A REVIEW OF EMBEDDED READOUT ELECTRONICS FOR EXISTING PORTABLE RADIATION INSTRUMENTS

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***Abstract*: This study presents new embedded readout circuits for current portable radiation equipment. New sophisticated mixed signal programmable system on chip platforms enabled cost-effective and dependable designs. Ongoing research on low-cost planar neutron detector optimization. We developed a PSoC-based Geiger Mueller detector readout that is small and dependable. The unique feature is that all peripheral operations of a GM survey meter, such as high voltage bias control and data transmission, are integrated on a single chip. The single chip solution increases dependability by reducing external interference and mechanical ruggedness. This paper examines the possibilities of current reconfigurable mixed signal hardware platforms to build cost-effective and reliable readout circuits for portable radiation measuring applications. The significance of low-cost detector alternatives is also demonstrated. Composite dead layers in the unit cell may enhance neutron detector optimization calculations. In Monte Carlo simulations, sophisticated semiconductor detectors such as neutron converter coated avalanche photodiodes with statistically variable multiplication factors may replace basic PIN diode-based devices. The firmware for the alpha spectrometer may be enhanced with isotope identification, user controlled ramping rate, long term stability monitoring, and battery monitoring. More sophisticated reset switch control waveforms and ultra-low charge injection switches may be used to minimize residual errors in pulse height measurement and improve resolution. This paper depicts research completed in two significant parts of compact radiation instruments in particular, execution of readout electronics utilizing a new reconfigurable mixed signal hardware platform alongside detector design and optimization.**

***Keywords*: Detector Design and Optimization, Embedded Readout Electronics, Portable Radiation Instruments**

I. INTRODUCTION

Radioactive materials, radioactive sources, and radiation sources are ubiquitous; they are used in practically all sectors, made of different radionuclides, emit different types of ionizing radiation (gamma rays, alpha and beta particles, neutrons), and are characterized by their activity (number of disintegrations per second). Gamma radiation survey forms the basis of various operational aspects of nuclear industry such as mineral exploration, routine monitoring of activity in and around nuclear facilities, risk assessment during nuclear emergencies etc. "This application demands portable instruments which aid health physics workers in measuring and recording the radiation dose rates at various locations in the field." Over the years, numerous portable instrument designs for gamma survey have been developed. Some of the detectors used in commercially available portable systems include, ion chambers, Geiger- Mueller (GM) tubes and scintillation-based detectors like NaI, CsI, LaBr3 etc. coupled with photo-detectors. Although many types of detectors are available, the detector that finds the most widespread use is the GM tube. This is due to its simple construction and large signal output which aids in implementing cost effective designs. The large signals in the GM tube are the result of a gas avalanche phenomenon known as Geiger discharge which occurs at high voltages (~500V) in a gas filled tube. The avalanche is started by a secondary electron which originally is generated by a gamma interaction either in the solid wall or the gaseous interior of the detector. This original interaction of gamma radiation is by photo-electric absorption, Compton scattering or pair production, which results in transfer of a major portion of gamma energy to the electron in a single interaction. The presence of large signals (> 1V) eliminates the need for precision amplification in the front-end while designing counting and read-out systems. However, the requirements for a stable HV bias, data processing and user interfaces slightly increase the complexity in this system design. In the present work, a novel scheme for implementing the GM tube read-out functions is designed, in order to overcome the drawbacks of microprocessor-based designs. This scheme integrates the implementation of the signal processing, HV biasing, data processing and user interface functions onto a single-chip mixed-signal PSoC platform.

RADIATION

Radiation is energy that originates from a source and travels at the speed of light across space. This energy is coupled with an electric field and a magnetic field, and it exhibits wave-like qualities. Radiation is sometimes known as electromagnetic waves. We discussed what makes up atoms, chemistry, matter, and ionizing radiation in previous Science 101s. Let's have a look at the many types of radiation. Alpha, beta, neutrons, and electromagnetic waves like gamma rays are the four basic forms of radiation. They are distinguished by their bulk, energy, and the depth to which they enter people and things. An alpha particle is the first. The heaviest form of radiation particle, these particles are made up of two protons and two neutrons. Alpha particles are emitted by several naturally occurring radioactive elements on Earth, such as uranium and thorium. The presence of radon in our houses is an example that most people are acquainted.

