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Research Article

BUILD VERY SIMPLE DESIGN AND COST EFFECTIVE GEIGER-MULLER COUNTER

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ABSTRACT

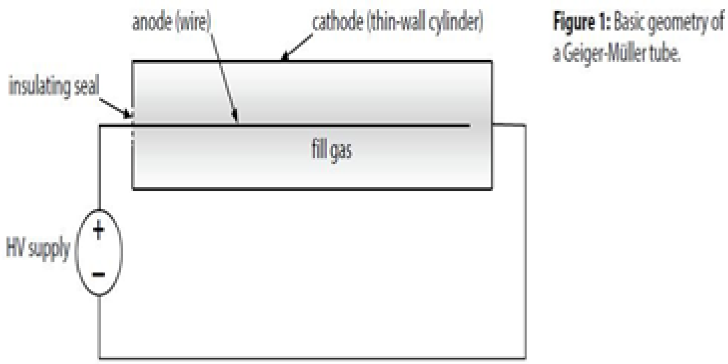
This paper describes our first undergraduate project experience, final report and findings on the subject matter. Initially according to our project title, we were focused on developing a low cost detector which can detect radiation only. To make one of these kinds of detector doesn't take much and can be prepared at fairly low cost being very common project in nuclear science arena. The Geiger-Muller tube, or GM tube, is an extremely useful and inexpensive way to detect radiation. While the GM tube can only detect the presence and intensity of radiation, this is often all that is needed.

KEYWORDS:.Introduction, Statement of Problem, Objectives, Plan of action, Technical specification, Theoretical Overview, Hypothesis, Procedure, Geiger Bot Compatibility, Application, Discussion, conclusion, Acknowledgment, References.

INTRODUCTION

For this project we build a very simple cost effective Geiger –Muller (GM) counter. GM counter is a fundamental type of radiation detector used for the detection of all types of radiation (alpha, beta and gamma) radiation. A Geiger counter consists of a Geiger- Muller tube, the sensing element which detects the radiation and the processing electronics which displays the result. [1]

Figure-1: Basic geometry of a Geiger-Muller tube [2]



STATEMENT OF PROBLEM

In the context of nuclear engineering we are primarily concerned with radiation that results from any of a variety of nuclear reactions, including the spontaneous decay of a nucleus, the fission of a nucleus and the fusion of two nuclei. The radiation which has enough energy to produce ion pairs.is called ionization radiation; human do not possesses any sense organ to detect this ionizing radiation, so we need to rely on instrument for the detection and measurement of radiation. Our idea is to build a very low cost simple GM counter by which we can detect all types of radiation very easily .GM counter is generally inexpensive, but in this project we made a home- made GM counter that can be made with very less cost than the commercial made one.[1]

OBJECTIVES

As we mentioned earlier that we need detector to detect the ionizing radiation, so we build a home-made GM counter by which we can detect all types of radiation.

PLAN OF ACTION

The parts are needed shown in the Figure below:

Figure-2: Materials that are needed [2]

Here in our project we bought the GM tube from Russia but we build the circuit all by ourselves which minimize the cost and make us self-dependent by using local electrical instruments and by this we can make this counter very easily as we mentioned earlier. And we also attach Arduino system so that we can manipulate our data and make some variation from typical counter by using software code which makes our counter special from others.

