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#10-179 Optimization of a VCO-Based Pixelated Particle Detector for particle discrimination and tracking

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This work deals with the study and optimization of a particle detection chain based on a CMOS-SOI voltage-controlled oscillator (VCO) circuit associated to a 3x5 matrix of detection. The matrix is a semiconductor radiation detector, also called solid-state detector. This detector is based on charge collection and amplification using a semiconductor volume such as a p-n junction. For a better detector sensitivity and tracking requirements, a pixel organization including several junctions is used. The solution was first optimized for the recognition and tracking of low energy particles but high energy particles can also be detected.

The detection chain presented in this work relies on an indirect particle detection through a voltage-controlled oscillator. Previous works have demonstrated the feasibility of identifying input signals from specific particles by analyzing the average output voltage of the VCO chain. This method offers significant advantages, in particular the comprehensive acquisition of input signal characteristics, including waveform, magnitude, and current duration, all with a high detection sensitivity.
The proposed detection system is composed of a detection matrix together with an innovative readout circuit based on a high frequency voltage-controlled oscillator. The detection chain has been designed and implemented on 130nm CMOS SOI technology, then simulated at circuit level using "Spectre"simulator (SPICE-based) under Cadence Virtuoso © CAO tool. The VCO chain is composed of three parts: a CMOS based pixel detector, a shaping circuit based on a voltage controlled ring oscillator and a system for frequency and amplitude detection. This system allows the evaluation of the circuit sensitivity to radiation by measuring the oscillator responses. As the lastest solution reaches an operating frequency of 4.8GHz, the shape of the signal is directly reproduced at the output of the VCO (Fig. 1). This method avoids most of the design problems. Then, the information is extracted by correlating the initial oscillation signal of the system with the oscillating signal after the particle has passed the detector. The only requirement to allow particle recognition is then to link the output information (i.e. voltage variation of the oscillating signal) to the input information (current stimuli).
Several pixel configurations have been explored in previous works. In this study, we will focus on a 3x5 matrix (Fig. 2). The current source comes from the realistic simulation of the matrix using TCAD device simulation tools (Synopsis ©). The effect of the ion strike is simulated using the Heavy Ion module of Synopsis, considering an electron-hole pair column centered on the ion track axis. The Linear Energy Transfer is defined as the energy lost by the particle, by unit of length and varies along the track. In this paper, an actual variation of the LET was integrated in our simulations, based on the value given by SRIM tables. The VCO based chain presented here is optimized for the detection and identification of particle fluxes lower than 109 particles per detection area and per second. This chain could be particularly suitable for the detection of low energy particle but also for more energetic particles. Then we decided to analyze the VCO response for different energies. The low energy will be studied through the particles generated by the initial interaction of a thermal neutron with boron-10, i.e. one Li with an initial energy of 0.9 MeV and one Alpha with an initial energy of 1.5 MeV. The case of a more energetic particle will also be examined. This is a 50MeV Aluminum (Fig. 3) which could be produced by the interaction of fast protons with silicon.
After the particle generation inside the matrix of detection, the key point is how the output parameters of the VCOs chain can give information about the input current. This could be done through the analysis of various characteristics extracted from the average voltage variation (Fig. 1). After a first step of calibration, a curve of reference is obtained (Fig. 2). When the detection is good, the variation of the average output signal (ΔVmax) versus the maximum of the input current (Imax) fits a linear evolution. Through the calibration curve, the

output parameters can be linked to the input currents, which could allow the incoming particle identification. Then tracking ability including particle discrimination can be evaluated by comparing the Imax-ΔVmax evolution of the studied particles to the calibration curve.

It is presented there for two particles: an Alpha and an Aluminum particle. Other configurations will be presented in the final paper. Both particles have been injected sequentially in the VCO. The average voltage is presented in Fig. 4 for the highest currents of the pixels, corresponding to the two particles. The metrics Imax-ΔVmax corresponding to these currents and voltages have been reported in Fig. 2. All the currents are correctly reproduced excepted the N10 current of the aluminum. This current should be large enough to be correctly detected by the VCO but, it is too high and its maximum value meets the saturation value of the VCO. To avoid this problem, one interesting application for the VCO based detector could be a spectrometry analysis. Then the oscillator frequency could be calibrated to select particles with various characteristics. In that case, several VCO working at different frequencies could be used, giving the opportunity to characterize accurately a given environment. This possibility will be explored in the final paper.
In the final paper, another aspect of our work will be to investigate the feasibility of utilizing a greater number of pixels (i.e. of VCOs) in terms of power consumption. The aim is to adopt a comprehensive approach to improve the capabilities and robustness of our detection and tracking methodology.

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