

During the prompt emission phase, Gamma-Ray Bursts (GRBs) simultaneously generate both soft X-rays and hard X-rays, with polarization observations of soft X-rays in the field of transient sources like GRBs remaining an unexplored frontier. The PolarLight CubeSat, developed by Tsinghua University's research team and equipped with the Gas Pixel Detector (GPD), was successfully launched. Over its one-year operational lifetime, the X-ray polarization detector successfully detected soft X-ray polarization signals from the Crab Nebula and pulsars. This detection result also signifies the reopening of the astronomical soft X-ray polarization detection window, which had been stalled for over 40 years due to technical difficulties. X-ray polarization detection technology is a pivotal frontier in astronomy, essential for understanding the radiation characteristics, magnetic field structures, particle acceleration, and radiation processes of transient sources such as Gamma Ray Bursts (GRBs). As quintessential transient phenomena in X-ray astronomy, GRBs present exceptional laboratories for probing cosmic explosive events. Polarimetric measurements, by providing two key observational parameters—polarization degree and polarization angle—enhance the detection capabilities of GRBs, aiding in more precise analysis of their physical properties and advancing theoretical model development. However, the inherent unpredictability, brief durations (often milliseconds to seconds), and characteristic high-flux states of such transients impose formidable observational challenges.

In the context mentioned above, the POLAR-2 experiment project on the Chinese Space Station has been initiated. Its Low-energy Polarimetry Detector (LPD) payload features a specially designed wide field of view (FoV) covering $90^\circ \times 90^\circ$ solid angle. This design aims to achieve precise detection and measurement of the X-ray polarization characteristics of GRBs and their extremely early afterglow phases through high sensitivity, a wide field of view, and extensive sky survey strategies. To verify the feasibility of the LPD design scheme, the wide field-of-view CXPD01, serving as a prototype verification, has successfully been operational in orbit. The pixel chip onboard CXPD-01 is the Topmetal-ii minus, developed by our team. However, the size of the chip and the array do not require the scientific application requirements of LPD. The large-area pixel chips of the Topmetal series, such as Topmetal-M1 and Topmetal-M2, have power consumption requirements that cannot meet the LPD's needs (power consumption must be below 1W). Moreover, considering the high flux characteristics of GRBs, the detector's readout system needs to promptly read out valid signal events. The pixel chip needs to ensure the large area and large array while ensuring that the power consumption of the single pixel is not too high. Therefore, improving the chip's readout rate from the single-pixel circuit structure will make it difficult to achieve the low power consumption target of the chip.

To address this technical challenge, this paper proposes an innovative readout system design based on the next-generation LPD prototype verification system, CXPD02. This readout design integrates the on-chip readout of the pixel chip with the electronic system readout, forming a fully collaborative and integrated readout system. The electronic structural design of CXPD02 is essentially consistent with CXPD01, with the main innovation being the adoption of a new generation of large-area pixel chip Topmetal-L.