J. Myanmar Acad. Arts Sci. 2026 **Vol. XXIII. No.2**

CONSTRUCTION OF PHOTODIODE BASED ACTIVE DETECTOR FOR RADON DETECTION

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Abstract

The main objective of this research work is to construct and analyze the photodiode based active detector for radon detection in air. It was intended to operate in pulse counting mode for real-time measurements. The constructed system is relatively simple, low-cost and reproducible, made of inexpensive and easy to acquire electronics components. The commercial low-cost Si-PIN planar photodiode SLCD-61N5 with an area of 10×10 mm^2 was used as a sensor for detection of alpha particles. An ATmega2560 microcontroller (MCU) based Arduino MEGA development was interfaced to the electrical circuit of the device to count the logic pulses and connected to a computer to send and save the detected data. Electrical pulse signals corresponding to the strike of the alpha particles on the photodiode, distinguishable from noise, were observed in the radon detection analysis. It was observed that the sensitivity response of the constructed system increased with a higher reverse voltage applied to the photodiode. The stability of the constructed radon detector was also analyzed for long-term measurements. It could be said that the constructed system detected the presence of radon gas in order to obtain exact concentrations values in air.

Keywords: Radon, alpha particles, photodiode, Arduino MEGA, concentration

Introduction

Radon, ^{222}Rn, is a naturally occurring gas. It is colorless, odorless, tasteless, almost chemically inert, and radioactive. It is the heaviest noble gas with the highest melting point, boiling point, critical temperature, and critical pressure. Radon is also soluble in cold water and such property increases the mobility of the gas in the environment [*UNSCEAR and UNEP*]. Radon is a radioactive gas that occurs naturally from the decay of ^{238}U. These elements could present in rocks, soils and even in building materials that contain radon progenitor radionuclides. After its formation, the gas diffuses into the atmosphere and tends to get into the buildings. Houses built in sites with a high concentration of radon can lead to an accumulation of this gas and consequently turning to be an important risk factor for human health [*Cothern C., et al*]. The main concern is not due to the gas itself but it is due to the solid short half-life decay products produced as free ions. As a consequence of the strong probability for these ions to be electrostatically attached to aerosols, these clusters can remain in suspension, being easily inhaled and deposited in different regions of the respiratory tract. Some of the radon progeny emit alpha particles that react strongly with matter depositing all their energy in a small volume in the lung tissue. Consequently, these constant irradiation damages the cells and can lead to the increase of probability of getting lung cancer [*Lubin H., et al*]. Exposure to ionizing radiation from natural sources is continuous and inevitable for all living organisms. About 13% of the radiation origin can be from outer space, like cosmic rays, and 67% as terrestrial radionuclides from the Earths' crust present everywhere in the environment including in the human body. Due to their short range, just a few centimeters(cm)s in air, the detector should be placed near the source. The development of photodiode based active detector for radon monitoring will allow continuous evaluation of radon levels in short-term and long-term measurements. In this research

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photodiode based active detector for radon detection was constructed by using Arduino ATmega2560 microcontroller, GLCD and Si-PIN photodiode.

Radon measurement system consists of a chamber within a silicon photodiode was placed inside. Radon from surrounding air entered by diffusion or actively pumped into the chamber and the positively charged progeny are collected on the surface of the photodiode [*Takeuchi Y., et al*]. Then when the charged alpha particles, from the progeny decay, stroked the surface of the photodiode its energy was absorbed along its track whose length was dependent on the energy of the incident particle. Electron/hole pairs were created in its path by coulomb interactions between the ionizing particle and the detection material. The electron/hole pairs were then separated by the electric field present in the photodiode junction in opposite directions. The photodiode operated in reversed bias mode, so electrons and holes migrated to the n-layer (cathode) and p-layer (anode), respectively, generating a flow of current in an external circuit. The produced charge was proportional to the energy of the particle incident [*Knoll F., et al*]. Fig 1 shows the schematic diagram of a Si-PIN photodiode cross section for charged particle detection.

