A High Compression Ratio Channel Multiplexing Method for Micro-pattern Gaseous Detectors

Yu Wang, Shubin Liu*, Hao Zhuang, Zhengwu Ding, Yulin Liu, Changqing Feng, Zhiyong Zhang

***Index Terms*—Detector readout, Multi-channel high-density signal readout and integration, Position encoding readout, Micro-pattern gas detectors**

I. INTRODUCTION

MICRO-pattern gaseous detectors (MPGDs) are a group of gaseous ionization detectors with sub-millimeter avalanche structures, such as gas electron multiplier (GEM) [1], micro-mesh gaseous structure (Micromegas) detectors [2], thick GEM (THGEM) [3], micro-Resistance Well (μRWELL) [4], etc. MPGD can be made into large detectors on the order of sub-square meters while maintaining sub-millimeter accuracy in spatial resolution.

In order to achieve finer spatial resolution, it is necessary to reduce the geometric dimensions of the readout unit in MPGDs, requiring more readout channels. In the case of strip readout, the strip width should be no more than 4∼6 times the target spatial resolution. For instance, to achieve a resolution better than $150\mu\text{m}$, the readout strip size is typically designed to be $400\mu\text{m}$. Therefore, for an MPGD with an area of $100\text{ cm} \times 100\text{ cm}$, a single-dimensional strip readout requires 2500 readout channels. The large number of readout channels constrains the application of MPGDs in larger areas and higher precision, posing significant challenges regarding integration, power consumption, cooling, and cost.

Currently, there are two approaches to address this issue. Firstly, highly integrated and compact front-end electronics with the corresponding data acquisition systems can read the signal within a small size. Secondly, the signal readout method should be further investigated and improved, which can reduce the required number of readout channels significantly. Notably, for experiments with low channel occupancy rates, a typical event hits several adjacent detector channels, resulting in only a few electronics channels having signals simultaneously. At the same time, the majority of electronics channels remain idle.

Therefore, under sparsity effective signals, channel multiplexing methods can be utilized to reuse a small number of electronics channels across several readout strips, thereby addressing the challenge of a massive number of readout channels. The core of channel multiplexing methods lies in compressing the readout channels based on the known information of the detector signal distribution. The implementation methods include inductive encoding readout and position encoding multiplexing readout.

In this study, we developed two types of high compression ratio multiplexing methods and their corresponding mathematical models. By applying these multiplexing techniques, we designed and implemented different types of multiplexing circuits and tested them with our self-designed thermal-bonding Micromegas detectors. The results illustrate that utilizing the channel multiplexing method with a compression ratio of 16:1 enables the reading of a detector with 1024 strips using only 64-channel front-end electronics, resulting in a noise increase from 0.57 fC to 1 fC. Furthermore, we employed these multiplexing circuits together with compact readout electronics to construct our large-scale muography facilities, showing the effectiveness of the multiplexing circuit in experiments with low channel occupancy rates.

II. PRINCIPLE OF THE ENCODING MULTIPLEXING METHOD

The process of position encoding involves pairing consecutive detector channels $strip_i$, $strip_{i+1}$ with a pair of electronics channels ch_a, ch_b. As the detector channels are contiguous, this process can be simplified to a unique mapping of (i, $i+1$) to (a, b). We have elucidated this mathematical model using the concept of Eulerian circuits in our previous study [5]. An Eulerian circuit refers to a path in a graph that traverses each edge exactly once and returns to the starting point. In this context, electronics channels serve as vertices, and detector channels as edges. Due to the avoidance of repeated edges in the circuit, each pair of detector channels uniquely corresponds to a pair of electronics channels.

The left side of Fig. 1 illustrates the schematic diagram of the connection using five electronics channels to read out eleven detector channels, and the right side of Fig. 1 displays the corresponding Eulerian graph. When any two electronics channels are fired, inferring the unique consecutively hit detector channels is possible. For instance, if chn2 and chn4 at the electronics side have signals over the threshold, the possible hit positions of the detector are 2, 4, 9, and 10. Only strips 9 and 10 are consecutive in this combination and provide the correct result.

Various encoding schemes correspond to specific Eulerian circuits during circuit design. For high spatial resolution detectors utilizing the channel encoding multiplexing method, it is crucial to maximize the distance between two strips connected to the same readout channels, referred to as the

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Yu Wang, Shubin Liu, Hao Zhuang, Zhengwu Ding, Yulin Liu, Changqing Feng, Zhiyong Zhang are with State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, No.96, Jinzhai Road, Hefei, Anhui, China (email: liushb@ustc.edu.cn).