A beta particle is the second kind of radiation. It's an electron that isn't bound to a molecule. It is light in weight and contains a negative charge. Tritium, which is created in the atmosphere by cosmic radiation and is found all around us, emits beta radiation. Carbon-14, which is used to date fossils and other artifacts, releases beta particles as well. Carbon dating is based on the fact that carbon-14 is a radioactive element. The amount of carbon-14 remains in the fossil may be determined by measuring the beta particles, which enables you to calculate how long ago the creature was alive. A neutron is the third particle. This is a neutral particle found in the nucleus of an atom that has no charge. When uranium atoms divide, or fission, in a nuclear reactor, neutrons are produced. You wouldn't be able to maintain the nuclear reaction that generates electricity if it weren't for neutrons. Electromagnetic radiation, such as X-rays and gamma rays, is the last kind of radiation. Because they are frequently utilized in medical treatments, they are arguably the most familiar sort of radiation. These rays are similar to sunshine, but they are more energetic. There has no mass or charge, unlike other types of radiation. The energy levels may vary from extremely low, as in dental x-rays, to extremely high, as in irradiators used to disinfect medical equipment.

Beta Particles

Naturally occurring materials release beta particles, which are analogous to electrons (such as strontium-90). In medical applications, such as the treatment of eye illness, beta emitters are employed. Beta particles are often lighter than alpha particles and have a better capacity to penetrate other materials. As a consequence, these particles have the ability to travel a few feet through the air and enter skin. Nonetheless, beta particles may be stopped by a thin sheet of metal or plastic or a block of wood.

Alpha Particles

Alpha particles are charged particles that are released by both naturally occurring and man-made materials (such as uranium, thorium, and radium) (such as plutonium and americium). These alpha emitters are mostly employed in smoke detectors (in extremely tiny concentrations). Alpha particles have a restricted capacity to permeate other materials in general. In other words, a piece of paper, skin, or even a few centimeters of air may prevent these ionizing radiation particles. However, materials that release alpha particles may be harmful if inhaled or eaten, although external exposure is seldom a problem.

Gamma rays

Gamma rays are electromagnetic radiation similar to X-rays, light, and radio waves. Gamma rays, depending on their energy, can pass right through the human body, but can be stopped by thick walls of concrete or lead.

Neutrons

Neutrons are uncharged particles that do not directly cause ionization. However, their collision with matter's atoms may result in alpha, beta, gamma, or X-rays, which cause ionization. Neutrons are permeable, and only large volumes of concrete, water, or paraffin can stop them.

II. REVIEW OF LITERATURE

Reviewing the literature entails halting the flow of already completed research. Review of relevant previous work, including inconsistencies, traps, and other flaws, in order to demonstrate the necessity for a new examination study. Past research considerations are extracted, and the essentiality composition of specialists in the subject area is examined. Such a review lays the groundwork for the present investigation's progression and encourages the reader to think forward. A brief overview should be included, highlighting areas of confusion or disagreement in findings, as well as gaps in current knowledge.

A good literature review is essential since it displays the current state of knowledge in the subject and also aids in the discovery of the most important as well as overlooked topics and their relevance to current research. Each of these elements is critical in defining a topic of study and its place within the setting. Reviewing relevant literature aids in the formation of a hypothetical structure and methodological center, which leads to the formulation of credible hypotheses. Regardless, this evaluating aids in the discovery and abridgement of additional identical queries regarding. This will shed light on any caveats or gaps that previous probes have failed to address. It reduces the need for current research and also aids in persuading the reader that what is going on is important. Last but not least, after reviewing the literature, scientists are in a better position to choose appropriate research strategies to address a specific issue and recognize areas of previous grant to avoid duplication of effort.

Any investigation or research project requires a thorough review of the literature. It arouses awareness and increases the depth of knowledge about the problem. A review of relevant literature is a key step forward in educational research. It gives the agent the ability to look for gaps and trends in a certain area. Future experts may use information on the structures, tests, and research gadgets used by various agents to better design their strategy. Specialists must be aware of previous research projects, and at that point, they will be in a position to add something unique. The following sections have been used to sift down the literature that is available:

B. D. Milbrath, A. J. Peurrung, M. Bliss and W. J. Weber (2008) The use of radiation-detection technology for applications in homeland security, nonproliferation, and national defense has expanded as a result of events during the last two decades. As a consequence, there has been a heightened awareness of these technologies' material limits, as well as increased demand for the development of next-generation radiation-detection materials. This study examines the current status of radiation-detection material science, with a focus on national security requirements and the purpose of recognizing the problems and possibilities this field brings to the materials-science community. The physics of radiation-detector materials is examined, setting the scene for performance measurements that compare current and novel materials. The two basic kinds of radiation detector materials of interest are semiconductors and scintillators. The state-of-the-art and constraints for each of these material classes are discussed, as well as potential research directions. There will also be a discussion of novel materials that might eliminate the requirement for single crystals. Finally, novel material discovery and development methodologies are proposed, with the objective of providing more predictive guidance and quicker screening of candidate materials, resulting in the production of improved radiation-detection materials.