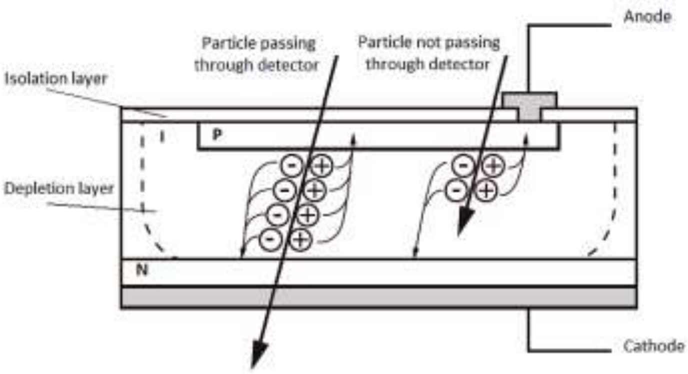

Figure 1. Schematic diagram of a Si-PIN photodiode cross section for charged particle detection [*HAMAMATSU*].

Photodiodes have a number of advantages such as good quantum efficiency, small ionization energy, good energy resolution, high stability, response timing characteristics, compact in size, low cost and simplicity of operation. However, electronic noise is a major problem due to the small signal amplitude. In this study, Si-PIN photodiode SLCD-61N5 was used as alpha particles detector for radon detection in air. Despite the desirable feature of superior energy resolution, a simple approach of pulse counting related with radon detection was taken in this work. The construction of photodiode based active detector for radon detection was divided into three main parts: the detector, preamplifier and signal processing, and the data acquisition system for pulse counting. A block diagram of hardware system for radon detection system is illustrated in Fig 2.

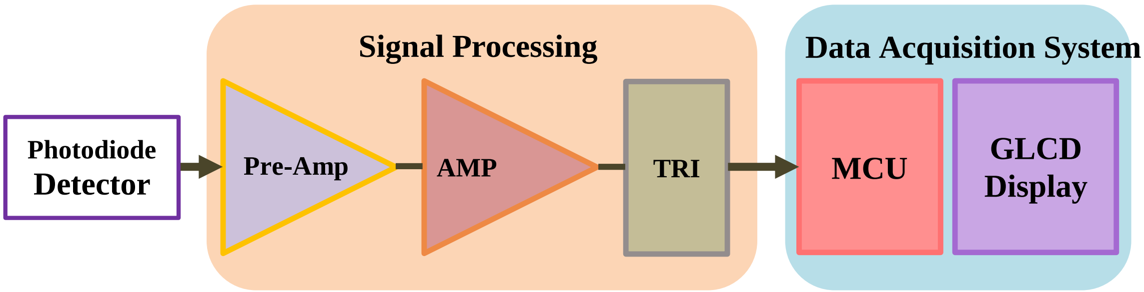

Figure 2. The block diagram of hardware system for radon detection system.

System Components and Circuit Operation

A low-cost photodiode SLCD-61N5 was used to detect alpha particles from the decay of radon and its progeny, under room temperature conditions. The active area of the photodiode is 10×10 mm^2. To achieve an efficient collection of charge created by the incident particles, and reverse external voltage was applied to the photodiode. For the SLCD-61N5 photodiode, the breakdown voltage is -20 V. The designed preamplifier circuit for photodiode is shown in Fig 3. The serial connected resistor R1 limited the reverse biasing current to avoid the increasement of the leakage current. The coupling capacitor C1 blocked the DC bias signals and coupled the detected ac signals from the collected charges. When a charged particle strikes the sensitive area of the photodiode a small current is generated with the amplitude proportional to the deposited energy. This current signal could be converted to a voltage signal using a transimpedance amplifier. Since the photodiode polarity was reversed and the current signal entered on the negative input of the op-amp, the output of the preamplifier would be a positive pulse. In order to have a conversion without significant degradation of the intrinsic signal-to-noise ratio, the preamplifier must be located as close as possible to the detector diode and the op-amp used must have a FET (Field-Effect Transistor) input stage. The op-amp employed in this research work was a dual LF442 low power JFET input operational amplifier, with high gain bandwidth (1 MHz) and high slew rate (1 V/µs) according to its specifications.

