Implementation of the preamplifier response function for the iThemba LABS segmented clover detector

T. D. Bucher[1,2], E. A. Lawrie[1], O. Shirinda[1, 2], T.S. Dinoko[1], J. L. Easton[1, 3], N. Erasmus[1,3], S. H. Mthembu[1, 4], W. X. Mtshali[1, 4], S. P. Noncolela[1, 3]
[1] iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
[2] Stellenbosch University, Department of Physics, P/B X1, Matieland 7602, South Africa
[3] University of Western Cape, Department of Physics, P/B X17, Bellville 7535, South Africa
[4] University of Zululand, Department of Physics, P/B X1001, KwaDlangezwa, 3886, South Africa.

E-mail:daphney@tlabs.ac.za

Abstract. In June 2013, iThemba LABS acquired the AGATA detector library (ADL) software to simulate the response of the segmented clover detector for an arbitrary gamma-ray interaction within a germanium crystal. In order to generate realistic pulse shapes that match the measured pulses for a specific position in (x,y,z), the detector characteristics, such as geometry, impurity profile, charge sensitive preamplifier response, cross-talk parameters and crystal orientation, must be measured and implemented into the software in high precision. The implementation of those detector characteristics into the ADL software is in progress. The charge sensitive preamplifier response of crystal A of the iThemba LABS segmented clover detector was measured and implemented into the ADL software. ADL simulated charge collecting signals for crystal A show an excellent agreement with the measured signal.

1. Introduction

The preamplifier represents an interface between the detector and the signal processing electronics. Its basic function is to amplify and shape the small signal from the detector and to transfer it to the electronic chain with the least degradation. Typically, charge sensitive preamplifiers are used for Ge detectors. In a charge sensitive preamplifier, the charge carried by the incoming pulse is first integrated on a capacitor and then removed by a slow discharge through a resistive feedback network. This produces a pulse with a fast leading edge (rise time), corresponding to the charge collection time in the detector, and a slow exponential decay (fall time). In order to preserve as well as possible the information carried in the signal leading edge, a very fast, low noise, low power consumption and stable preamplifier is required. To obtain a fast response, i.e. a signal with short rise time, a large bandwidth (BW) preamplifier is required.

2. iThemba LABS segmented clover detector

The iThemba LABS segmented clover detector consists of four n-type HPGe crystals. The crystals dimensions are; diameter of 60 mm (before tapering) and 90 mm length with depth segmentation at 35 mm. Each crystal is electrically segmented into 8 contacts on the outer surface. This results in a total of 36 electronic channels of which 32 are associated with the outer contacts and 4 with the inner core contacts of the detector.

During γ-ray interaction, all segments and inner core contacts produce a signal with a certain pulse shape. These pulse shapes carry information about the position (x,y,z) of the energy deposition occurred when a γ-ray interacted within the Ge crystal. To make use of this position sensitivity of the detector, we have to create a database of simulated pulse responses for various interaction positions and ensure that the simulated pulse shapes are realistic.

3. Motivation

The determination of the position of a gamma-ray interaction inside a germanium detector uses a database of simulated realistic pulses. This process requires pulse shape analysis and determination of the best match between the measured pulses and the simulated ones. The simulation of pulse shapes for the iThemba LABS segmented clover detector is performed using the AGATA Detector simulation Library (ADL) software [1, 2]. In order to obtain a good match between the measured pulses and the simulated pulses, the default parameters, such as geometry, impurity profile, charge sensitive preamplifier response, cross-talk parameters [3, 4] and crystal orientation, used in the code should be replaced with experimentally measured ones that are specific for the iThemba LABS segmented clover detector.

For each simulated gamma-ray interaction within the germanium, ADL outputs the integrated current signal that reflects the movement of the charges, shown in figure 1 (red). This signal is rising fast and has sharp edges, different from the experimentally observed signal which has smooth edges figure 1 (blue). The difference is caused by the preamplifier response function. What is needed is to measure it, to find a best fitting function for it, to calculate its derivative, to normalise it and then to input it in the ADL. The ADL has a built-in function that convolutes the derivative of the response function with the charge signal. In this work analysis of the detector preamplifier response was performed in order to implement it in the ADL code.

