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การออกแบบเครื่องตรวจจับรังสีแกมม่าแบบพกพา
Design of the Portable Gamma Radiation Detector

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บทคัดย่อ

ในปัจจุบันกัมมันตรังสีถูกประยุกต์ใช้ในงานอย่างกว้างขวาง เช่น ทางการแพทย์ใช้รังสีในการวินิจฉัยและรักษาโรค และการถนอมอาหารที่ใช้รังสีฆ่าเชื้อโรคและจุลินทรีย์ เป็นต้น ซึ่งกัมมันตรังสีก็มีอันตรายในกรณีที่มีการรั่วไหลอาจสร้างด้านสุขภาพแก่สิ่งมีชีวิต เพิ่มความเสี่ยงการเกิดมะเร็ง โครงงานนี้จึงได้จัดทำระบบตรวจจับค่ากัมมันตรังสี ซึ่งเป็นระบบที่คอยแจ้งเตือนผู้ใช้งานหากมีค่ากัมมันตรังสีเกินกว่าที่กำหนด โดยใช้ไดโอดแสงชนิดพิน ซึ่งสร้างขึ้นโดยศูนย์เทคโนโลยีไมโครอิเล็กทรอนิกส์ (TMEC) เป็นเซนเซอร์ตรวจจับรังสี ร่วมกับวงจรขยายชนิดสัญญาณรบกวนต่ำ เพื่อให้ระบบการตรวจจับค่ากัมมันตรังสีสามารถตรวจจับรังสีแกมม่าแล้วส่งสัญญาณไปเข้าไมโครคอนโทรลเลอร์ ทำการนับและแสดงปริมาณรังสีออกมาในเป็นจำนวนครั้งที่จับรังสีได้ โดยวงจรต้นแบบที่สร้างขึ้นสามารถประยุกต์ใช้กับอุปกรณ์เซ็นเซอร์และอุปกรณ์แสดงผลจอแอลซีดีชนิด I2C 16x2 Module ผลการทดสอบการทำงานของระบบแสดงให้เห็นว่าสามารถใช้งานได้จริง สามารถตรวจจับรังสีที่ปลดปล่อยจากแหล่งกำเนิดรังสีทดสอบ Americium-241 ได้

คำสำคัญ : กัมมันตภาพรังสี, การแผ่รังสีแกมม่า, เครื่องตรวจจับการแผ่รังสี, ไดโอดแสงชนิดพิน, ไมโครคอนโทรลเลอร์

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การออกแบบเครื่องตรวจจับรังสีแกมม่าแบบพกพา
Design of the Portable Gamma Radiation Detector

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Abstract

Nowadays radioactive is widely used in various fields. Medical radioactivity is radioactive for diagnostic and treatment. Food preservation uses radioactivity to sterilize bacteria and microorganisms. Dangerous in case of accidental radioactive leakage can cause severe health effects, including radiation sickness, and an increased risk of cancer. The development of a radiation detection system has been completed for the purpose of alerting individuals in the event of excessive radiation exposure. The TMEC utilizes a PIN photodiode as a radiation sensor, working in conjunction with a low noise amplifier to detect gamma radioactivity. Result signal pulse from the amplifier will input to process and counter by microcontroller (Arduino Uno R3) then display result on LCD I2C 16x2 Module. The detector can detect gramma radioactivity from Americium-241 testing source.

keyword : Radioactivity, Gamma radiation, Radiation detector, PIN-photodiode, Microcontroller.

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1. Introduction

Currently, gamma radiation is widely applied in various fields such as medicine and the food industry. Gamma radiation can be hazardous in cases of leakage, potentially causing damage to the DNA of living organisms, leading to cancer or even death [1]. Radiation detectors play a crucial role in preventing and controlling the risks associated with radiation exposure by measuring the amount of received radiation. Gamma radiation detectors enable users or individuals conducting measurements to be aware of the levels of radiation that may impact human health. This information allows users or workers to adjust and protect themselves appropriately. Moreover, Portable radiation detector is necessary applications such as nuclear safety monitoring and environmental inspections. These devices allow users to quickly assess radiation levels in various settings, enabling timely decisions to protect the victims. The goal of this project is to design and develop a portable personal gamma radiation detector capable of detecting gamma-ray radiation only and displaying the results on an LCD screen in counts per second, along with LED flashing.

