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Building homemade detector for detecting and monitoring Radon Gas in ambient air

Rida S N Mahmudah[1], Restu Widiatmono[1], Laila Katriani[1], Ahmad F Harish[2], Dhani N I Syamputra[2], Azzam Z Iman[2] and Muhammad R Fauzi[2]

[1]Physics Education Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, D I Yogyakarta 55281, Indonesia
[2]Students of Physics Education Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, D I Yogyakarta 55281, Indonesia

Corresponding author: rida@uny.ac.id

Abstract. Radon is one of the noble gasses that is difficult to detect but can be danger for health when it surpasses safety level dose. Several commercial radon detectors can be found in the market nowadays, but in relatively expensive price. This research is aimed to build detection system of radon gas by using simple instrumentation that can be found in our daily life. This detection system consists of three parts, i.e. ionization chamber, which was made by utilizing an empty can beverage as radon detector chamber, amplifier to strengthen signal from the ionization chamber, and rate meter to calculate amount of emitted radiation. The process to build this detection system was begun by doing literature study about homemade radon detector, system design, purchasing instruments and materials, building the system and test it. In the end of the research, several ionization chambers, amplifiers and rate meter have been built as they have been designed. Detection system testing result indicated that this system can detect radioactive decay of surrounding radioactive material and can be improved to get a better result.

1. Introduction

Nowadays, the world is facing the more complex health problems in comparison with several decades ago. These health problems occurred due to the advancing technology, changing lifestyles and eating habit. One of the most common occurring health problems is cancer. According to World Health Organization (WHO), cancer is the second leading cause of death globally, and is responsible for an estimated 9.6 million deaths in 2018, or about 16% of all death [1]. This number is a significant increase from the year of 2000, where cancer was estimated to account for about 7 million deaths, or about 12% of all deaths [2]. In Indonesia, based on a national survey in 2007, cancer became the 7th largest cause of death, or about 5.7% of all death [3]. According to WHO's Global Burden of Disease 2000, the top four of most cancer incidences from the highest are trachea, bronchus and lung cancers; breast cancer; colon and rectum cancers; and stomach cancer. While the mortality rate from the highest is, respectively, trachea, bronchus and lung cancers; stomach cancer, liver cancer; and colon and rectum cancers [4]. In both incidence and mortality, lung cancer is rated as the highest globally in the world. Most of lung cancers are caused by smoking and radon exposure, and for that reason, radon has been categorized as a carcinogenic substance by WHO [5].

Discovered in 1900 by Dorn, radon is a naturally occurring radioactive gas that is odourless, tasteless and colourless. Radon is resulted from radioactive decay of uranium, which decays into radium, then into radon [6]. Uranium is found in small amounts in most rocks and soil; thus, we can find radon almost everywhere in the earth. According to [7], approximately every square mile of soil to a depth of six inches contains about one gram of radium, which releases radon into the atmosphere.

Radon is also a radioactive element, and decays into -also-radioactive daughters. Those daughters will continue to decay until becomes a stable element. Being an inert element, radon is not easily reacting to any materials. Hence, it is not dangerous itself. Problem occurs when we inhale radon into our body, and in 3.8 days radon will decay into polonium and release alpha particles. As alpha particle has ionizing capabilities, it can be very dangerous to internal organs, especially with energy of more than 5 MeV. High energy alpha particle can lead to a serious cellular damage [8]. Moreover, polonium has only 3.1 minutes of half-life. Meaning that in 3 minutes after it is formed from radon, it will decay into lead and release another alpha particle with even higher energy. Thus, it will produce even more damage. The radon's daughters, their half lives and their respective decay energies are shown in table 1.

Table 1. Radon-222 Decay Chain [9].

Isotope	Element's name	Half life	Mode of Decay	Decay Energy
$^{222}_{86}$Ra	Radon	3.8235 days	alpha	5.59 MeV
$^{218}_{84}$Po	Polonium	3.10 minutes	alpha	6.115 MeV
$^{214}_{82}$Pb	Lead	26.8 minutes	beta	1.024 MeV
$^{214}_{83}$Bi	Bismuth	19.9 minutes	beta	3.272 MeV
$^{214}_{84}$Po	Polonium	164.3 μs	alpha	7.833 MeV

In order to prevent such hazards due to radon and its daughters, several countries, including United States of America, strongly encourage their citizens to own a radon detector in their homes. Unfortunately, commercially sold radon detectors are expensive and hardly can be afforded by all households. Several studies have been conducted in building homemade, affordable, and easy-to-make radon detectors based on ionization chamber principle. Amongst them are homemade ionization chamber for radiotherapy beams [10], and for mammography standard radiation beams [11].