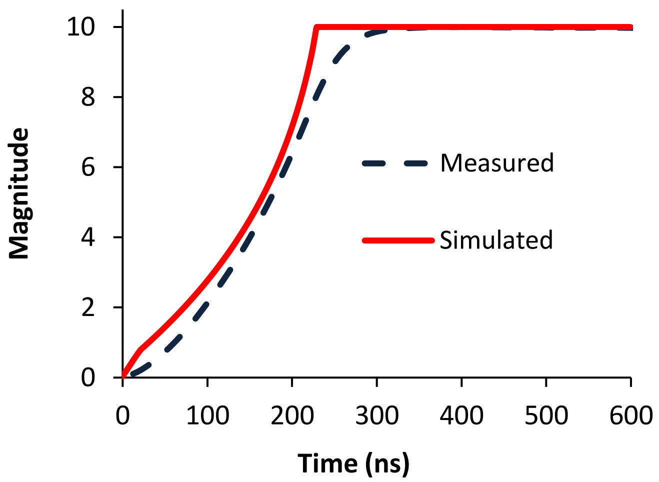

Figure 1. ADL simulated signal without the preamplifier response function (solid) and the experimental measured signal (dash).

4. Experimental measurements

The measurements to extract the detector's preamplifier response for the core signals were done using a pulse generator which produced a step function signal with 5 ns rise-time; see figure 2 (yellow). The pulser was connected to the four test inputs, one for each core of the segmented clover, and the output signals were measured, see figure 2 (blue). This allowed determining the response of the preamplifiers for the four core contacts but not for the segment contacts. As the input signal passes through the preamplifier the sharp edges are smoothed due to the finite bandwidth of the preamplifier [5], and the rise time is increased to ~40 ns. The preamplifier output has under-shoot just before rising and this is a characteristic feature of this charge sensitive PSC823C preamplifier [6].

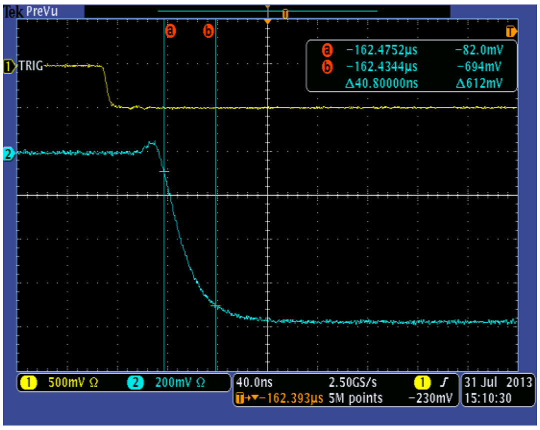

Figure 2. The input pulser (yellow) and the output preamplifier response (blue) signals as observed on an oscilloscope for the core of crystal A.

5. Data analysis and results

Initially, the measured preamplifier response was compared with the function *f(x)*, equation (1), used to fit the AGATA preamplifier response function [7], as shown in figure 3 (black). Then the preamplifier response was fitted with an exponential function *g(x)*, equation (2), see figure 3 (red). Both response functions were found unsatisfactory, because the simulated pulse shapes showed considerable difference from the experimentally measured ones.

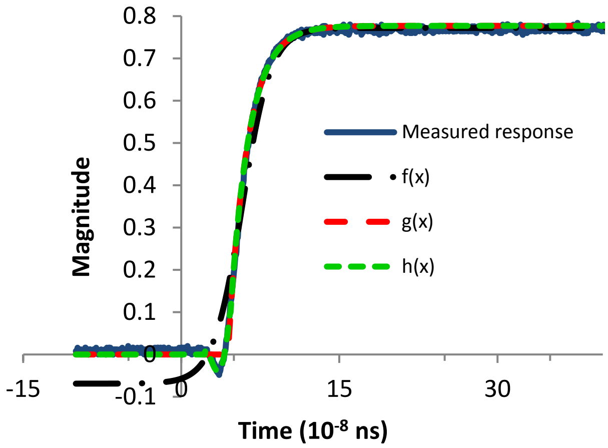

Figure 3. The function *f(x)* (dash dot) and exponential *g(x)* (large dash) function were initially used to fit the measured preamplifier response (solid). The function *h(x)* (small dash) includes both exponential and an undershoot.

$$f(x) = g * \left(\frac{1}{1-c}\right) * \left\{\frac{1}{1+\frac{1-c}{c}*\exp(-b*t)} - c\right\} * exp\left(-\frac{t}{t_d}\right), \quad \ldots\ldots (1)$$

Where b controls the slope, the rise of the signal, and $\frac{1-c}{1}$ shifts the point where the curvature changes, t_d is the decay time of 45µs.