This radiation detector will utilize a PIN photodiode sensor, created by Thai Microelectronics Center (TMEC). The sensor is specifically designed to detect gamma radiation, providing a practical and compact solution for individuals to monitor and safeguard against potential radiation exposure.

2. Theory and Method

Radioactivity is the intrinsic property of certain atomic nuclei to spontaneously undergo decay, transitioning from an unstable to a more stable state. This process emits various particles and electromagnetic radiation, contributing to the intricate field of nuclear physics. At its core, radioactivity is governed by the delicate balance between the number of protons and neutrons within the atomic nucleus [2]. Three primary types of emitted radiation characterize radioactivity: Alpha particles, comprising two protons and two neutrons; Beta particles, high-energy electrons or positrons; Gamma rays, electromagnetic waves with short wavelengths and high energy. Gamma, upon interacting with substances and possessing adequate energy to induce reactions, leads to the emission of electrons [3]. These electrons serve as secondary charged particles, and the occurrence of these newly generated charged particles results in the subsequent decay of atoms through the following reactions: photoelectric and Compton scattering.

2.1 Photoelectric Effect [4]

Within the realm of radioactivity, the photoelectric effect is a noteworthy phenomenon. This effect involves the ejection of electrons from a material when exposed to electromagnetic radiation, such as gamma rays. Electrons absorb the energy of incident photons, leading to their liberation from the material. The photoelectric effect played a pivotal role in establishing the particle-like nature of electromagnetic radiation.

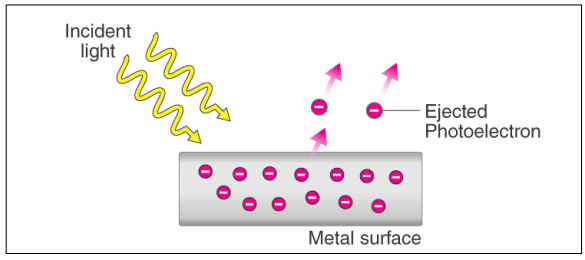


Figure 1 Photoelectric effect

2.2 Compton Scattering [5]

Compton scattering is another significant phenomenon associated with radioactivity. In this process, incident gamma rays collide with

electrons, resulting in a change in their direction and a decrease in energy. Compton scattering demonstrates the dual nature of electromagnetic radiation, showcasing both particle-like and wave-like characteristics.

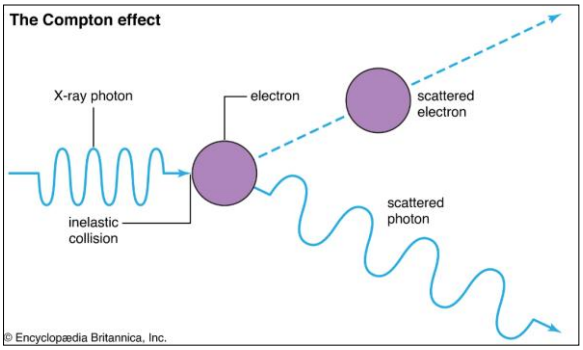


Figure 2 Compton Effect

2.3 Quantifying radioactivity Unit

Units for measuring the impact of radiation on humans include several commonly used terms:

1. Curie (Ci): It measures the quantity of radioactive decay. One Curie indicates the transformation of atoms decaying in a specific system in one second (1 Ci equals 3.7 x 10^10 decays per second).

2. Gray (Gy): This unit gauges the absorbed dose of radiation in a substance corresponding to one joule per kilogram (1 Gy equals 1 joule per kilogram).

3. Rad: The rad is a unit measuring the amount of energy absorbed by tissues, equivalent to 0.01 gray (1 Rad equals 0.01 Gy).

4. Rem: Rem is a unit used to assess the risk of radiation exposure. It is obtained by multiplying the dose in Rad by the Quality Factor, which considers the type of radiation (1 Rem equals 1 Rad x Quality Factor).

5. Sievert (SV): The Sievert is used to measure the radiation dose in terms of risk, taking into account the type of radiation and the affected body part (1 Sv equals 1 Gy x Quality Factor).

