Simulation of new charge summing and hit allocation algorithm

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Introduction

- Pixel detectors have a high demand for the spatial and energy resolution of individual photons.
- With decreasing size of pixels, pixel detectors are losing spatial resolution and spectroscopy abilities.
- There are two possible solutions to resolve charge sharing effects and in high-Z materials problems with long-travel fluorescent photons:
  - Off-chip post processing with FPGA or microprocessor, which limits the throughput and latency of pixels detectors.
  - On-chip algorithm which deals with the charge sharing effect and fluorescent photons.
- Most of the algorithms sum the charge from the four neighboring pixels [1], [2]. This prevents the possibility of collecting the charge from more considerable distance which is generated by long-travel fluorescent photons.
- There is a high demand for developing new on-chip algorithms, which can be used for precise hit allocation in particle physics detectors or X-ray spectroscopic imaging detectors.

Winner-Master-Slave algorithm

- Winner-Master-Slave (WMS) is a new asynchronous algorithm, which deals with charge sharing effects as well as with long travel fluorescent photons.
- Allocates hit to the pixel with highest charge deposition.
- Sums charge from 25 pixels (cluster size up to 5 x 5).
- Uses digital logic for arbitration and cluster creation and analog circuits for charge summing.
- The algorithm consists of three types of pixels (Winner, Master, and Slave) and uses a three step procedure:
  - Select winner pixel: Pixel with the highest charge is selected as a winner.
  - Create cluster: Winner requests neighboring pixels for cluster creation.
  - Sum cluster charge: Winner sums charge from all active pixels in cluster and store its value.

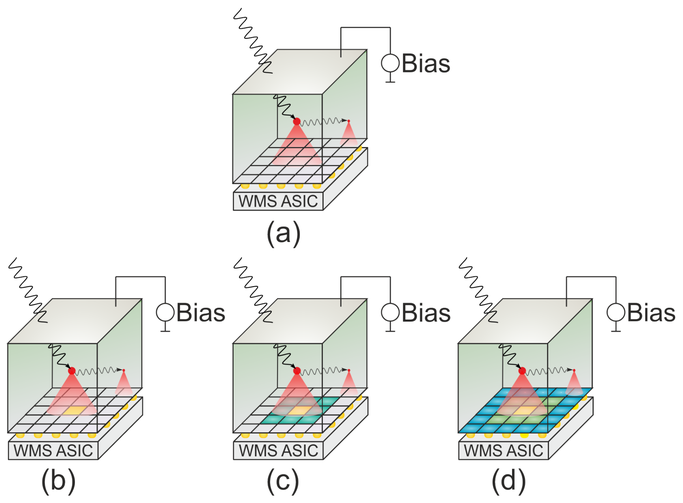

Figure 1: **(a)** hit with fluorescent photon, **(b)** Winner pixel selection, **(c)** Master pixels selection, **(d)** Slave pixels selection

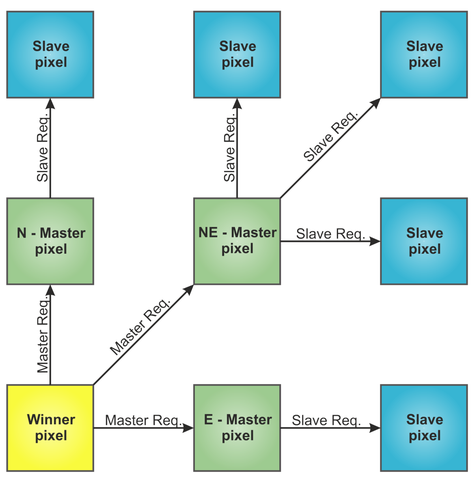

Figure 2: Communication between neighboring pixels

- Winner pixel selection is based on a result of arbitration between all neighboring pixels.
- Once the winner is selected, it requests its neighbors (8 pixels) to join to the cluster as master pixels.
- Master pixels based on their position in cluster send a request to one or three neighboring pixels to become slave pixels.

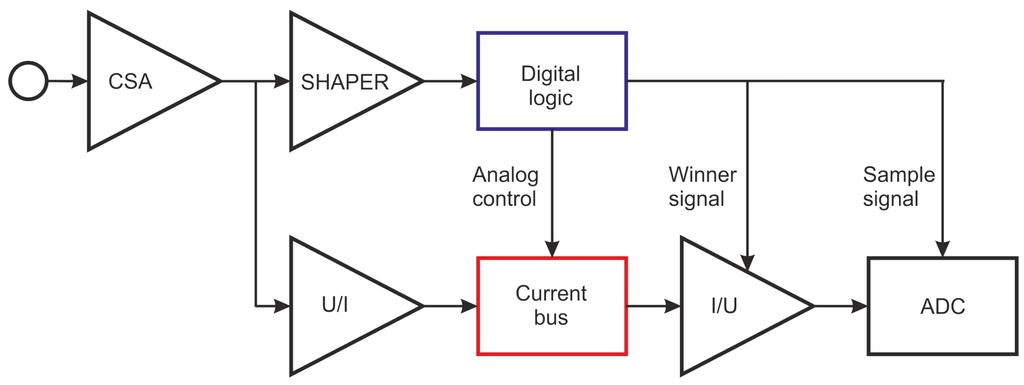

Figure 3: Block diagram of pixel architecture.

- Once the cluster is created, all active pixels in the cluster are connected to common current bus.
- The winner is responsible for summing currents generated by each pixel, performing I-V conversion, sampling and saving its value.