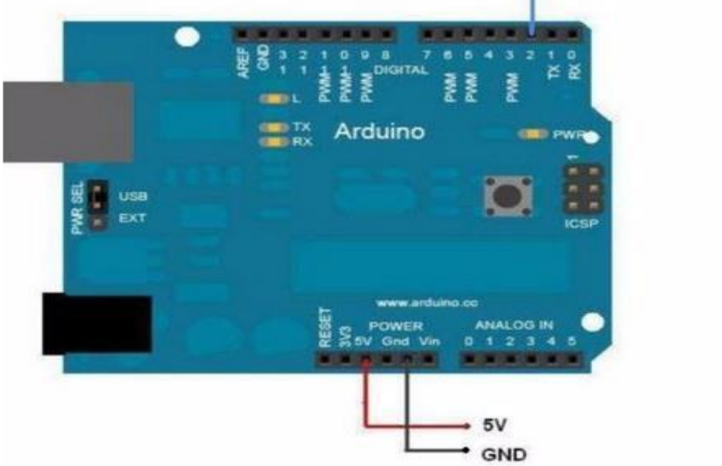
TECHNICAL SPECIFICATIONS

i. Geiger tube PCB Compatibility: M4011, STS-5, SBM-20, J305.
ii. Geiger tube Voltage Compatibility: All General GM Tubes with anode voltage 350-480V.
iii. Sound and Visual Indication.
iv. Arduino Compatible.
v. Supply Voltage: 5V; 3x 1.5V Battery; 4x 1.2V Battery.
vi. Include high impedance voltage divider.
vii. Supply Current: 12mA - 30mA.
viii. Dimensions: 120 x 50 mm[3]

Arduino MCU Communication

i. The PCB has 3 pins for communication with MCU: INT, GND, 5V. We can power up the kit from 5V Arduino board directly or if we use batteries for Geiger Kit, we have to connect only 2 pins to Arduino: INT and GND.
ii. There is much different application we can build by using this kit.
iii. high-low-high interrupts to Arduino. [3]

Figure-3: Arduino [3]



APPARATUS

The Board

The radiation board has two main parts, the power circuit and the signal circuit. The power part is used to provide the voltage necessary for the tube (400V - 1000V) and the signal circuit is used to adapt the pulses output from the tube and connect it to the input of the microcontroller. Once the tube is powered, we can receive the pulses in the microcontroller and count them, then with an easy calculation we can get the value of radiation. The code we use for the board is counting pulses for 10 seconds, then we multiply the number of pulses by.6, so we get the number of pulses by minute (cpm), then, according to the tubes documentation we divide cpm by the conversion factor of the tube (360 by default) and we have the value of radiation in µSV/h.[4]

M4011 Geiger tube Specification

Tin oxide Cathode, Coaxial cylindrical thin shell structure(Wall density 50±10cg/cm2), Application of pulse type halogen tube application temperature:-40°C~55°C
Could be used for :γ Ray 20mR/h~120mR/h and β Ray in range 100~1800 Changing Index/minutes·CM2 soft β Ray (Both beta and gamma radiation detection)
Working Voltage: 380-450V
Working Current: 0,015-0,02 mA
Sensitivity to Gamma Radiation: 0.1 MeV Own Background: 0,2 Pulses/s
Length: 88mm
Diameter: 10mm [4]

The basic instruments are

PCB 120 x 50 mm 1x CD4011 IC
1x 2N3904 Transistor
1x 10 Ohm Resistor
1x 100 Ohm Resistor
4x 1K Ohm Resistor
1x 2K2 Ohm Resistor
1x 4K7 Ohm Resistor
3x 47 K Ohm Resistors
1x 220 K Ohm Resistors
1x 470 K Ohm Resistors
1x 4M7 Ohm Resistor
1x 10K Trimmer Potentiometer
2x 1N60 Diode
1x 1N4148 Diode
3x 1N4937 Diode
1x Red Led 3.00mm
4x 10nF Multilayer Ceramic Capacitor
5x 100nF Multilayer Ceramic Capacitor
1x 100pF Multilayer Ceramic Capacitor
3x 2.2nF HV Multilayer Ceramic Capacitor
2x 10uF Electrolytic Capacitor
1x Radial Inductor HV Coil 6x8 size

1x Terminal Block Connector
1x Slide Switch On/Off Button
2x Tube Clips for SBM-20
1x Piezo Buzzer
1x 14 Pin IC Socket
1x Male Header 10 Pins
3x Jumper Cups
4x Standoff M3
4x Screws M3 [6]

THE ELECTRONIC USED IN THE RADIATION BOARD COULD BE DIVIDED IN FIVE PARTS

High voltage power supply

For the high voltage power supply we use a circuit based on an oscillator connected to a voltage multiplier made with diodes, transistors, resistors and capacitors (see schematic for detail). With this circuit we get a power of 500V in the tube. We've added a line of zener diodes connected in series that can be used if we need more than 500V for powering the tube. We add as volts to the output as volts in zener diodes we add.

Adaptation circuit for the Geiger output

The adaptation circuit for the output is based on a NPN transistor, this transistor trigger the interrupt pin in the microcontroller, and this transistor is also activating / deactivating the piezo speaker and LED indicator generating the audio/visual signal.

