VHDL Simulation of Trapezoidal Filter for Digital Nuclear Spectroscopy systems

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Abstract- VHSIC Hardware Description Language (VHDL) simulation of trapezoidal filtering algorithm was done. The exponentially decaying sequences were considered as the input to the filter. Such kinds of signals are usually obtained after processing (i.e. in analog domain) and digitizing the nuclear detector signals. The trapezoidal filter acts as a pulse shaping filter in a typical nuclear spectroscopy system to optimize the value of ballistic deficit, signal to noise ratio and pulse pile-up losses in order to facilitate improved measurement of time of arrival and energy of radiation particle. The simulation qualifies the algorithm for its implementation in Field Programmable Gate Array (FPGA) for real time applications.

Index Terms- Trapezoidal Filter, VHDL, FPGA, Ballistic deficit, Pile-up.

I. INTRODUCTION

Now days, the performance of nuclear spectroscopy systems have been considerably improved by opting the modern digital systems over the conventional analog systems. In the analog domain, a current pulse produced by detector is integrated using a charge sensitive preamplifier which produces a step-like or a slow decaying exponential pulse. In a typical digital nuclear spectroscopy system, the detector signal is digitized using a fast analog to digital converter (ADC) directly after the preamplifier stage and the pulse processing operations such as baseline correction, pulse shaping and pile-up correction are carried out on a digital hardware (e.g. FPGA). The pulse shaping algorithms are implemented in the digital hardware to shape the detector signals to optimize spectrometer parameters that are ballistic deficit, signal to noise ratio and pulse pile up losses. Ballistic deficit is the loss in the pulse height which arises due to mismatch of maximum charge collection time of detector and the pulse shaping time [1]. So, reducing the ballistic deficit facilitates insensitivity of the spectrometer to rise-time fluctuations in the detector signals. The pulse shaping makes high count rate measurement possible by reducing pulse pile ups (superimposing of two close detector pulses) [2]. In order to optimize the above mentioned parameters, mostly the digital trapezoidal filtering is used in digital spectroscopy systems [3], [4]. This paper is organized as follows. Section II briefly describes the theory of trapezoidal filtering algorithm. It also briefly discusses the governing 'statement' of the developed VHDL code. Section III discusses the simulation results. Finally, the concluding remarks are included in Section IV.

II. THEORY

Many algorithms have been developed to implement trapezoidal filtering using convolution and transfer function method respectively [3],[5],[6]. In this paper, we adapted the trapezoidal filtering algorithm using convolution method. The figure1 shows block diagram representation for the same. The trapezoidal function can be expressed using following recursive equations [3].

$$\mathrm{a}^{\mathrm{K,L}}[\mathrm{n}] = \mathrm{x}[\mathrm{n}] - \mathrm{x}[\mathrm{n}-\mathrm{K}] - \mathrm{x}[\mathrm{n}-\mathrm{L}] + \mathrm{x}[\mathrm{n}-\mathrm{K}-\mathrm{L}] \tag{1}$$

$$\mathrm{b}[\mathrm{n}] = \mathrm{b}[\mathrm{n}-1] + \mathrm{a}^{\mathrm{K,L}}[\mathrm{n}], \ \ \mathrm{n} \geq 0 \tag{2}$$

$$\mathrm{c}[\mathrm{n}] = \mathrm{b}[\mathrm{n}] + \mathrm{M}\mathrm{a}^{\mathrm{K,L}}[\mathrm{n}] \tag{3}$$

$$\mathrm{y}[\mathrm{n}] = \mathrm{y}[\mathrm{n}-1] + \mathrm{c}[\mathrm{n}], \ \ \mathrm{n} \geq 0 \tag{4}$$

Where X[n] is digitized input exponential signal and Y[n] is output of the filter respectively. The value of M is given by the following equation.

$$M = \frac{1}{e^{(\frac{T_p}{\tau})} - 1} \tag{5}$$

Where T_p is digitizer's clock frequency and τ is time constant of exponential input signal (i.e. output of the preamplifier).The duration of the rising (falling) edge of the trapezoidal shape is given by the smaller value of K and L, and the duration of the flat top of the trapezoid is given by the absolute value of the difference between K and L. The parameters of trapezoidal filter that can be adjusted are rise time, fall time and width of the flat top respectively. The shorter rise time allows higher pulse count rate by reducing the pile up effects. Whereas the larger rise time improves the signal to noise ratio. Hence the value of rise time should be chosen to optimize the two parameters [7]. To eliminate the effect of ballistic deficit the duration of flat top should be longer than the longest detector charge collection time [8].