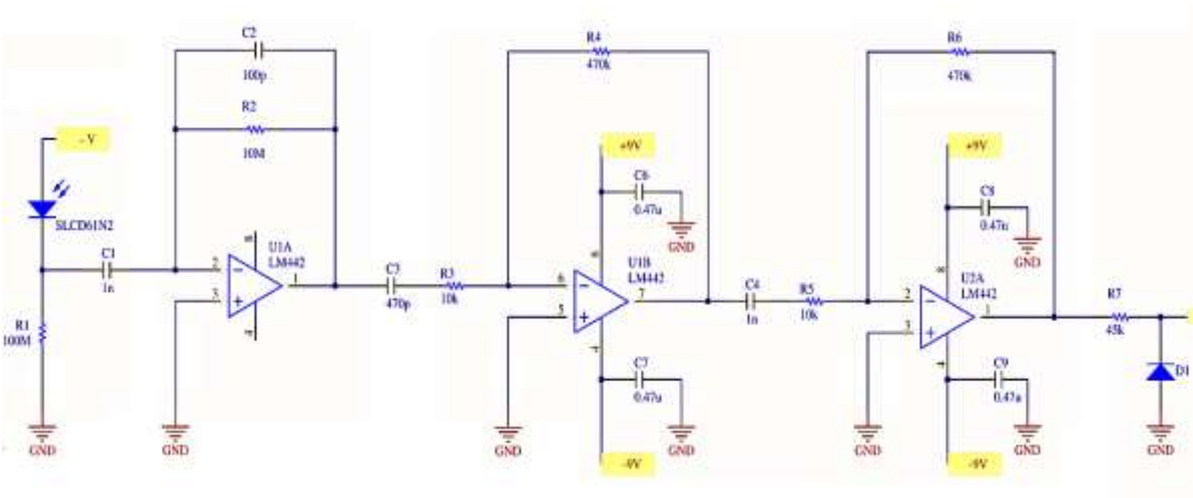

Figure 3. The constructed preamplifier circuit for photodiode detector.

When the sensor was exposed to the radon rich atmosphere, alpha particles could be detected with the maximum energy of 7.69 MeV, which corresponds to the decay of the ^{214}Po radon daughter. The maximum output voltage of the signal to be in the order of magnitude of a few 27 mV. In order to increase the amplitude of this signal from the mV range into the 1 V ~ 5 V range, and to make the possible accurate pulse detection, two stages of amplification were implemented. The resistors R4 and R6 set the voltage gain in the order of two thousand, being sufficient for the output signal to be in the desired range. The coupling between amplifiers was conducted by coupling capacitors also working as filters. A diode limiter circuit was placed on the output of the amplifier to limit the negative phase of the amplifier output signal. For counting the pulses from radiation detector, amplifier output signal was converted into logic pulses with a discriminator that produced a logic pulse, with a fixed height, when the input pulse is above a certain threshold level. This allowed to reject noise and small pulses from background radiation. The logic pulse represented the information that was recorded only the presence or absence of a particle hitting the detector.

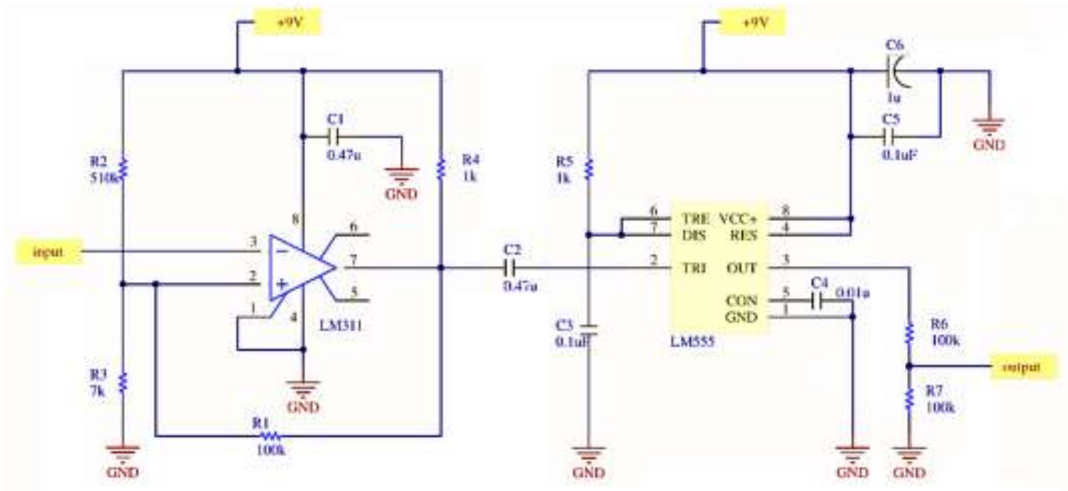

Figure 4. LM311 and NE555 based discriminator and pulse trigging circuit.