Piezo speaker and LED indicator

The piezo speaker and LED indicator are connected to the adaptation circuit, so the LED started blink with each pulse and the speaker would buzz with each pulse.

LCD screen

The LCD screen is connected to the microcontroller using the 4-bit mode (4 data lines in addition to RS, Enable and RW control lines).

LED bar

The LED bar is made with five standard LEDs, 3 green and 2 red. These LED's are connected to digital pins of the microcontroller with a series resistor. [4]

THEORETICAL OVERVIEW

Radiation Detection

Radiation cannot be seen or cannot be felt unless it is of high dose, that means a person under radiation exposure would never know that, if he is being exposed to radiation or not. This fact about radiation makes the necessity of radiation detection as the most important of all. Radiation is basically the emission of energetic particle from the radioactive nuclide, cosmic rays and from particle accelerator. However, radiation is of two types, namely ionizing and non-ionizing radiation. The radiation after-effect which concerns us is that of ionizing radiation as it ionizes neutral atoms or molecules into positive or negative charged ions or even disrupts the cells of human body by changing the basic makeup of atoms in cell and resulting a health hazard. The ionizing radiations are alpha, beta, gamma, X rays, and neutron rays. Charged-particle radiation, such as alpha or beta rays, has a direct ionizing effect; whereas neutral radiation, such as X, gamma, or neutron rays, have an indirect ionizing effect. Radiation detection can be defined as an energetic particle detection system which can detect, track, and locate ionizing particles from radioactive sources or even from environment. Radiation detection system can be both mobile ad stationary. The mobile system is the most effective one for finding out the unknown radioactive source. Most of the detectors used today are ionization chambers, scintillation detectors and semiconductor detectors. But using other principles like Cerenkov radiation and transition radiation new detection systems also have been introduced. Radiation is a form of energy. This energy can be partly or wholly deposited in a suitable medium and thus produce an effect. The detection and measurement of radiation is based upon the detection and measurement of its effects in a medium, and the history of the emergence of radiation detectors is closely related to the discovery of radiation and radiation effects. Radioactive material emits ionizing radiation without having been subject to any external influence.

Gamma Interactions with Matter

Among all the rays emitted from radioactive source the alpha rays are not dangerous biologically. Because the presence of death skin outside our body prevents alpha rays to destroy the living cell by sealing it. However, it's very hazardous if someone is contaminated internally. The gamma radiation is the most dangerous ionizing radiation because it interacts with any matter particle to create charged ions and radicals that can even damage the DNA inside our body. Gamma ray due to its biological hazard and high penetrating power is one of the most dangerous radiation ray that must be detected. The gamma rays can be stopped by thick lead shielding. However, gamma interacts with materials in various ways. Among them most important three ways are described below.

Photoelectric Effect

Photoelectric effect is a phenomenon where a gamma photon interacts with an atom and releases an electron from the outer shell of the atom. The sum of the energy absorbed by electron to break the bond and its kinetic energy is equal to the energy deposited by the incident photon. The photoelectric effect occurs when the photon energy is above threshold energy and the electron is loosely bonded in the outer shell.

Compton Scattering

Compton scattering is a process when a photon strikes on an atomic electron and some of its energy is used to release an electron and the photon is emitted with reduced energy and a new wavelength. The incident angle of gamma photon and emission angle is different. The probability of Compton scattering decreases with increasing photon energy. Compton scattering is thought to be the principal absorption mechanism for gamma rays in the intermediate energy range 100Kev to 10MeV. Compton scattering is relatively independent of the atomic number of the absorbing material, which is why very dense materials like lead are only modestly better shields, on a per weight basis, than other less dense materials [9].