This study aims to build a homemade radon detector based on ionization chamber from household materials. Most of the circuit are inspired by Paul Neher, who wrote an article about building radon detector at home [12]. Several adjustments were made to make it simpler and more compact. The homemade detector was built successfully and was tested against radiation from several sources. The results are not sufficient enough, though several suggestions for improvement are given in the end of this paper.

2. Circuits and fundamental theory

2.1 Ionization chamber

The easiest way to detect radon is by detecting high energy alpha particle resulted from its decay. As can be seen in table 1, radon's decay energy is 5.59 MeV, and approximately 5.49 MeV goes to alpha particle as its kinetic energy. This energy will ionize the air on its paths. In average, 34 eV of energy is needed to ionize the air. Thus, if the alpha particles use all their energy to ionize the air, 10^5 pair of ion-electron will be produced in 4 cm distance. It is resulting in 10^{-14} Coulomb of charge collected by electric field inside ionization chamber. The scheme of this chamber can be seen in figure 1.

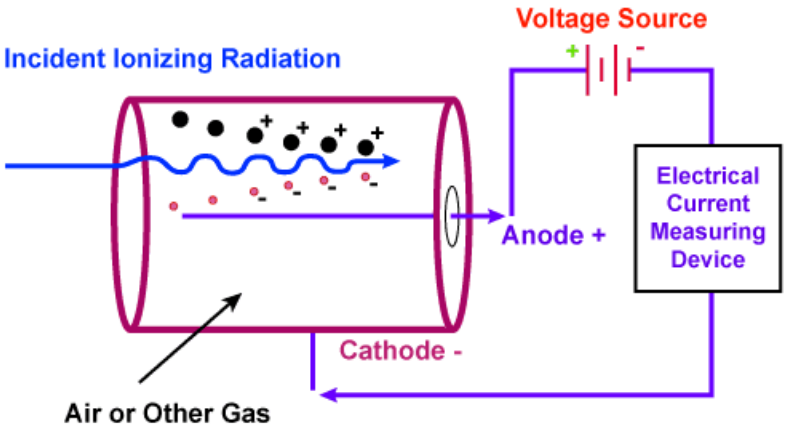

Figure 1. Ionization Chamber Scheme (http://electricalvoice.com).

We utilized beverages aluminium cylinder can as the body of the ionization chamber. In the centre of the can, there is a positively charged anode that will be connected to amplifier.

Negatively charged electrons will be attracted to anode several microseconds after ionization. Meanwhile, positively charged ions will be attracted to the can's surface which has negative charge. Several microseconds after, those ions will merge again with electrons from high voltage DC source.

Current flows resulted from ionization chamber leads to a small voltage pulse between resistors that are serially connected with voltage source. This pulse is then amplified, detected and measured. Resulted counts per minutes then can be multiplied by constants, including the effective chamber volume to describe radon's activity in the unit of pCi/l. The presence of radon's daughters in the chamber will increase counting rate. This ionization chamber was designed by assumption that the air in the chamber are sample representing the whole air in monitored room.

A metallized-polypropylene film capacitor was utilized as the voltage source for the ionization chamber. This capacitor must first be filled with charges until it reaches 500 V potential different. To do this, we employed a circuit depicted in Figure 2.

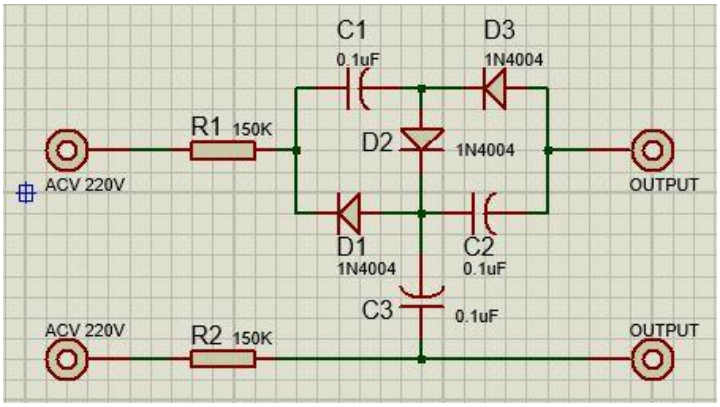

Figure 2. Capacitor Charging Circuit.

2.2 Amplifier

Figure 3 is the circuit scheme for amplifier. To maximize the input signal of amplifier, the capacitance needs to be minimized.

