Abstract

Silicon Photomultipliers are emerging as new photodetectors in a growing number of scientific fields thanks to their great performance. In particular, this thesis concern two experiments in which SiPMs are employed: the space mission TERZINA and DarkSide-20k for dark matter detection at cryogenic temperature. In both cases, a mixed-signal readout ASIC has been developed from the VLSI group at INFN of Turin.

TERZINA is a groundbreaking space mission that aims to validate a new detection technique for studying Ultra-High Energy Cosmic Rays (UHECRs) and Cosmic Neutrinos (CNs). It aims to monitor the terrestrial atmosphere from space thus detecting the air showers which generate from the interaction of highly energetic particles with the air molecules. Moreover, TERZINA is a pioneering mission in which SiPMs are employed in a space environment. Hence, the use of these sensors and their electronics must be validated. The results obtained by TERZINA will be crucial for the design of the larger-scale POEMMA experiment. In this context, a new 64-channel ASIC has been developed by using a 65-nm CMOS technology. The single channel includes a front-end stage followed by a 256-cell analog memory in which the amplified waveform is sampled at 200 MHz frequency. Each cell embeds both a storage capacitor and a single-slope Analog-to-Digital Converter (ADC) with a resolution from 8 to 12 bits. Hence, the sampled values are digitized in parallel thus saving conversion time. Moreover, the digitization phase is carried out only if a trigger signal is acquired by the control logic. The analog memory can be also segmented into shorter slices of 32 or 64 cells which work in parallel thus allowing for data derandomization. Due to the space application, the power consumption must be kept as low as possible and care must be paid in radiation hardness.

Silicon Photomultipliers (SiPMs) can be also suitable for instrument detectors operating at cryogenic temperature since cooling down the sensors allows for the

reduction of dark count rate. The DarkSide-20k experiment aims to employ these sensors for dark matter study. Hence, the mixed-signal chip named ALCOR has been implemented to perform timing measurements with 25-50 ps resolution. Both single-photon detection and Time-over-Threshold measurements can be carried out. The chip has been designed in a commercial 110-nm CMOS technology and it embeds 32 pixels fashioned in a 4×8 matrix.

The author has taken part in both the TERZINA and the DarkSide-20k projects. For what concern the former experiment, she contributed in the design phase of the chip by implementing its analog blocks with a focus on the front-end and the analog memory. On the other hand, she joined the test campaign for the performance evaluation of ALCOR for DarkSide-20k. Hence, this dissertation first describes the architecture of the ASIC for the TERZINA experiment. The second part is related to the characterization of ALCOR.

Chapter 1 reports an overview of the Silicon Photomultiplier structure and operating principle. Then, a survey about the state-of-the-art electronics for SiPMs is presented to find out if one of the present ASICs is suitable for the TERZINA mission or to readout these sensors at cryogenic temperature.

Chapter 2 gives a brief description of the physics of UHECRs and CNs. After that, the POEMMA and TERZINA space missions are illustrated. The chapter ends with a description of the specifications for the front-end electronics for TERZINA.

In Chapter 3, the chosen architecture for the TERZINA readout is presented. In particular, a deeper description of the analog memory is given. Then an insight into the derandomization technique and the trigger system is illustrated.

Chapter 4 describes the ASIC requirements and architecture of ALCOR. The pixel building blocks and operation modes are illustrated. Then, the configuration registers of the chip are described.

The results of the test campaign for the characterization of the first prototype of ALCOR are reported in Chapter 5. The front-end has been characterized both by sending a digital test pulse and by exploiting the dark counts of SiPMs. The obtained data are analysed by using the s-curve method. Then, the Time-to-Digital Converters (TDCs) are tested through the histogram method and the Differential Non-Linearity (DNL) and the Integral Non-Linearity (INL) are evaluated.