G. P. Srivastava (2013) This article provides an overview of current electronic technologies for India's nuclear power program. Instrumentation and control (I&C) operations in the fields of detector development, nuclear instrumentation, monitoring and control electronics, and specific sensors led to nuclear industry self-reliance. Liquid Zone Control System (LZCS), flux mapping system, and advance reactor regulating system are among the most modern I&C systems designed for 540 MWe reactors. Apart from meeting functional requirements, the design of electronics in a nuclear plant must also satisfy high levels of dependability, safety, and security. As a result, tasks including design review, testing, operation, maintenance, and certification of I&C systems are given a lot of weight. Induction of computer-based I&C systems necessitated a thorough verification procedure that corresponded to the system's safety class as defined by the Atomic Energy Regulatory Board (AERB) safety guidance. Software dependability is ensured by adhering to a stringent development life cycle and a zero-defect policy, as well as verification and validation (V&V) procedures. New data transmission methods using optical fibers as the transmission medium, as well as wireless networks in control systems, are being studied. With modern I&C systems, attempts were made to standardize the hardware and software platforms by using the same hardware and software platforms for multiple plant applications. The usage of Field Programmable Gate Arrays (FPGA) and Application Specific Integrated Circuits (ASIC) was pushed in order to reduce component count and increase system dependability. Modern current solutions such as ASICs, HMCs, System on Chip (SOC), and detector mounted electronics have become essential, and many ASICs and HMCs have been created in-house to address the problems.

G. Prasanna and J. Jayapandian (2014) This work describes a cost-effective embedded solution for Geiger Mueller counter biasing and read-out utilizing a programmable system-on-chip. Geiger Mueller counters (GM-counters) are basic radiation detectors that need read-out electronics to execute the duties of pulse counting and measurement data display. They are frequently utilized in the detection of nuclear events. Furthermore, the functioning of GM-tubes necessitates the use of high-voltage biasing circuits. Ruggedness, low power consumption, and interference immunity are all design criteria for a GM-tube based radiation counter. These criteria are difficult to meet with traditional read-out system hardware circuit design. An innovative embedded architecture based on the cypress semiconductor's single chip programmable-system-on-chip (PSoC) is detailed in this study, which takes use of the PSoC's mixed signal array of analogue and digital modules. The data from the GM counter was sent to a PC through the UART protocol. This document also discusses the calibration processes for the GM counter with the updated read-out design. This design's readings were compared to those of current commercial radiation monitoring systems and found to be equivalent to off-the-shelf sensors. In addition to its read-out electronics, this dependable and precise single-chip embedded design includes high-voltage biasing circuits for the GM counter.

Buddena et al (2015) A new class of elpasolite scintillators has garnered recent attention due to the ability to perform as simultaneous gamma spectrometers and thermal neutron detectors. Such a dual-mode capability is made possible by pulse-shape discrimination (PSD), whereby the emission waveform profiles of gamma and neutron events are fundamentally unique. To take full advantage of these materials, we have developed the Compact Advanced Readout Electronics for Elpasolites (CAREE). This handheld instrument employs a multi-channel PSD-capable ASIC, custom micro-processor board, front-end electronics, power supplies, and a 2-photomultiplier tube for readout of the scintillator. The unit is highly configurable to allow for performance optimization amongst a wide sample of elpasolites which provide PSD in fundamentally different ways. The study herein provides an introduction to elpasolites, then describe the motivation for the work, mechanical and electronic design, and preliminary performance results.

Ihantola et al (2019) During the last decade, emerging radiation detection technologies allowed smaller and cheaper radiation sensors, as is the case of: novel gamma-ray scintillating crystals with increasing efficiency and better energy resolution (e.g., standard and enhanced lanthanum bromide), novel neutron detectors with high efficiency and good gamma-ray discrimination, sensors sensitive to either neutron and gamma radiation (dual-mode sensors), the use of compact semiconductor photosensors instead of the fragile and heavier photomultipliers (PMTs), compact and low power data acquisition systems, smart detector instruments that allow the data fusion of multiple radiological and non-radiological sensors (contextual sensors), portable and lightweight gamma cameras, and the new dual particle cameras (gamma and neutrons). Additionally, noteworthy is the growing demand for low weight, low power consumption and high radiation tolerance detectors in the aerospace industry, particularly in space technology where some detectors were already deployed. The recent developments in robotics allowed the integration of such compact radiation detection systems in small unmanned systems. The use of such technology with the help of new algorithms resulted in improvements in the reliability of source detection, location and identification reducing in the same way the false alarm rates. An important new feature is the autonomous localization of a radiation source.