LM311 and NE555 based discriminator and pulse trigging circuit is illustrated in Fig 4. Due to the comparator input signal being noisy around the threshold value, a feedback resistor R1 was implemented. The function of this resistor was to make the circuit have two input thresholds, instead of just one, preventing multiple triggering and consequently false pulse detection. The output signal was fed to the Arduino MEGA to count, store and display the number of pulses detected, corresponding to the presence of the radon in the air. The signal entering into the Arduino was a square impulse. The transition of a state from LOW to HIGH means one interaction on the photodiode, and consequently one more count. When one of these signals arrive at Arduino's interrupt pin, an interrupt to the microcontroller was obtained and logic state changed value (from LOW to HIGH). These operations were controlled by software to take account when the signal is rising. To count the number of detected impulses, the state variable was checked and recorded the number of impulses detected at 10 minutes intervals. And the obtained results were displayed on the LCD and the count variable was reset.

Results and Discussion

Performance Analysis

To analyze the performance of the constructed circuit, ac signal output from the function generator was fed to the photodiode detector input and measured the voltage response at three different test points (TP) on the circuit. TP1 corresponded to the amplifier output, TP2 analyzed the trigger output, and TP3 checked the NE555 timer output. Due to the mixing with noise, the output signal of the preamplifier was not observable with the digital oscilloscope. Fig 5 shows the signal observed at TP1 in absence of incident charged particles. Since its amplitude, about

100 mV, was lower than trigger threshold, no signal was observed at TP2 and TP3. The measurement of this signal amplitude was important to get a reasonable future threshold value. Fig 6 and Fig 7 show the signals observed at TP1, TP2 and TP3 when the uranium salt-based photo-luminance object was placed above the photodiode detector. The amplitude of the pulses at TP1 was in a range from 400 mV to 1.8 V. It was sufficient to set the trigger and characteristic signals were observed at TP2 and TP3. It could be seen that the signal from TP1 was a positive pulse whose amplitude was much higher than the noise. According to the presence of these signals, it could identify them as the interactions of charged particles in the photodiode.

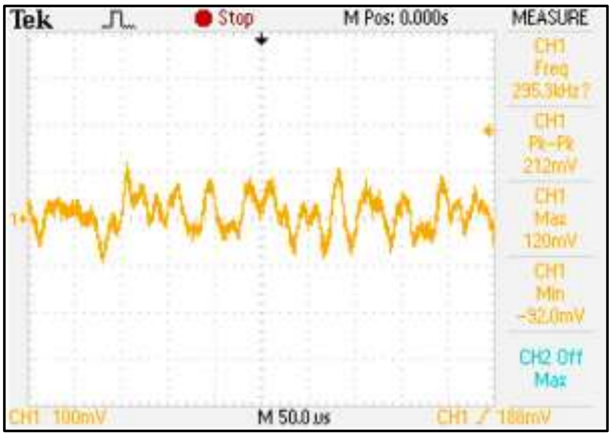

Figure 5. The signal observed at TP1 in absence of incident charged particles.

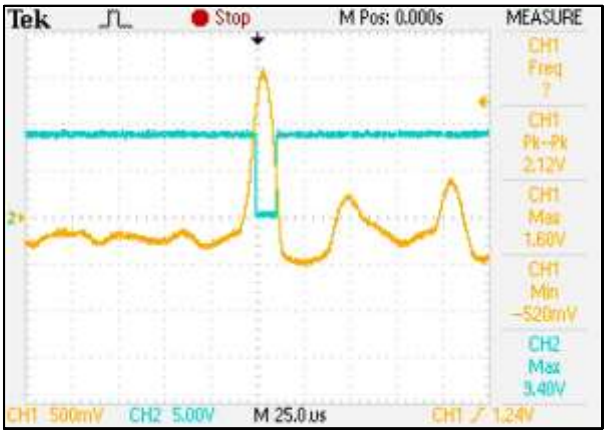

Figure 6. The signals observed at TP1(orange) and TP2(cyan) when the charged particle was detected.

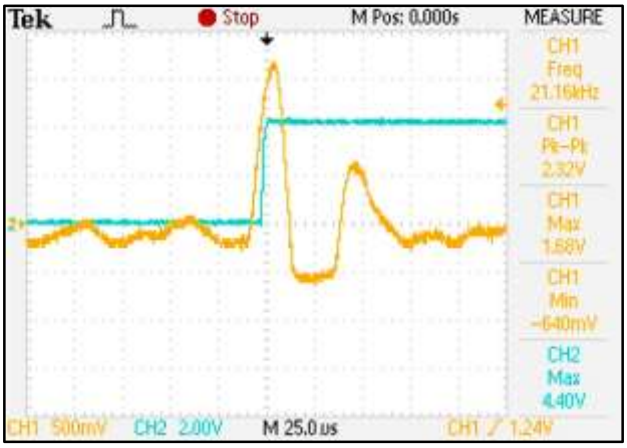

Figure 7. show the signals observed at TP1(orange) and TP3(cyan) when the charged particle was detected.