Simulation and results

- WMS was implemented in Verilog-AMS and simulated with AMS simulator in Cadence Virtuoso environment.
- Size of the pixel matrix was set to 10x10.
- Charge clouds with Gaussian distribution were placed randomly over the pixel matrix.
- The maximum size of the charge cloud was set to 5x5.
- Total charge deposition in one cluster was 27000e.
- To simulate the effect of fluorescent photons, nonzero probability of generation random charge cloud of size 1x1 with 6000e was added.

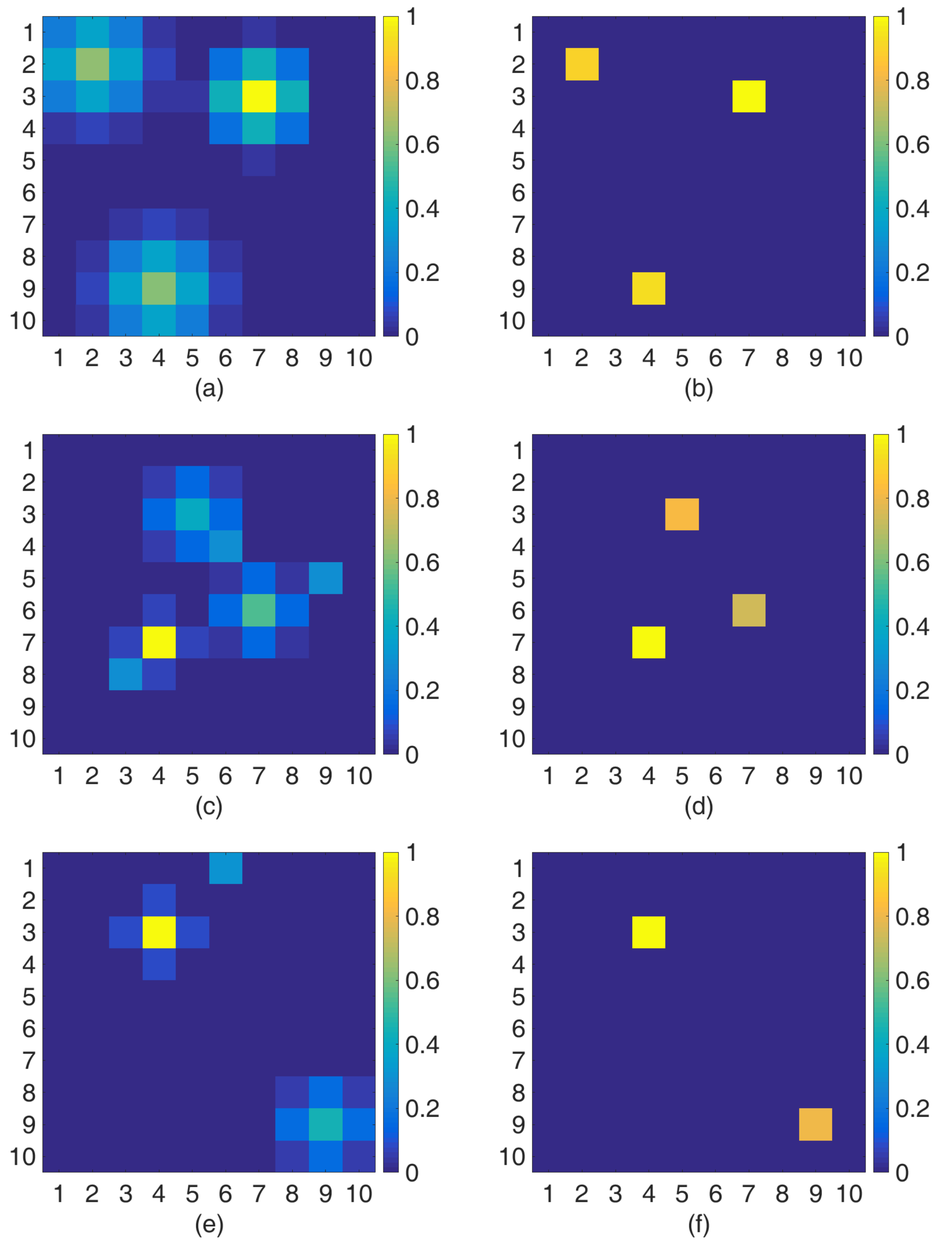

Figure 4: Three separate hits **(a)** and their allocation **(b)**. Three hits with fluorescent photons **(c)**, resolution and allocation **(d)**. Two hits **(e)** and their allocation **(f)** b.

- WMS resolves all single photon hits with charge sharing effect in cluster size up to 5x5 pixels.
- WMS also resolves events with fluorescent photons and reconstructs the total energy deposition.

Conclusion

Winner-Master-Slave was designed in Verilog-AMS and simulated with AMS simulator in Cadence Virtuoso environment. The algorithm has been systematically tested using randomly generated clusters. The simulation outcome proved that WMS solves several problems of existing solutions and is suitable for implementation in a front-end ASIC for a spectroscopic imaging detector.

References

[1] G. W. Deptuch, F. Fahim, P. Grybos, J. Hoff, S. Holm, P. Maj, D. P. Siddons, P. Kmon, M. Trimpl, and T. Zimmerman.
An Algorithm of an X-ray Hit Allocation to a Single Pixel in a Cluster and Its Test-Circuit Implementation.
IEEE Transactions on Circuits and Systems I: Regular Papers, 65(1):185–197, jan 2018.

[2] T. Koenig, E. Hamann, S. Procz, R. Ballabriga, A. Cecilia, M. Zuber, X. Llopart, M. Campbell, A. Fauler, T. Baumbach, and M. Fiederle.
Charge summing in spectroscopic X-ray detectors with high-Z sensors.
IEEE Transactions on Nuclear Science, 60(6):4713–4718, dec 2013.

Acknowledgments

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