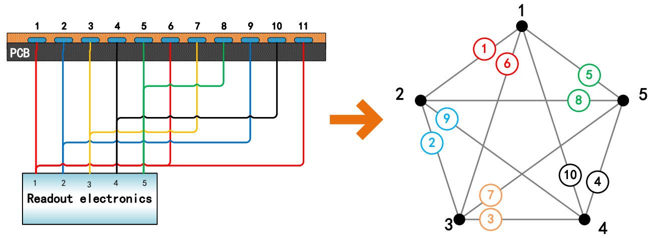

Fig. 1. Left: An example of multiplexing 5 electronics channels to 11 detector strips. Right: The corresponding encoding graph.

reuse distance. The correctness of decoding results depends on the reuse distance being greater than the maximum number of fired strips in one event, addressing the Eulerian Reuse Length (ERL) problem. We have mathematically solved this problem for complete graphs and bipartite graphs with even vertices, extending the solution to situations with odd vertices (These two papers [6], [7] provided the proof with odd vertices).

Two types of Eulerian circuits are then constructed based on Hamilton paths of complete graphs and bipartite graphs, and Fig. 2 shows the photograph of the circuit. Both circuits can compress the required readout channels by a factor of 8, meaning that with 64-channel readout electronics, 512 detector strips can be read out. As described in the next section, subsequent test enabled us to expand our compression ratio to 16:1. This implies that 64-channel electronics can now read out 1024 detector strips. Fig. 3 displays the encoding circuit, where we have separated the encoding circuit part from the detector connection part for a versatile design. An encoding circuit with 1526 detector channels to 128 electronics channels is currently under manufacture, promising a larger reuse distance and improved performance.

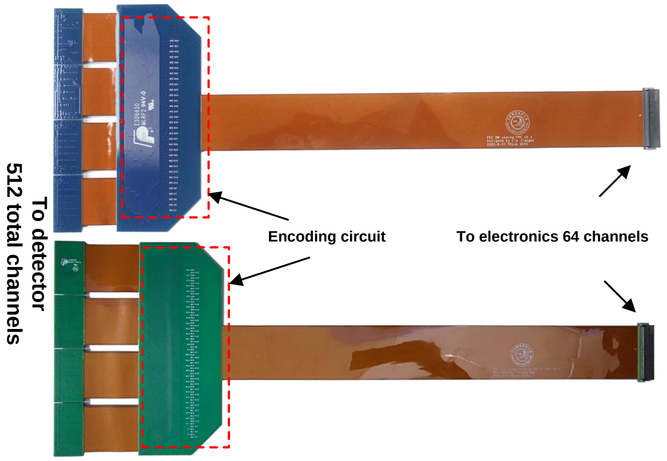

Fig. 2. Upper: Encoding circuit multiplexing 512 detector strips to 64 readout electronics using the complete graph method; Lower: Encoding circuit multiplexing 512 detector strips to 64 readout electronics using the bipartite graph method.

III. Test with cosmic-ray

These encoding circuits have been employed in our muon imaging facilities, showcasing their capability to minimize the necessary readout electronics. Figure 4 displays two distinct muon imaging facilities: muon tomography and muon radiography.

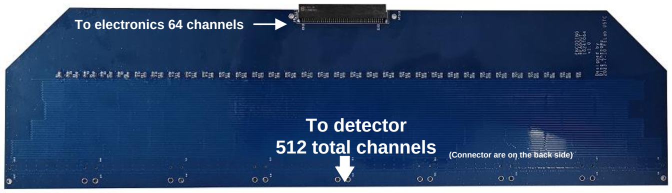

Fig. 3. Encoding circuit multiplexing 1024 detector strips to 64 readout electronics using the complete graph method.

Fig. 4. Left: Muon tomography facility with Micromegas detector, multiplexing circuit, and compact front-end electronics; Right: Muon radiography facility.

We installed various encoding circuits at different layers to assess their performance. Fig. 5(a) illustrates the noise test conducted with different encoding circuits. Meanwhile, Fig. 5(b) presents the image result of the muon radiogarphy, measured by the detectors using our encoding circuits. Based on this analysis, we deduce a spatial resolution of 0.23 mm for our thermal-bonding Micromegas detectors.

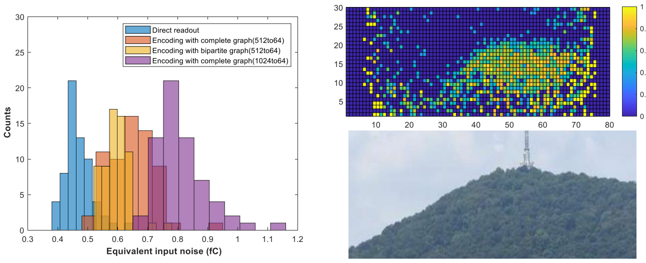

Fig. 5. Left: Statistics of equivalent input noise for direct readout and various encoding methods; Right: Radiography results from our facility showcasing the capability of the multiplexing circuit.

IV. Conclusion

We have developed two different types of encoding multiplexing schemes and their corresponding circuits, achieving a maximum compression ratio of 16:1. These circuits, along with the waveform recording front-end electronics cards, were implemented in large-scale Micromegas detectors, demonstrating their ability to read detector signals without compromising detector performance.

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