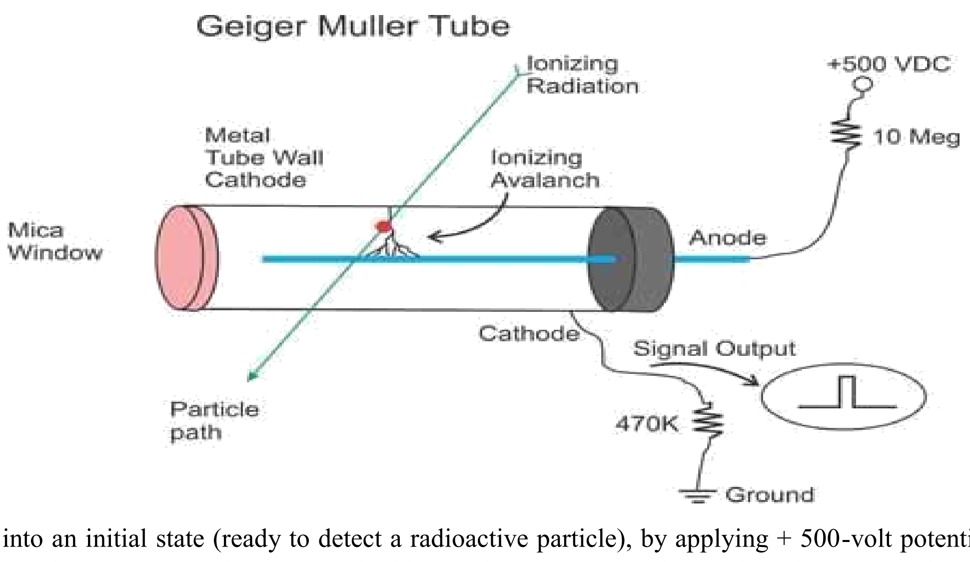
Pair Production

Pair production is the process in which an electron positron pair is formed due to the interaction between an atomic nuclei and high energy incident photon. The photon energy must be greater than 1.02 Mev. At the end of the positron's range, it combines with a free electron and annihilates each other. And the entire mass of these two is then converted into two gamma photons of at least 0.51 MeV energy each (or higher according to the kinetic energy of the annihilated particles) [10].Gamma photons also undergoes many other forms of interactions such as triplet production, internal conversion etc. Due to the above described interaction processes gamma interacts with an atom in such a way that it changes the atom and its chemical and molecular stability resulting in a dangerous after effect for living cells. Also, gamma detection requires a sufficient knowledge on gamma interactions with the matter and a well-constructed detection system.

HYPOTHESIS

Geiger Mueller tubes are simple devices that detect and measure radioactivity. The original design by H. Geiger and E.W. Mueller in 1928 hasn't change very much. The basic sensor functioning remain the same. A cut away drawing of a typical Geiger Mueller (GM) tube is shown in Figure 3. The wall of the GM tube is a thin metal (cathode) cylinder surrounding a center electrode (anode). The metal wall of the GM tube serves as the cathode of the GM Tube. The front of the tube is a thin Mica window sealed to the metal cylinder. The thin mica window allows the passage and detection of the weak penetrating alpha particles. The GM tube is first evacuated then filled with Neon, Argon plus Halogen gas. [1]

Figure-4: Geiger-Muller tube [9]



Our GM tube is put into an initial state (ready to detect a radioactive particle), by applying + 500-volt potential to the anode (center electrode) through a ten mega ohm current limiting resistor. A 470K-ohm resistor is connected to the metal wall cathode of the tube and to ground. The top of the 470K resistor is where we see our pulse signal whenever a radioactive particle is detected. In this initial state the GM tube has a very high resistance. However, when a radioactive particle passes through the GM tube, it ionizes the gas molecules in its path and creates a momentary conductive path in the gas. This is analogous to the vapor trail left in a cloud chamber by a particle. In the GM tube, the electron liberated from the atom by the particle, and the positive ionized atom both move rapidly towards the high potential electrodes of the GM tube. In doing so they collide with and ionize other gas atoms, creating a momentary avalanche of ionized gas molecules. And these ionized molecules create a small conduction path allowing a momentary pulse of electric current to pass through the tube allowing us to detect the particle. This momentary pulse of current appears as a small voltage pulse across the 470 K ohm resistor. The halogen gas quickly quenches the ionization and the GM tube returns to its high resistance state ready to detect more radioactivity. For the short amount of time the GM tube is detecting one particle, if another radioactive particle enters the tube it would not be detected. This is called dead time. The maximum dead time for our GM tube is 90 microseconds (or .00009 seconds). There is a mathematical formula for adjusting a Geiger counter read out to compensate for the GM tube's dead time. However the adjust is so small that for practical applications it can be ignored. High-end nuclear work would take a tube's dead time into consideration.

