Resolving time beyond the sampling rate for MRCOFFEE

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Introduction

MRCOFFEE is a 16 detector X-ray spectrometer whose key performance metric is to achieve a resolution better than 0.5 eV for 100 eV electrons which corresponds to a flight time resolution of under 50 ps. This is well beyond the sampling precision of our digitizers. We propose to "resolve" this problem by designing a high-speed analog preprocessing circuit upstream to the detectors, generating insightful data for subsequent post-processing/Machine Learning algorithms in the FPGA.

Design Considerations

- The signal components with f<20 MHz only contribute signal power, hence not important for our application.
- The signal components with f<2.5 GHz contains the timing information.
- The sampling rate of our digitizers is 6 Gsam/sec⇒3 GHz bandwidth(Nyquist) and a resolution of 200 ps.
- The non-linear transformation between timing and energy resolution:

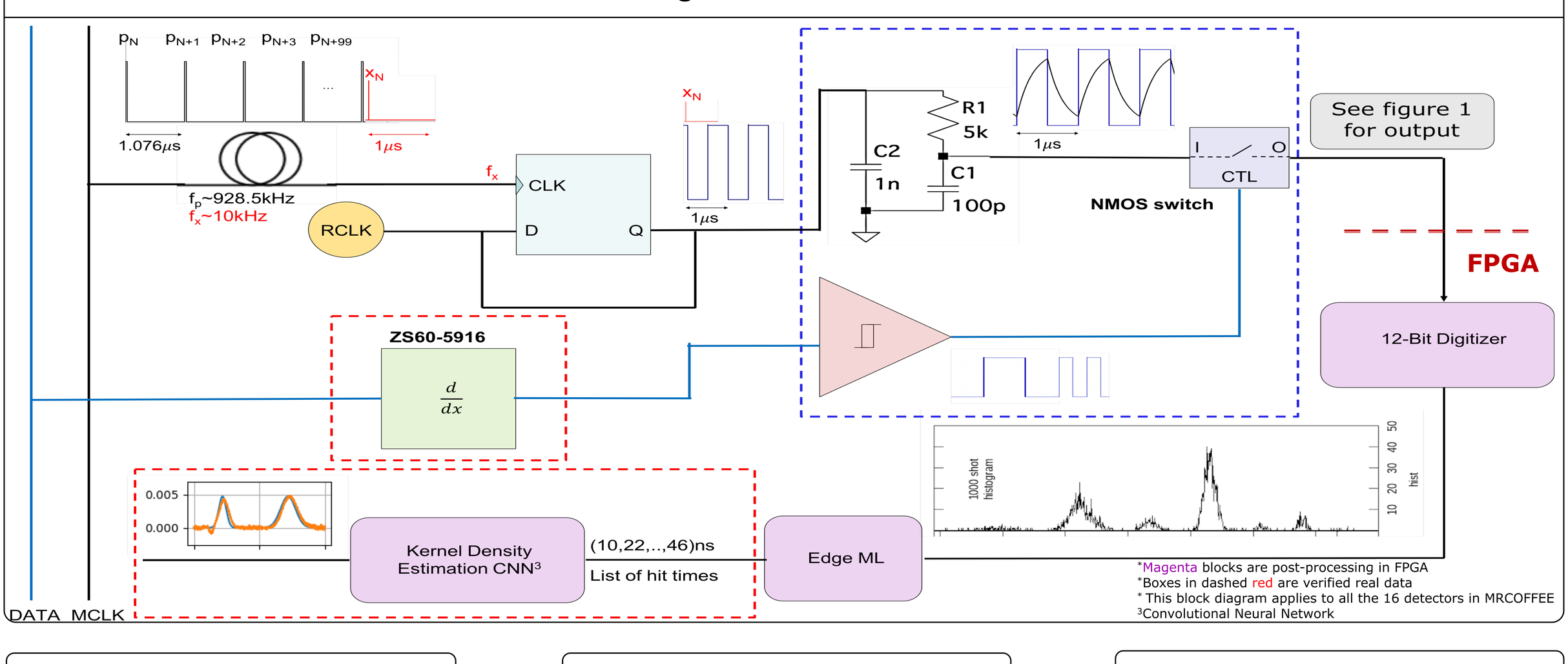
$$\Delta t \propto \frac{1}{\sqrt{E}} \Delta E$$

Building Blocks

Element	Purpose
Differentiator	Eliminate DC[1]/LF[2] and create crossings
RCLK	Local clock for ramp generation(1 MHz)
D Flip Flop	Synchronization to beamline clock
Schmitt Trigger	Generate a control signal
Switch	Hold ramp according to the control signal
Sample-and-hold circuit (dashed)	Generate non linear transformation ramp

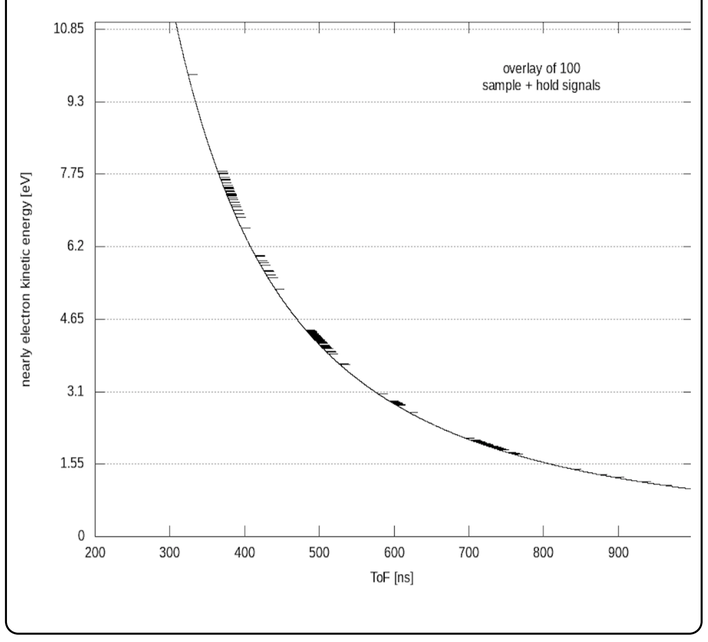
[1]Direct current
[2]Low frequency

Block Diagram and Process Flow



*Magenta blocks are post-processing in FPGA
*Boxes in dashed red are verified real data
* This block diagram applies to all the 16 detectors in MRCOFFEE
[3]Convolutional Neural Network

Figure 1: Sample and hold output



Future Work & Conclusion

The immediate next step in the project will be to build all the simulated blocks with actual hardware and test.

The implementation of this hardware is extremely crucial in improving the performance of MRCOFFEE and the post-processing algorithms. Simulations suggest that, with the current designs, the resolution can reach 0.25 eV, which is even better than our current objective.

References/Acknowledgements

- Machine Learning to digest CookieBox data, Audrey C. Therrien et al.
- Machine Learning at the edge: FPGA Implementation, Audrey C. Therrien et al.
- The CookieBox and Edge Machine Learning, Audrey C. Therrien et al.
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