Title

Architecture and Circuit Design of Photon-Counting Readout for X-Ray Imaging Sensors

ABSTRACT

Hybrid pixel array detectors for X-ray imaging are based on different technologies for sensor and readout electronics. The readout electronics are based on standard CMOS technologies that are experiencing continuously rapid improvements by means of down-scaling the feature sizes, which in turn lead to higher transistor densities, lower power consumption, and faster circuits. For pixel-array imaging sensors the improvements in CMOS technology opens up new possibilities of integrating more functionality in the pixels for local processing of the sensor data. However, new issues related to the tight integration of both analog and digital processing circuits within the small area of a pixel must also be evaluated.

The advantages of down-scaling the CMOS technology can be utilized to increase the spatial resolution by reducing the pixel sizes. Recent research indicates however that the bottleneck in reaching further spatial resolution in X-ray imaging sensors may not be limited by the circuit area occupied by the functions necessary in the pixels, but are instead related to problems associated with charge-sharing of charges generated by the sensor which are distributed over a neighbourhood of pixels and will limit the spatial resolution and lead to a distortion of the energy spectrum. In this thesis a mechanism to be implemented in the readout circuits is proposed in order to suppress the charge-sharing effects. The proposed architecture and its circuit implementation are evaluated with respect to circuit complexity (area) and power consumption. For a photon-counting pixel it is demonstrated that the complete pixel, with charge-sharing suppression mechanism, can be implemented using 300 transistors with an idle power consumption of 2.7μW in a 120nm CMOS technology operating with a 1.2V power supply.

The improvements in CMOS technology can also be used for increasing the range of applications for X-ray imaging sensors. In this thesis, an architecture is proposed for multiple energy discrimination, called color X-ray imaging. The proposed solution is the result of balancing the circuit complexity and the image quality. The method is based on color sub-sampling with intensity biasing. For three-level energy discrimination, that corresponds to color imaging systems for visible light with R, G, and B color components, the increase in circuit complexity will be only 20% higher than that for the Bayer method but results in significantly better image quality.

As the circuit complexity in the digital processing within each pixel is increased, the digitally induced noise may play an increasingly important role for the signal-to-noise ratio in the measurements. In this thesis an initial study is conducted regarding how the digital switching noise affects the analog amplifiers in the photon-counting pixel.