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GET: A generic electronics system for TPCs and nuclear physics instrumentation

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A R T I C L E   I N F O

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A B S T R A C T

General Electronics for TPCs (GET) is a generic, reconfigurable and comprehensive electronics and data-acquisition system for nuclear physics instrumentation of up to 33792 channels. The system consists of a custom-designed ASIC for signal processing, front-end cards that each house 4 ASIC chips and digitize the data in parallel through 12-bit ADCs, concentration boards to read and process the digital data from up to 16 ASICs, a 3-level trigger and master clock module to trigger the system and synchronize the data, as well as all of the associated firmware, communication and data-acquisition software. An overview of the system including its specifications and measured performances are presented.

1. Introduction

General Electronics for TPCs (GET) is a scalable and generic electronics system that was originally designed for gas-filled detector applications in nuclear physics including Time Projection Chambers (TPCs)

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Table 1
Summary of detector projects worldwide and their total demand in terms of number of GET electronics channels. Applications for the GET system include gaseous detectors (G), auxiliary detectors such as silicon and caesium-iodide detectors (A), as well as beam trackers and beam monitors (T).

Detector project	Application	Country	Channels	Ref.
LAMPS TPC	G	Korea	33792	[2]
ACTAR TPC	G,A	France	20480	[3]
SπRIT	G	Japan	14080	[4]
AT-TPC	G	United States	12800	[5]
HypTPC	G	Japan	8192	[6]
FARCOS	A	Italy	6144	[7]
nTOF	T	Switzerland	4352	[8]
CAT	G	Japan	2816	[9]
ELI-NP TPC	G	Romania	2048	[10]
CAS Lanzhou	G	China	2048	[11]
PANDAX-III	G	China	2048	[12]
SpecMAT	G,A	Belgium	2048	[13]
TexAT	G,A	United States	2048	[14]
Notre Dame	G	United States	1024	[15]
S^3	T	France	1024	[16]
UCAS Beijing	G	China	1024	[17]
Other Projects	G,A,T		2560	
Number of channels worldwide			118528	

and “active targets”, which are TPCs where the gas volume is used as both the detection medium and as a thick target to induce secondary nuclear reactions. Some of the key requirements for these types of detection systems in the nuclear physics community (and that are not available with existing commercial electronics) include a high-density front end with a corresponding large number of electronic channels, the need to trigger the system with events from both external (e.g. Si detectors) and internal sources (e.g. total multiplicity), and high-rate data transfer with minimal system dead time. To achieve these goals, we have developed the GET system whose electronics architecture is based on a versatile Application Specific Integrated Circuit (ASIC) design with several modes of acquisition, a 256-channel front-end card with an analog-to-digital converter (ADC), a data concentration system with an embedded Field Programmable Gate Array (FPGA) to improve the rate of the data acquisition and to process data flow from thousands of channels, and a unique three-level programmable trigger. As described below, these developments are essential for realizing many of the experimental programs foreseen with next-generation active target and time projection chamber detection systems in nuclear physics. A recent review of some of the existing and planned detector projects can be found in Ref. [1].

Although GET was initially motivated by gas-filled detectors, the system was designed to be as generic as possible with the intention of using it for other applications. Today, GET is being successfully employed in a growing number of projects using silicon detectors and scintillating detectors such as caesium iodide (CsI), lanthanum bromide ($LaBr_3$) and cerium bromide ($CeBr_3$) for charged-particle and γ-ray spectroscopy. A summary of detector projects that have adopted the GET system and their demand in terms of total number of electronic channels is provided in Table 1.

In this article, an introduction to the different types of physics programs and detection systems that were used to define the conceptual design and specifications of the GET system will be presented in Section 2. A broad and detailed overview of the system architecture will be described in Section 3. Measured performances obtained through several tests performed by users of the GET system and comparisons to the design specifications will be discussed in Section 4. We will then conclude with a brief summary of a select number of detector projects that have adopted the GET system, introduce future projects that could benefit from these developments, and provide an outlook towards possible upgrades of the GET system for future applications.

2. Physics opportunities with GET

Studies of nuclear structure and rare decay modes for the most exotic nuclei, those furthest from stability, are crucial for understanding the origins of matter in the universe, describing the evolution of nuclear forces towards extreme neutron-to-proton ratios, and predicting the onset of new and exotic phenomena. Due to the significant decrease in the production cross sections, access to these nuclei in statistically significant quantities is a fundamental challenge that is continually being addressed through upgrades and construction of large-scale rare-isotope beam accelerators. Even with such powerful facilities, intensities of rare-isotope beams are, and will be, extremely limited and their optical properties (beam size and emittance) will be relatively poor compared to beams of stable ions. Large acceptance detection systems with the highest possible efficiency and inherent spatial and energy resolution are thus essential for providing as much detailed and quantitative spectroscopic information as possible.

Given these challenges, the use of gas-filled time projection chambers and active targets offers an attractive alternative to conventional experimental techniques because of their intrinsic efficiency, spatial resolution, versatility, portability, event-by-event tracking and particle identification capabilities. Operated as an active target, the target thickness (gas pressure) can be increased by orders of magnitude relative to solid foil targets without an appreciable loss in resolution thus compensating, in part, for the low beam intensities. There are several different types of previous generation active targets and TPCs already operating in nuclear physics including IKAR at GSI [18], the MSTPC at RIKEN [19], the MAYA active target at GANIL [20], and the CENBG TPC [21]. Some of the physics highlights from these detectors over the past decade include the discovery of the ground-state resonance in the unbound ^{7}H system [22], studies of neutron-rich halo structure phenomena in ^{11}Li [23,24] and ^{14}Be [25], pioneering studies of giant resonances in unstable Ni isotopes [26,27], and the first direct observation of two-proton radioactivity from the ground states of ^{45}Fe [28] and ^{54}Zn [29].

While extremely successful, many of these detectors suffered from a number of limitations that have prevented them from achieving their full potential. For detectors that track both the incident beam and the (light) reaction products simultaneously, the dynamic range is often a significant challenge. The typical energy loss of the ion beam is on the order of 1 GeV while light products deposit energies of only 1 MeV or less. It is very difficult, if not impossible, to find a common gain that is high enough to observe the light particles without saturating the signals from the beam. A second limitation arises from exceedingly long dead times associated with present data-acquisition systems that significantly reduce the total number of accepted events. In two-proton radioactivity experiments with the CENBG TPC for example, nearly one third of the decay events could not be recorded due to dead-time losses [29]. The lack of an internal trigger option has, until now, further hindered the ability to select only the rare events of interest. Tracking multiple particles following a reaction or decay is also a major challenge for present data-acquisition systems based on analog electronics as signals often overlap on common strips or pixels. Separating the individual contributions from each particle would thus require digital signal processing on a channel-by-channel basis. Another limitation concerns the relatively poor spatial resolution that could be improved with smaller pad sizes or strip pitches. However, as the pixel size decreases, both the total number of electronic channels (cost and complexity) and the overall data throughput (bandwidth and disk space) increases significantly. Present-generation detection systems have thus been limited to approximately 2000 channels or, as in most of the detectors described above, significantly less.

Owing to a large number of recent technological developments in micro-pattern gaseous detectors [30–32], connectors and cables to achieve higher-density point-to-point contacts, and coupled to the achievements made in the GET project in terms of high-density electronics, front-end data processing, and a high-throughput data acquisition