PROCEDURE

Geiger Counter Schematic Diagram

Figure-5: Geiger counter schematic diagram [11]

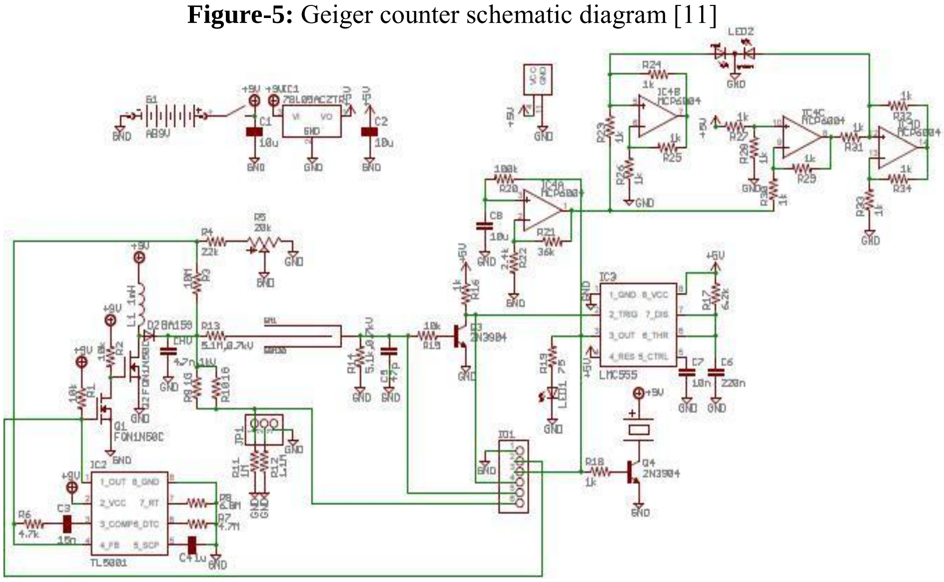
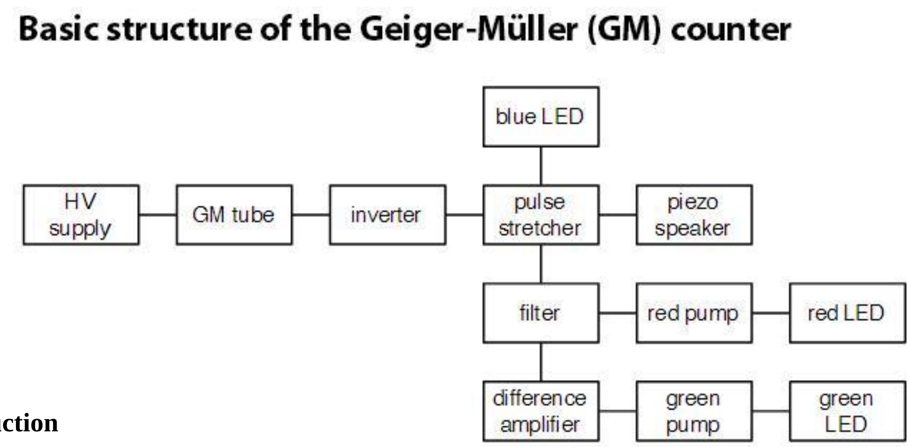