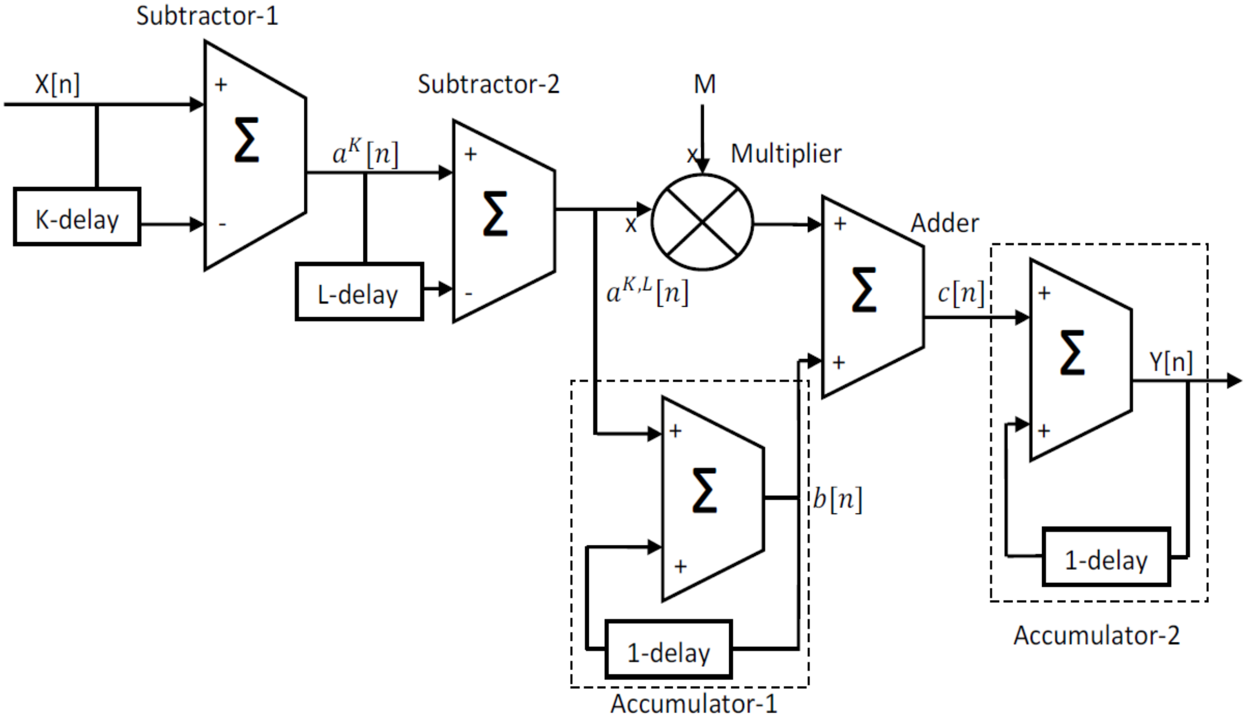

Figure 1: Block diagram of convolution type trapezoidal filter

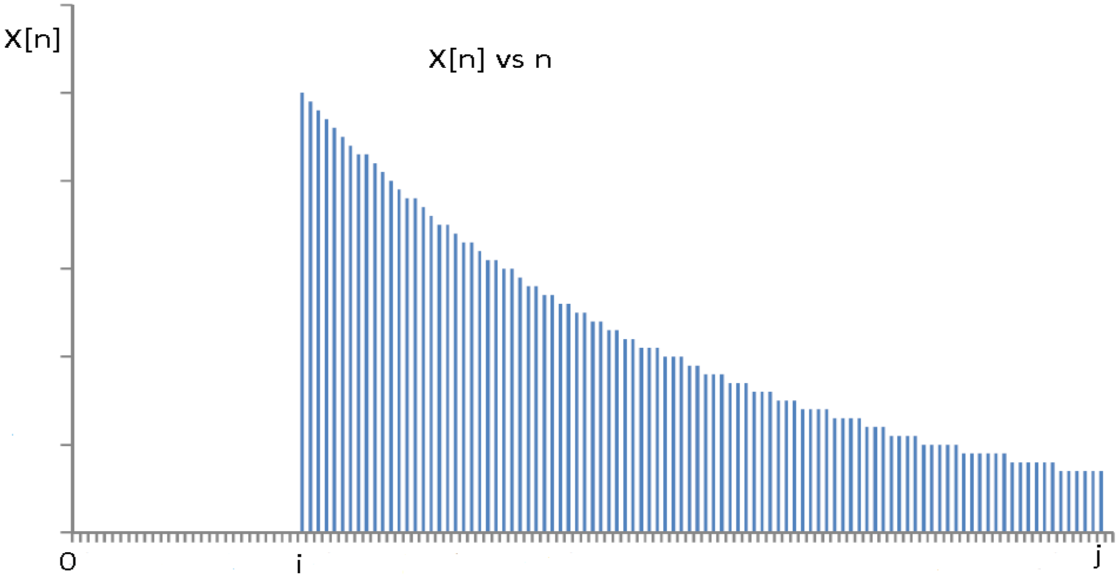

Figure 2: Input sequence to trapezoidal filter

The figure 2 shows a typical input sequence that is applied to a trapezoidal filter. The exponentially decaying pulse of (j-i) samples corresponds to a nuclear event. The same takes place when a radiation quanta interacts with the nuclear radiation detector. The governing 'statement' of the developed VHDL code that simulates the algorithm of convolution type trapezoidal filter is given below.

```
Trapezoidal filter : for n in i to j generate
Subtractor-1 : subtract_module port map (x(n), x(n-K), delayK(n));
Subtractor-2 : subtract_module port map (delayK(n), delayK(n-L), delayKL(n));
Multiplier : multiply_module port map (M, delayKL(n), product(n));
Accumulator-1 : add_module port map (delayKL(n), b(n-1), b(n));
Adder : add_module port map ((b(n), product(n), c(n));
Accumulator-2 : add_module port map (c(n), y(n-1), y(n));
end generate Trapezoidal filter;
```

As given in the code (also shown in figure 1) the filtering scheme comprises of two subtractors, a multiplier, two accumulators and an adder respectively. The subtractors and adders are generated by instantiating subtract_module and multiply_module respectively. Whereas the adder and accumulators are generated by instantiating the add_module. The first two 'signal's in parentheses (after the keyword 'port map') for each module are mapped to input ports while the third 'signal' is mapped to output port respectively. All the 'signal's are one dimensional array of size 'j'.

III. SIMULATION RESULTS

The simulations were performed for single exponential sequences as well as for piled up exponential sequences by considering different values of shaping parameters (i.e. K and L). Figure 3 shows the simulation result for single exponential sequence. The value of K, L and M was selected to be 6, 24 and 50 respectively. Figure 4 shows the performance of the filter when the input is a piled up exponential sequence. The value of K, L and M in this case was selected as 4, 12 and 50 respectively.