We utilize two LM392s as a low-power operational amplifier or voltage comparator as an amplifier and a comparator. High gain op-amp with compensated internal frequency is LM392 on the left side, and the comparator is LM392 on the right side. Both of them can operate from one power supply in a

wide range of voltage (3-32 Volts). Drain current is 600 microamperes, and independent of supply voltage.

The comparator on the right side operates as pulse-amplitude comparator and detector. Time-constant circuit combination makes it able to trace low frequency current as well as respond to alpha ionization pulse that is five time larger than threshold. By adjusting amplifier gain to meet with ionization chamber signal, we can detect a lot of alpha ionization. While the low sum of beta particle, gamma rays and ionization noise will be rejected.

Comparator's output is open collector which will become lower (low impedance) when alpha particles are detected. This output is then connected to the count-rate meter.

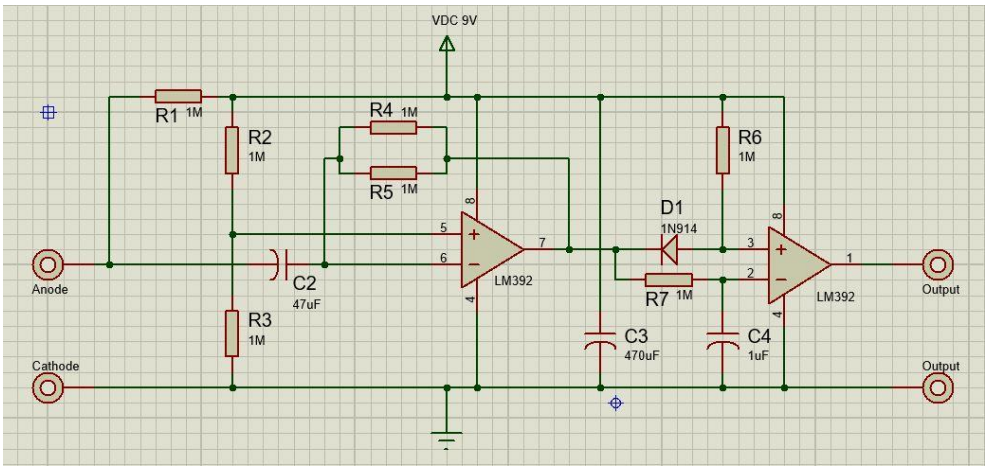

Figure 3. Amplifier Circuit Scheme

2.3 Rate meter

To calculate how many radiations counts in certain time span, a rate meter was utilized, and its circuit scheme can be seen in Figure 4. Electrical components in the left side are as pulse counter circuit, and the right side is the output from analogue voltmeter.

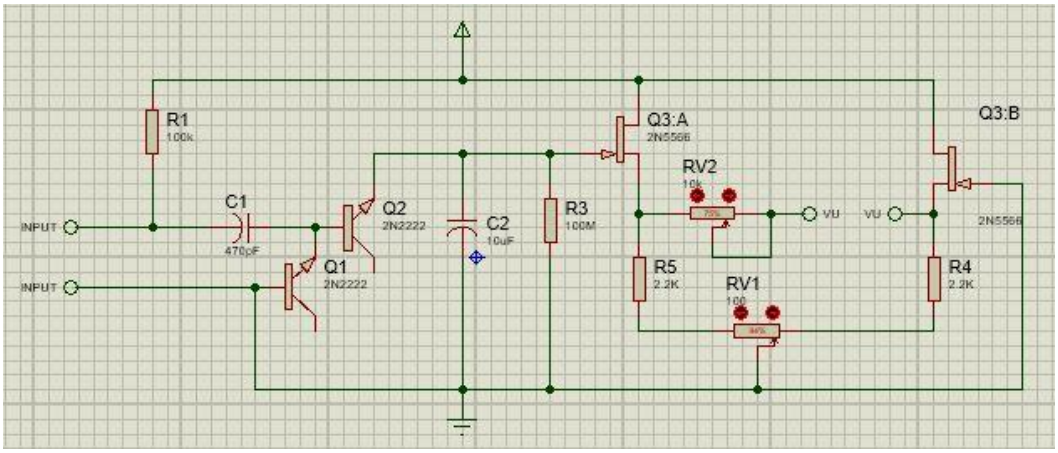

Figure 4. Rate meter circuit

When comparator LM392 gets input from ground, capacitor C1 in rate meter releases charge through emitter-base diode 2N2222 (Q1). Then, when comparator becomes high, resistor R1 charges C1 through emitter-base diode (Q2) and accumulator capacitor C2. These components form simple charge pumps where charge in accumulator capacitor C2 at a certain rate is define by pulse rate.