$$g(x) = \begin{cases} a * \exp\left(-\frac{(t)}{t_d}\right) & \text{for } t > 4.4 \times 10^{-8} \\ 0 & \text{for } t < 4.4 \times 10^{-8} \end{cases} \quad \ldots\ldots (2)$$

Where a is the gain. To obtain a better agreement a preamplifier response function describing also the undershoot was defined. Two functions, a polynomial of 4th order and an exponential function were employed to fit the preamplifier response signal, as shown in Figure 3 (green). These functions are:

$$h(x) = \begin{cases} (-At^4 + Bt^3 - Ct^2 + Dt - E) & \text{for } t > 2.28 \times 10^{-8} \text{ and } t \le 4.6 \times 10^{-8} \\ a * \exp\left(-\frac{t}{t_d}\right) & \text{for } t > 4.64 \times 10^{-8} \end{cases} \quad \ldots\ldots (3)$$

With parameter values: *A = 1.3539E+30, B = 2.1716E+23, C = 1.1938E+16, D = 2.7033E+8*, and *E = 2.1556*. The new preamplifier response function was implemented in the ADL. To test it, a pulser signal was simulated in ADL by selecting an interaction position very close to the electrode such that the rise-time of the signal is as short as that of the pulse generator, about 5 ns; see figure 4 (dash red). ADL convoluted this raw charge with the preamplifier response function; see figure 4 (solid blue) and the simulated signal is in agreement with the measured response function; see figure 4 (dash dot black).

The preamplifier response function for core A of the iThemba LABS segmented clover detector was successfully implemented into the ADL simulation software, see figure 5. It was also ensured the ADL is performing the convolution of the simulated charge signal with the response function correctly.

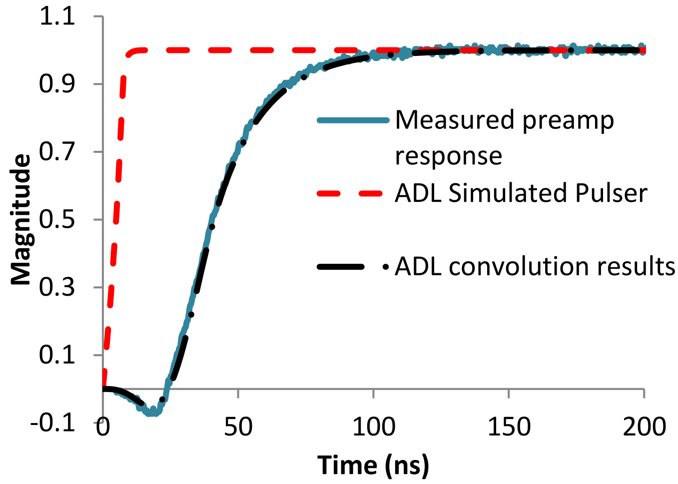

Figure 4. Measured preamplifier response (solid), ADL simulated pulser (dash), and the ADL output of the convolution of charge signal with preamplifier response function (dash dot).

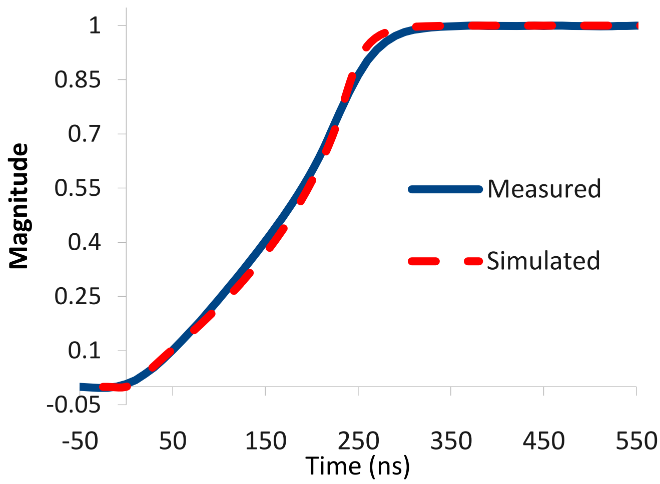

Figure 5. Comparison of the experimentally measured (solid) and simulated signal (dash) for the core of crystal A at a positon of x = 35, y = 55 and z = 62 mm.