In conclusion, radioactivity is a multifaceted field that explores the natural decay processes of atomic nuclei, shedding light on the fundamental nature of matter. The associated phenomena of the photoelectric effect and Compton scattering further enrich our understanding, providing valuable insights into the dual nature of electromagnetic radiation. This scientific inquiry not only contributes to our understanding of the atomic world but also paves the way for various technological applications and advancements. The ongoing exploration of radioactivity remains vital for unlocking the mysteries of the universe and harnessing its potential for the betterment of humanity.

2.4 PIN Photodiodes [6-7]

The sensor used in this study is a semiconductor sensor, specifically a PIN photodiode. It functions as a radiation detector with an intrinsic semiconductor layer, or the I layer, situated between the P-type and N-type regions. The intrinsic layer has a higher resistance than the P-type and N-type regions. When a reverse bias is applied to the PIN photodiode, the depletion region expands within the intrinsic layer. This expansion extends to the thickness of the intrinsic layer, turning the depletion region into a region devoid of free charge carriers, preventing the combination of electrons and holes.

When light with sufficient energy (greater than the bandgap of the semiconductor) enters the intrinsic layer as photons, each photon absorbs and generates an electron-hole pair. These pairs face a strong force due to the electric field within the depletion region, causing them to move in opposite directions and creating an electric current. This

process effectively transforms light energy into electrical energy.

The PIN photodiode utilized in this study comprises an intrinsic layer between P-type and N-type regions, forming a depletion region under reverse bias. This layer enables the detection of gamma radiation by generating electron-hole pairs when photons of radiation interact with the intrinsic layer.

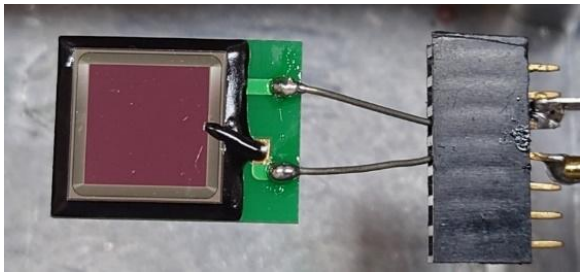


Figure 3 PIN Diode

2.5 Charge Detector Unit

The signals detected from radiation not only have small magnitudes but also exhibit narrow pulse characteristics, making it challenging to amplify and process them. Therefore, it is essential to use a charge sensitive pre-amplifier (CSPs) circuit. CSPs are electronic devices capable of combining current signals and converting them into voltage signals. The amplitude of these signals is proportional to the incoming charge. CSPs perform the conversion from charge to voltage, and subsequently, an Inverting Amplifier circuit is employed to amplify and provide appropriate feedback to obtain an output signal suitable for further processing.

The resistor ratio (R1 and R2) in the feedback network of the Inverting Amplifier circuit determines the amplification ratio, independent of the amplifier's gain. This allows for the calculation of the voltage amplification ratio using the formula.

$$v_0 = -v_i \frac{R_2}{R_1} \quad (1)$$

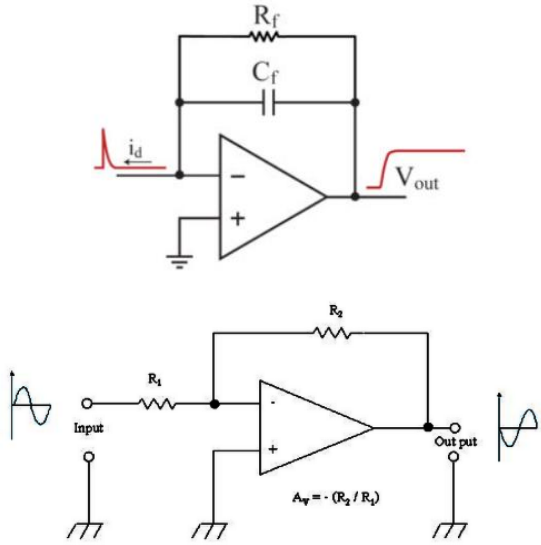


Figure 4 Charge sensitive pre-amplifier and inverting amplifier

2.6 Processing Unit

The microcontroller used to control the radiation detection system for this detector is Arduino Uno R3. As this controller is an Open-Source Platform and belongs to the AVR microcontroller family, providing a user-friendly electronic prototype board. It allows easy signal processing and pulse counting from the expansion section through programmed instructions. Additionally, it features output signal ports for connection to the display module.

