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Enhancing Sensor Readout Efficiency: Innovations and Challenges

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The increasing segmentation of sensors, especially in tracking and vertexing applications, along with the drive to reduce the material budget, necessitates that processing of charge signals from sensors through amplification, filtering, extraction of amplitude, time of occurrence, as well as of additional features, such as particle trajectory direction and type identification, be confined to ever-smaller areas on readout integrated circuits. The circuit networks that transmit information about detected events from radiation interactions with the sensor material to an external data acquisition system compete for the space needed for implementing relevant circuit networks. Both signal processing from radiation interaction events and information extraction aims at minimization of power dissipation, reduction of interference-causing activities, and ensuring low latency.
The human eye is the most efficient biological system operating in the mentioned manner. Optic nerves extending from the retina in parallel transmit highly efficiently encoded data from each light sensitive element to the brain for parallel processing. How the eye achieves its biological efficiency is not understood, and the eye remains an unattainable model for human-built readout detector systems. However, numerous efforts aim to bring readout methods closer to this ideal.
Over the years, technological miniaturization, reflected in node dimensions decreasing from 1 micron in the early nineties to 28 nm today, could have enabled fitting parallel readouts by increasing the density of readout electronics. However, this technological gain has been largely consumed by the miniaturization of individual channel sizes and implementations of additional advanced functionalities, primarily enhancing the performance of front-end blocks through digital assistance in correcting process variabilities, rather than easing the readout.
In radiation detector systems, sensor matrix data are typically transmitted to the periphery before being sent to the data acquisition system. This periphery-oriented approach applies regardless of whether all data or only trigger-confirmed data are read, whether empty data are removed or compressed in the readout circuits, or whether data are read continuously or selectively. The main difficulty is ensuring that the data transmission link, with its bandwidth optimized to match the combined event information generation from the channels it serves, transmits data without losing time slots (which would otherwise carry empty data). This must be done without collisions and, most importantly, by allocating transmission rights to individual channels based on their need for service.
Upon closer examination, all the readout methods to be presented fall into the category of Address-Event Representation, differing in address generation, address information coding, latency, and whether readout is framed or frameless. The presentation will start with simple x-y readouts like Delphi pixel, then move to polling methods such as token passing/token rings used in current LHC detector systems and similar setups. It will then cover framed methods with self-identification of channels for readout using various priority encoder schemes, and finally address frameless methods within neuromorphic engineering. In the latter, the discussion will start with globally asynchronous, locally synchronous systems, including arbitration issues, and provide examples of fully event-driven, collision-free readouts. This comprehensive review will enable a broader discussion based on collected material.

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Classification de Session: Monolithic sensors

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