Design of a Time-over-Threshold Bilinear Front-End for Photon Science Applications with High Dynamic Range in 28 nm CMOS

Andrea Galliani[1], Luigi Gaioni[1], Valerio Re[1], Gianluca Traversi[1]

[1]Università degli Studi di Bergamo (IT)

In the context of the so-called PRIN 2022, funded by the Italian Ministero dell'Università e della Ricerca, the project *Front-end channels in a* 28 nm *CMOS process for Pixel detectors in future High Energy physics colliders and advanced X-ray imaging instrumentation* (PiHEX) has, as one of its objectives, the development of ASIC prototypes for for modern photon science applications, which require front-end electronics capable of processing signals with a wide dynamic range, while maintaining low noise levels.

In this paper, a new front-end channel designed in a commercial 28 nm CMOS technology based on a bilinear, dynamic gain architecture is presented. The front-end is designed to operate with energies in the range from 1 to 10^4 photons at ~ 9 keV and a maximum frame period of 250 ns.

Each channel consists of a preamplifier with an automatic mode switching system: a high-gain mode for weak signals (from 1 to 100 photons) and a low-gain mode for strong signals (from 100 to 10^4 photons). Cascaded with the preamplifier is a comparator whose output is fed to the Time-over-Threshold counting system employing a ring oscillator and an 8-bit counter. The Time-over-Threshold behavior is adapted according to the selected gain mode. This ensures that the counter does not overflow and that the counted time over the threshold value remains within the 250 ns time frame in both the operating modes. The pixel has a size of 110 µm × 55 µm.

Simulations show that in the high gain mode, the Signal to Noise Ratio (SNR) is about 10. The low-gain configuration features an SNR of about 20. Post-layout simulations confirm a linear relationship between input photons and Time-over-Threshold in both low gain and high gain modes, supported by a ring oscillator at ~ 1 GHz, which demonstrates good stability even in the presence of process and power supply variations. Additionally, post-layout simulations show that, for 1 to 100 photons, the input-output characteristic has a non-linearity index of 3.3%. For 100 to 10^4 photons, the non-linearity index drops to 2.3%.

These simulation results validate the bilinear Time-over-Threshold approach implemented as an effective solution to extend the dynamic range and optimize the noise performance of front-ends conceived for synchrotrons and advanced imaging systems. The first prototype will be submitted in Q2 2025 and will integrate two versions of the same channel, one that exposes the output of the preamplifier, whose signal is driven by buffers connected to the chip PADs, and one that allows the study of the entire channel.