The Charge sensitive preamplifier with inverting amplifier circuit utilizes the TL082I dual Op-Amp to amplify signals from the PIN Photodiode. The CSPs circuit is employed to amplify the circuit, followed by further amplification through an inverting amplifier circuit with a 180-degree feedback phase, using the same Op-Amp.



Figure 5 Arduino Uno R3 Board and display unit

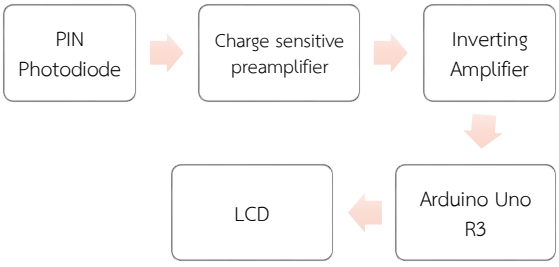


Figure 6 Operation flow chart of the detector system

3. Result

In the initial experiment, the simulation of the signal amplification from the PIN Photodiode yielded a signal waveform as shown in Figure 8. The waveform exhibited a pulse-like pattern, resembling charge dissipation, especially at the end of the signal. The prototype system was then tested using the radioactive source Americium-241, which undergoes random decay following the half-life theory. Upon detection of radioactive decay or radiation, the PIN Photodiode produced an output signal for the amplifier circuit. The observed signal closely matched the expected output of the pre- amplifier + inverting amplifier circuit, as depicted in Figure 10. Therefore, it can be concluded that the amplifier circuit operates as designed.

The test results indicated that the system effectively detected radiation events, generating small, distinct pulses each time the PIN Photodiode successfully detected radioactive decay. The PIN Photodiode functioned by drawing power from the battery-powered Power Supply during its operation.

Subsequently, the system was tested for display on the I2C 16x2 LCD Module. The test,

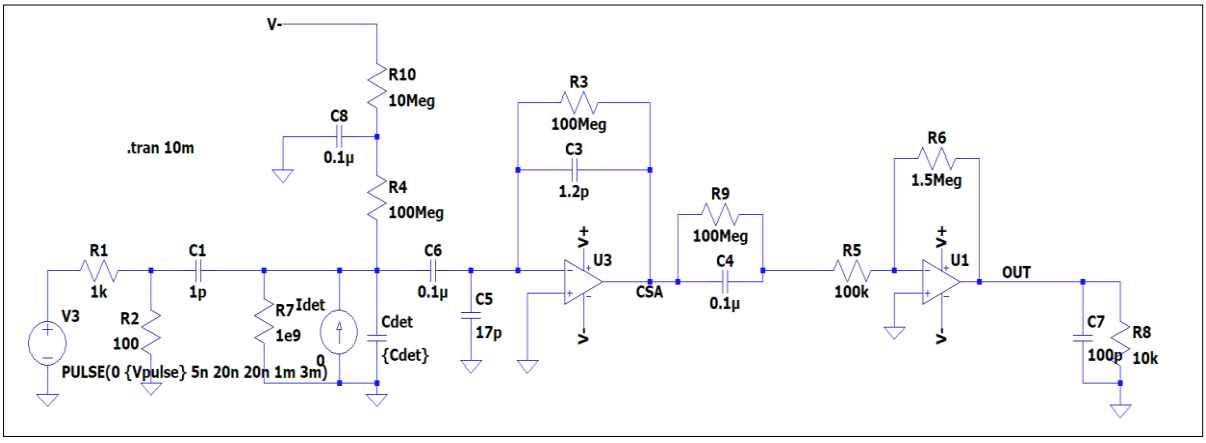


Figure 7 Charge sensitive Preamplifier with Inverting Amplifier

utilizing Arduino and an LED, demonstrated successful display on the LCD screen, as depicted in Figures 11. This confirms that the system can detect gamma radiation emitted from the radiation source. The radiation quantity was relatively low, and the experiment was conducted within safe parameters.