Detection Response Analysis with Biasing Voltage

Fig 8 illustrates the measurement results of the constructed radon detection system for three different values of biasing voltage. Each experimental dot corresponds to the sum of counts acquired in a ten-minute interval.

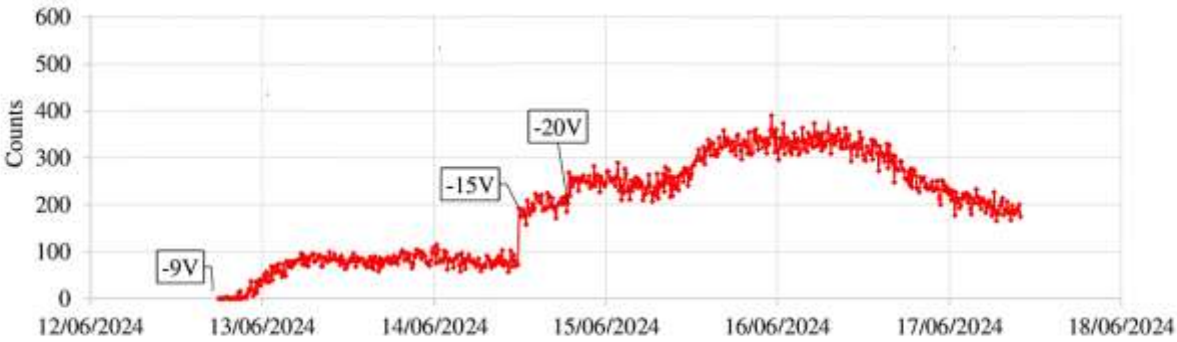

Figure 8. The measurement results of the constructed radon detection system for three different values of biasing voltage.

When the applied biased voltage of -9 V, it was possible to observe a progressive increase in the number of counts. However, it did not show sufficient sensitivity to detect radon level fluctuations. When biased at -15 V, it could be seen an increase in the number of counts but a sufficient acquisition was not acquired. It could be compared with -9V biasing voltage, there was no distinguishable peaks were observed. With the applied voltage of -20 V, the sensitivity of the constructed detector increased and it was being possible to observe the radon level fluctuations. Therefore, the detection response was shown to be affected by the biased voltage applied to the photodiode, with the increase of the biased voltage, increasing the sensitivity of the detector. It could be said that this effect may be due to the increase of the electrostatic attraction or due to the larger collection of charges in the depletion region of the junction of the photodiode. It was also estimated that the acquisition time necessary to have the required data statistics was observed about 4 days to 1 day respectively.

Conclusion

In this research work, active sensor for radon detection in air was designed and constructed with silicon PIN photodiode working in counter mode. It is remarkable that the detector has a low fabrication cost, and it has a good performance for alpha particle detection. The design of the detector circuit was mainly focus on that simply counted the pulses generated by the charged particles hitting the photodetector. The signal generated by the sensor fed an electronic circuit composed of LF442 op-amp based preamplifier and transimpedance amplifier, LM311 based discriminator, NE555 timer and data logging and display system with Arduino MEGA development board which can also connect to a computer for data acquisition. The detection response of the constructed system was carried out with different biasing potential -9 V, -15 V and -20 V. It was observed that the detection response was affected by the applied potential to the photodiode, increasing the sensitivity of the detector with the increase of the biasing voltage. Despite the low bias voltage, in all cases it was possible to detect pulses since the deposited energy was high enough to generate pulses above the electronic noise. The constructed radon detector could be implemented as portable device for working powered only with batteries, and using a memory card shield attached to the Arduino to store the data.

Acknowledgements

I would like to express my special thanks to Rector, Dr Khin Thant Sin and Pro-Rector, Dr Win Mar and Dr Lae Lae Kyaing Mandalay University of Distance Education for giving permission to submit this research paper. The author would like to thank Professor Dr Wah Wah Thin, Head of Department of Physics and Professor Dr Soe Soe Oo, Department of Physics, Mandalay University of Distance Education, for their kind permission to carry out this research. I have appreciated the support I received from everyone who gives me unconditional support and aid.

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