Flowing currents from C2 through R3 is proportional with the collected charges, and, at the equilibrium, is equal to the flowing currents. In other word, pulse rate defines voltage V_R in resistor 100 MΩ R3. The equation for this response is:

$$V_S = \frac{r \times R3 \times C1 \times (V_S - 2V_D)}{1 + r \times R3 \times C1} \quad (1)$$

where r is pulse rate (counts per second), V_S is supply voltage and V_D is voltage drop of forward diode (0.5 Volt). This equation can be approximated as linier if the sum of $r \times \mathrm{R3} \times \mathrm{C1}$ is smaller than one. If, for example, the circuit is designed so that the maximum counts result in R3 voltage that is almost 10% of supply voltage, then the nonlinearity error will become 2%. With 9 Volt supply, this circuit will result in V_R 120 mV with input rate 20 counts per minute, or $r = 20/60$ counts per second. The uncertainty of counts rate as time constant is given by:

$$U_r = \left(\frac{r}{2RC}\right)^{1/2} \quad (2)$$

This circuit has time constant RC of 1000 second. This means, take one hour to get 3% of the final result.

3. Working principle

As mentioned above, this homemade detection system has three important parts: ionization chamber, amplifier and rate meter. To summarize, the working procedures of this system are:

- Radon gas that are collected in ionization chamber will decay, resulting alpha particle with 5.49 MeV kinetic energy. This alpha particle will then ionize air inside the chamber and produce ion-electron pair.
- A film capacitor 0.1 microfarad that has been fully charged can power the ionization chamber for several weeks, thus there are anode and cathode inside the chamber.
- Negatively charged electrons will be attracted to anode and positively charge ions will be attracted to cathode. Those ions will merge with electrons from DC voltage source.
- The electron flows will result in pulse or signal.
- Anode is connected with IC 2N5458 to minimize capacitance and maximize amplifier signal input.
- At the amplifier, incoming current is changed to voltage and is amplified by IC LM392N.
- The amplifier output is then connected to the rate meter.

4. Materials, components and detector's construction

The tools that was used in this research are all common and easy to find, such as: voltage source, digital multimeter, solder and tin plucker, cutter, screwdriver, scissor, circuit board, and drill. We also utilized simple materials, i.e. aluminum beverage can, polyethylene paper, conductor cable, multipurpose glue, 9 Volts battery, masking tape, single and parallel cable, resistor, capacitor, transformer and transistor. To be exact, the components of the circuits are: film capacitor 0.1 µF 630V (body slim), transistors 1N914, 1N4004, NE555, IC LM392N, J201 JFET. We need three values of resistors, i.e. 1 MΩ, 150kΩ, 100kΩ, and four kinds of capacitors: 47 µF 630 V; 47 µF 15 V; 470 µF 15 V; and 1 µF 15 V.

To construct the detector, first we must cut the beverage can and make hole in the bottom of it. This beverage can will act as the ionization chamber. As for the circuits, we made them from scratch. First, all the electronic circuits are drawn in Eagle application. The drawings are then printed in A4-sized glossy paper, and glued to the circuit board. Next step is to iron the boards to make it stick even stronger, and to thickened electric circuit path in the boards. After that, the boards are dissolved with circuit board's dissolver and hot water. Then, drill holes according to the drawing to prepare component's place on the boards. After the holes are ready, the components are placed in the boards and soldered to make it firm.

We did those procedures to make each of circuits in Figure 2, 3 and 4. For the sake of simplification, we combined amplifier and rate meter circuits into one integrated circuit board. After all the circuits are

ready to use, we start building the detector by charging the capacitor. Then, the system is ready to be tested.

5. Result and discussion

In this study, we made several ionization chambers to anticipate failures. One of the chambers is shown in Figure 5, and the integrated amplifier-rate meter circuit is shown in Figure 6.

The ionization chamber, integrated amplifier-rate meter circuit, voltage source, and a micro ampere meter are then connected with several cables as can be seen in Figure 7. To test the detector, a radioactive source is placed in front of ionization chamber.