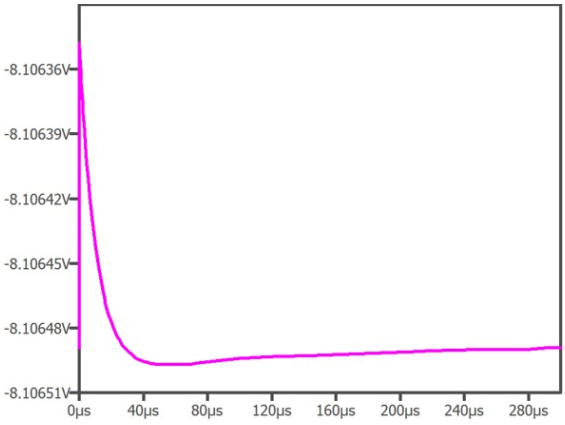


Figure 8 Simulation output waveform from PIN Photodiode



Figure 9 Americium 241

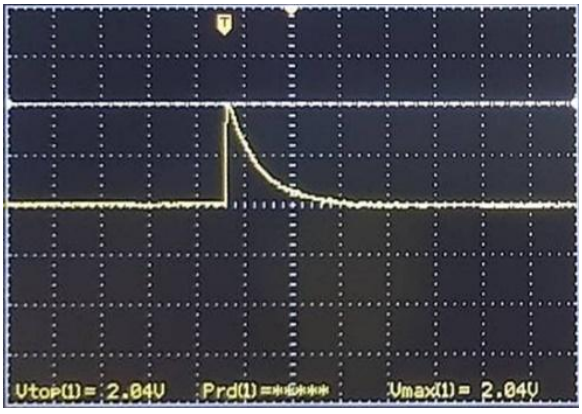


Figure 10 Output waveform of amplifier circuit

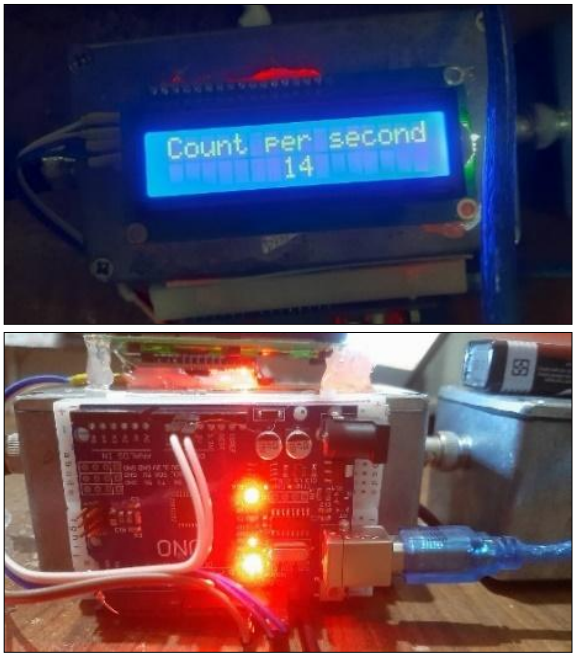


Figure 11 Output result from the portable system

A limitation of this prototype system is its limited detection range with certain types of radiation sources, such as Americium-**241.** and may be affected by environmental factors such as temperature and humidity. Furthermore, the measurement resolution is limited to displaying only the number of radiation decay per second. The energy of the radiation cannot be analyzed. The system also relies on batteries, which have

limited operating time. And the microcontrollers used may not be suitable for advanced computing in the future.

Future enhancements may focus on extending the detection range and incorporating wireless data transmission for remote monitoring capabilities.

4. Conclusion

In conclusion, the implementation of the personal radiation detection system proceeded as planned, encompassing two circuits. The first circuit is responsible for receiving radiation values from the sensor, while the second circuit amplifies the obtained signals before transmitting them to the Arduino. The Arduino then calculates signal values per second, displaying the results on the LCD screen and signaling gamma radiation detection through LED flashes. The Charge-Sensitive Preamplifier effectively converts the current signal from the PIN Photodiode into an electrical signal, further amplified by the Inverting Amplifier before being processed by the Arduino. The system operates smoothly, showcasing its capability to amplify and process signals for efficient radiation detection and monitoring. This portable gamma radiation detector can be effectively utilized in field operations for nuclear safety, environmental assessments, and real-time radiation monitoring. Its compact design and affordability make it suitable for widespread adoption. Future developments may focus on expanding detection range, enhancing environmental resistance, and integrating wireless data transmission for broader applications

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