Kumar et al. (2020) presented the recent developments in radiation detection systems used in ground and air-based platforms for emergency radiation monitoring scenarios (radiation contamination resulting from nuclear accidents); described the aerial platforms used in airborne radiation mapping and perspectives; presented the unmanned systems with potential to be used for radiation measurements and sampling; describes the recent detection technologies for nuclear security and their impact; a review of gamma and neutron imagers, the latter also included a review of passive gamma ray detection. This paper aimed at describing the salient developments in mobile radiation detection systems coupled to ground-based (handheld equipment included) and air-based platforms from the era after the Fukushima Daiichi nuclear power plant accident (FDNPP), considering four reference scenarios. The advantages and limitations of each detection system are also analyzed, highlighting the challenges and future research needed in these fields.

Wolfgang Hennig and Shawn Hoover (2020) The time synchronization and trigger distribution across multiple channels of detector readout circuits becomes increasingly difficult as radiation detector arrays in nuclear physics applications get bigger and physically more isolated. Clocks and triggers have historically been delivered through specialized cabling, but modern technologies such as the IEEE 1588 Precision Time Protocol and White Rabbit enable clock synchronization via Ethernet by exchanging timing messages. As a result, we present the application of White Rabbit in the Pixie-Net XL, a novel detector readout module. A Kintex 7 FPGA is used to build the White Rabbit core, data acquisition from multiple digitizing channels, and subsequent pulse processing for pulse height and constant fraction timing. The White Rabbit time stamps are included in the detector data records, which are sent to storage through the White Rabbit core's gigabit Ethernet data channel or a slower diagnostic/control connection utilizing an internal Zynq processor. Temporal-of-flight measurements and time correlation of high-energy background events from cosmic showers in detectors separated by larger distances describe the performance. Software for the Zynq processor may use software triggering to restrict data recording to occurrences when a minimal number of channels from several modules detect radiation at the same time, for example.

Watkins et al (2020) Unlike in a laboratory, MRD systems measurements are performed in a non-controlled environment. For example, indoor environments are characterized by the possible global navigation satellite system (GNSS) signal denial and obstacles (e.g., stairs, doors and narrow passages), while outdoor environments are characterized by the weather influence (e.g., rain, wind, and atmospheric pressure) and obstacles, like tall vegetation, sea lines, steep slopes, and artificial constructions. A special challenging outdoor environment is an urban area, which may also cause GNSS signal denial (e.g., between tall buildings). While there are some papers already published about these topics, they cover only a part of the scope of this work, thus missing the interconnection between different scenarios or the reference of either neutron or gamma detection systems.

Luís Marques, Alberto Vale and Pedro Vaz (2021) Since the Fukushima nuclear disaster, scientific developments in the areas of gamma-ray and neutron measurements utilizing mobile radiation detection devices have been reviewed and discussed. Radiological and nuclear accidents and crises are examined, as well as criminal trafficking of specific nuclear and radioactive materials, nuclear, accelerator, targets, and irradiation facilities, and naturally occurring radioactive materials monitoring-related activities. The purpose of the work presented in this paper is to: compile and review information on the radiation detection systems, contextual sensors, and platforms used in each scenario; assess their advantages and limitations, looking ahead to new research and challenges in the field; and assist national radioprotection agencies and response teams in making decisions about appropriate detection systems. An detailed literature study was done for this purpose.

III. CONCLUSION

In the present work, novel embedded readout electronics for existing portable radiation instruments have been designed and implemented. The cost effective and reliable designs were made possible by the use of recent advanced mixed signal programmable system on chip platform. A design optimization study of low-cost planar neutron detector has also been carried out. Brief conclusions of each of these studies are given below:

- A compact, reliable readout for Geiger Mueller detector was designed and implemented using the PSoC platform. The novel feature has been built in the design in which all the peripheral functions in a GM survey meter like, high voltage bias regulation and data communication along with the core counting function are integrated on to a single chip. The single chip implementation improves reliability by increased immunity to external interference and by providing mechanical ruggedness through miniaturization.
- The potential of recent reconfigurable mixed signal hardware platforms to implement cost effective and reliable readout electronics for portable radiation measurement applications is established after a thorough survey of different platforms and their functional capabilities. The importance of low-cost alternatives in detectors for achieving cost effective designs is also established.

The neutron detector optimization simulations can be further improved by incorporating composite dead layers in the unit cell. Further advanced semiconductor detector alternatives like neutron converter coated avalanche photodiodes with statistically varying multiplication factors can be substituted in place of simple PIN diode-based structures in the Monte Carlo simulations for efficiency calculations. The alpha spectrometer application can be further improved by incorporating features such as isotope identification, user controlled ramping rate, long term stability monitoring and battery monitoring in the firmware. Further modifications in the reset switch control waveform and the use of recent advanced ultra-low charge injection switches can be incorporated in the hardware to reduce the residual errors in pulse height measurement thereby enhancing the resolution.

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