Figure 5. One of the ionization chambers from beverages can

Figure 6. Amplifier and rate meter circuit

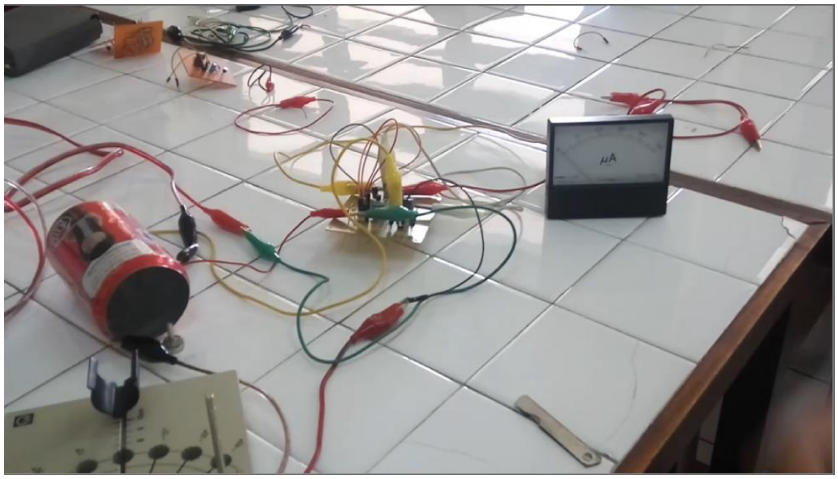

Figure 7. Detector system testing

The purpose of this study is to make a radon detection system, by utilizing the alpha ionizing that resulted from radon decay. Before operating the system on the open space, we tested the system in laboratory. First, the detector was tested using hand phone's radiation and then the radioactive source.

The data was taken by variating the phone's distance from the detector. The results of this testing are shown in Table 2.

Table 2. Headphone's testing results.

Distance (cm)	Output (μA)
5	9
10	7

15	5.5
20	4
25	3
30	2.5
35	2

As we can see from the table, the output decreases as the distance increases. This is because, the further the distance, the weaker the source. Thus, the ionized air is also lesser. With lesser ionized air, the charge collected in anode and the current flowing through the detector system becomes lower. These results are aligned with the theory; hence we can say that the detector system works.

The second step is to test it with radioactive source. The main challenge in this study is to provide an appropriate radioactive source, especially alpha-radiating source. The only available source in our laboratory that meet the need was Radium-226 or Ra-226. Ra-226 is a descendant from U-235, an alpha emitter with the half-life of 1599 years. The testing with Ra-226 came with no significant changes to the micro ampere meter. It means, that there were no detected current nor the air ionization inside the chamber were not large enough to produce a detectable current. This is due to the usage of Ra-226 for the test. As we know, the decay reaction of Ra-226 is as follow:

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Ra} + {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma \tag{3}$$

with the decay energy of 4.87 MeV [13]. This energy is divided amongst $^{4}_{2}He$ or alpha particle and gamma. There is 93.84% probability that alpha particle gets 4.7843 MeV enery and the rest goes to gamma; and 6.16% probability that the alpha particle gets 4.601 MeV and the rest goes to gamma [14]. Either way, the alpha particle energy produced from Ra-226 decay is far lower than that of Radon, which is 5.49 MeV. Thus, the detector cannot get any signal from this source because it was designed to detect much higher alpha particle energy.

For the above reason, authors were then searching for another radioactive source to be tested with the detector. Owing to Center for Accelerator Science and Technology of National Nuclear Energy Agency (BATAN) in Yogyakarta, we were able to test the detector with Americium-241, or Am-241. Am-241 is also an alpha emitter with the half-life of 432.6 years. It decays by following below reaction:

$$^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma \tag{4}$$

The alpha particle's energy produced from this decay is 5.48 MeV (84.8%), or 5.44 MeV (13.1%) [14]. These energies are almost same with that from radon's decay; thus, we could expect some results.

As the previous test, we move the source back and forth, makes it nearer and further from the detector, and see the changes in micro ampere meter. When the source was placed further from the detector, the ampere meter showed 0 current, which was expected. But, when the source was placed nearer, a fluctuate deviation around 0 and 1 μA was observed. This means that the current flowing through the detector system was considerably smaller than it should. This could be due to the air inside the chamber are not sealed, so it can move around and go outside the chamber. There are ionized an un-ionized air flowing in and out the chamber, thus make it difficult to gain a stable measurement. On the other hand, if we close the chamber's opening, the alpha particle will not enter the chamber at all, due to its penetration capability. For future consideration, we can add a cover in the chamber, that can be penetrate by alpha particle but can prevent the air from escaping the chamber. Nonetheless, the detector was able to detect. The authors believe with further refinement, and change the micro ampere meter to pico-ampere meter, then it should be able to measure the radiation with better results.

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