As a next step the preamplifier response function of a segment was studied. Since one cannot measure directly the preamplifier response function for a segment contact, an alternative method to determine it was used. The comparison of the measured trace for the hit-segment A5 figure 6 (solid blue) and the simulated one assuming that the segment has the same preamplifier response function as the core (solid black) showed a large difference. The observed signal on the segment is rising much slower. To correct for this, a time difference between the core signal and the charge collecting segment signal was calculated. This difference was then added to the preamplifier response function of the core to delay it and have long rising time. With this technique an agreement between the measured pulse and the ADL simulated charge collecting segment was obtained, figure 6 (dash red and the solid blue).

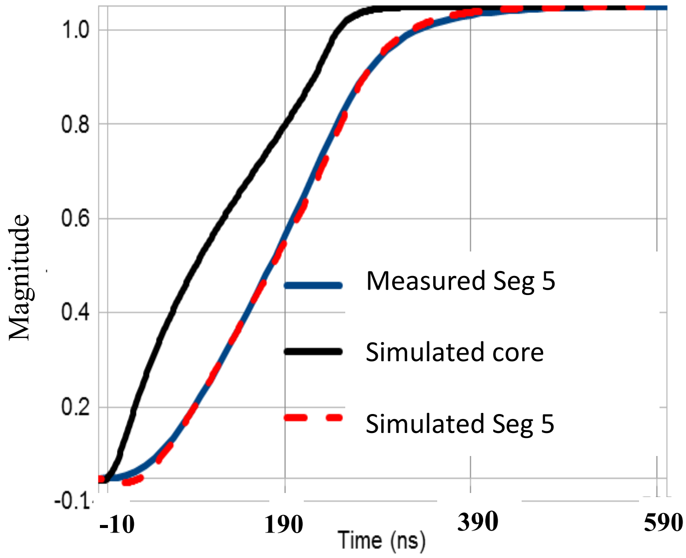

Figure 6. Experimentally measured pulse for hit segment 5 (solid blue), ADL simulated pulse with core preamplifier response function (solid black), and simulated pulse with delayed core preamplifier response function (dash red).

6. Conclusion

The preamplifier response for crystal A was measured with a step function signal of 5 ns rise-time and the core has showed a rise-time of 40ns. The preamplifier response functions for the core and charge collecting segment 5 were successfully implemented on ADL code. For both functions we have obtained an excellent agreement between the measured and simulated charge collecting signals for the core and charge collecting segment crystal A.

Work to determine the response functions of the remaining contacts of crystal A, and of crystals B, C and D, is in progress. Note that the other simulation parameters such as crystal lattice orientation, and electron and hole charge drift velocities of crystal A were experimentally determined and implemented in the ADL to achieve this excellent results [8, 9, 10].

7. References

[1] Bruyneel, B., Birkenbach, B. & Reiter, *P. Eur. Phys. J.* A **52** 70 (2016)

[2] B. Bruyneel and B. Birkenbach, AGATA Detector simulation Library (ADL) v. 2.0, http://www.ikp.uni-koeln.de/research/agata/data/ReadMeADL.pdf.

[3] S.P. Noncolela, T.D. Bucher, E.A. Lawrie, T.R.S. Dinoko, J.L. Easton, N. Erasmus, J.J. Lawrie, S.H. Mthembu,W.X. Mtshali, O. Shirinda, J.N. Orce, *A Phys Pol* B **48**, 347 (2017).

[4] T.D. Bucher, S.P. Noncolela, E.A. Lawrie, T.R.S. Dinoko, J.L. Easton, N. Erasmus, J.J. Lawrie, S.H. Mthembu,W.X. Mtshali, O. Shirinda, J.N. Orce, *Phys. Scr*. **92,** 114004 (2017).

[5] M. Lauer, PhD thesis, Combined Faculties for the Natural Sciences and for Mathematics of the Ruperto-Carola University of Heidelberg, Germany, 2004

[6] EURISYS PSC823C Operating Manual, https://siliconpr0n.org/media/camac/1/PSC823.pdf

[7] M. R. Dimmock, PhD thesis, University of Liverpool, Oliver lodge laboratory, 2008

[8] S. H. MTHEMBU, SAIP 2016, NPRP oral presetion: Crystals Orientation Measurements of the iThemba LABS Segmented Clover Detector.

[9] T. Dinoko, SAIP 2016 NPRP poster presetion: Orientation of the Ge Crystals of the iThemba LABS Segmented Clover Detector.

[10] S. Noncolela, SAIP 2016 NPRP poster presentation: Crystal orientation of the iThemba LABS segmented clover detector.