiation Detection and Measurement*. John Wiley & Sons, Inc., 1999.