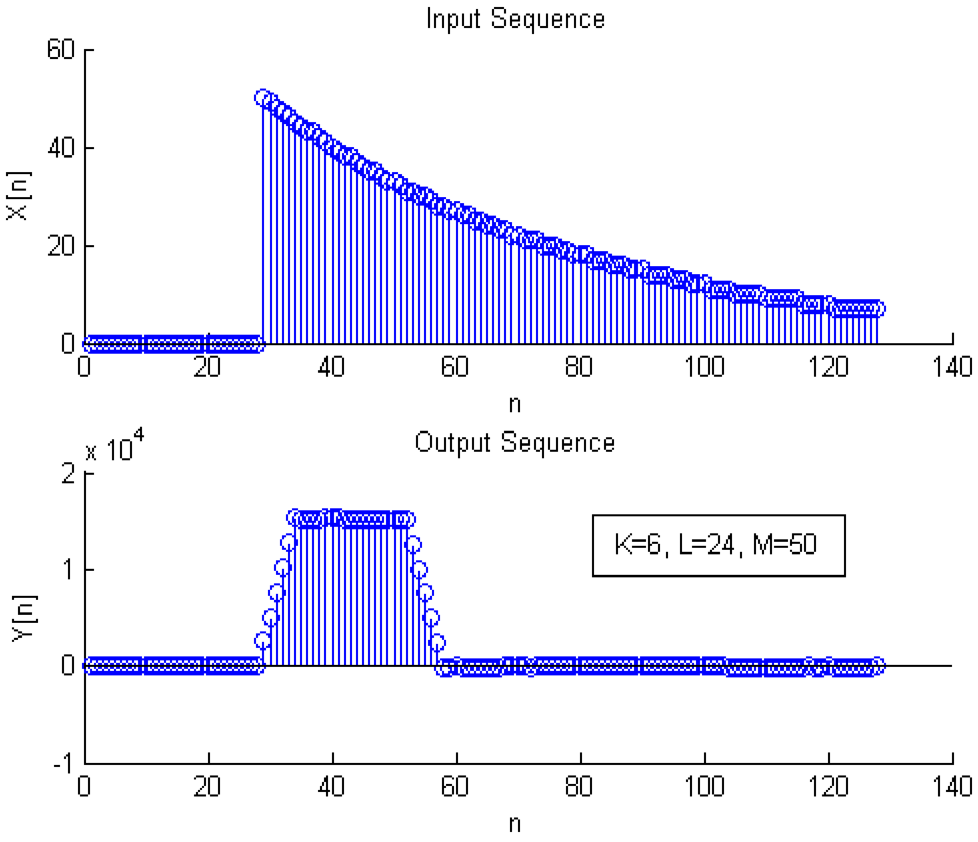

Figure 3: Trapezoidal filtering of single exponential pulse

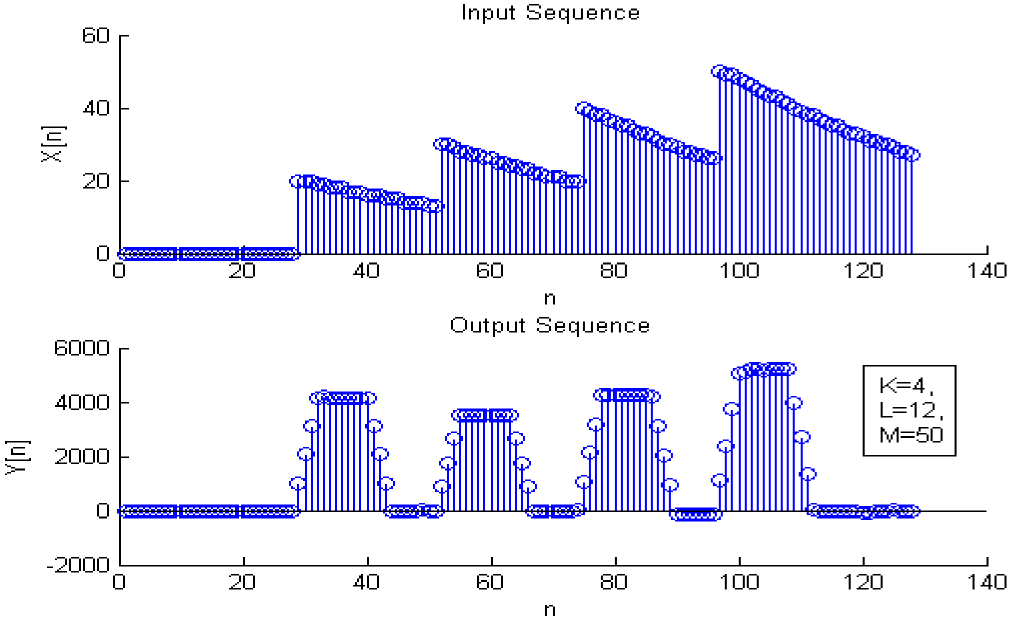

Figure 4: Trapezoidal filtering of piled up exponential sequence

IV. CONCLUSION

The VHDL simulation for trapezoidal filter was performed for single and piled up exponential sequences. It was observed that the selection of shaping parameters (i.e. K and L) plays a vital role in reducing pile up effect. The algorithm can be implemented in Field Programmable Gate Array (FPGA) to carry out the trapezoidal filtering in real time applications.

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REFERENCES

[1] Glenn F. Knoll, “Radiation detection and measurement”, 4th Ed., John Wiley and Sons, Inc , 2010, pp. 183, 632-633.
[2] Kafaee, M., Nucl. Instrum. Meth. Phys. Res., Sect. A, 2009, vol. 607, p. 652.
[3] V.T. Jordanov, F. Glenn, Knoll, ” Digital synthesis of pulse shapes in real time for high resolution radiation spectroscopy”, Nucl. Instrum. Method Phys. Res. A , Vol. 345, 1994, pp 337–345.
[4] N. Menaa, P. D’Agostino, B. Zokrzewski, and V. T. Jordanov, “Evaluation of real-time digital pulse shapers with various HPGe and silicon radiation detectors,” Nucl. Instrum. Methods Phys. Res. A, Vol. 652, 2011, pp 512-515.
[5] V.T. Jordanov, G.F. Knoll, A.C. Huber, J.A. Pantazis, “Digital techniques for real-time pulse shaping in radiation measurements”, Nucl. Instrum. Method Phys. Res. A Vol. 353, 1994, pp 261–264.
[6] Wuyun Xiao, Yixiang Wei, Xianyun Ai, Qi Ao, “System simulation of digital pulse spectrometer”, Nucl. instrum. Method Phys. Res. A, Vol. 555 , 2005, pp 231–235
[7] R. D. Bingham, “A Digital Filter for High-Purity Germanium Detector Spectrometry”, Dissertation, University of Tennessee, 1996
[8] Keyser, Ronald M., Twomey, Timothy R., and Bingham, Russell D, “Improved Performance in Germanium Detector Gamma Spectrometers based on Digital Signal Processing,” ORTEC, 801 South Illinois Avenue, Oak Ridge, TN 37831s.

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