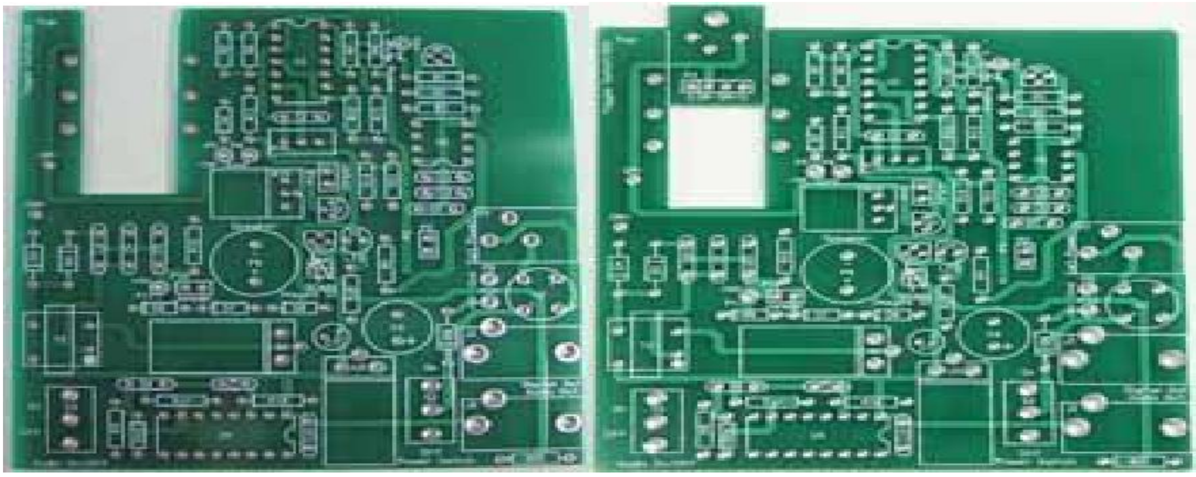
Figure-6: Basic structure of GM Counter [11]



PCB Board Construction

We may hardwire this circuit to a breadboard or use the available PCB board. Although we do not need the PCB, the PCB construction is easier. Electronics are assembled using solder. Soldering is the process of fixing one or more components as one by one by dissolving and running a solder in the joint is called as soldering. The solder metal has a lower melting temperature than the working piece. The soldering process can be applied in electrical and electronic projects, plumbing, etc. Soldering process is done in various electrical and electronics projects to combine the components with the roots of the printed circuit board. The circuit performance and working depends on the perfect soldering, it needs talent and working on the good soldering techniques would help us to make an excellent working circuit. The top silkscreen of the PCB is shown in Figure below. Begin construction by soldering resistors R17 5.6K (color bands green, blue, red), R18 4.3K (color bands yellow, orange, red) and R9 15K (color bands brown, green, orange). Next we would wire the square wave generator and pulse shaping circuit using the ICS-16 socket for the 4049, marked U4 on PCB. Insert the ICS-16, making sure to orient the notch on socket to the drawing on the PCB and solder to the board. Place and solder components C8 (.01uf), C9 (.0047uf), C10, (.1uf) and D10 (1N914). Now construct the high voltage section consisting of the step up transformer T2, diodes D4 & D5 (1N4007) and capacitors C3, C4 and C5 (.01uf 1KV). Mount IRF830 transistor Q2 to the PCB, bend the transistor outward so it lays flat on the PCB, see Figure 6, and solder. To this add the 5 volt 7805 regulator (U3), bending it outward so it lays flat as with transistor and solder into position. Next mount and solder capacitors C6 (220uf-330uf), C7 (22uf), and diode D9 (1N5817). Place and solder the 9-volt battery cap on the PC board. The red lead connects to the positive terminal P12. The black lead connects to GND, marked P9. Solder the power switch to the PCB at S2. Insert 4049 into the socket, making sure to orient the notch on the chip to the notch on the socket. [13]

Figure-7: PCB BOARD



Attaching GM Tube

The GM tube is mounted on the bottom side of the case The Geiger Mueller tube is delicate and needs to be protected in an enclosure. Keep sufficient length of wire so that we can open and close the case. [13]

Test before Continuing General Construction

Before mounting the PCB inside the case, check to make sure the entire Geiger counter circuit functions. Background radiation would cause the Geiger counter to click about 12— 22 times a minute depending on the location. When we are satisfied that the circuit is working properly we can mount the circuit inside the case. Mount the PC board to the front of the case. The shafts of the two PC mounted switch and LED should fit into the pre-drilled holes. The PCB is held to the case front using the two nuts to the PC mounted switches. Finish by placing the 9-volt battery cap into the battery compartment of the back case. Close the case and secure with case screws. [13]

Check out

Turn on the Geiger counter. If we have a radiation source bring the GM tube close to it. The radiation would cause the Geiger counter to start clicking. The LED would pulse with each click. Each click represents the detection of one of the radioactive rays; alpha, beat or gamma. Background radiation, from natural sources on earth and cosmic rays would cause the Geiger counter to click. In my corner of the world I have a background radiation that triggers the counter 12-20 times a minute.[13]

Figure-8: Geiger- Muller Counter connection points [3]

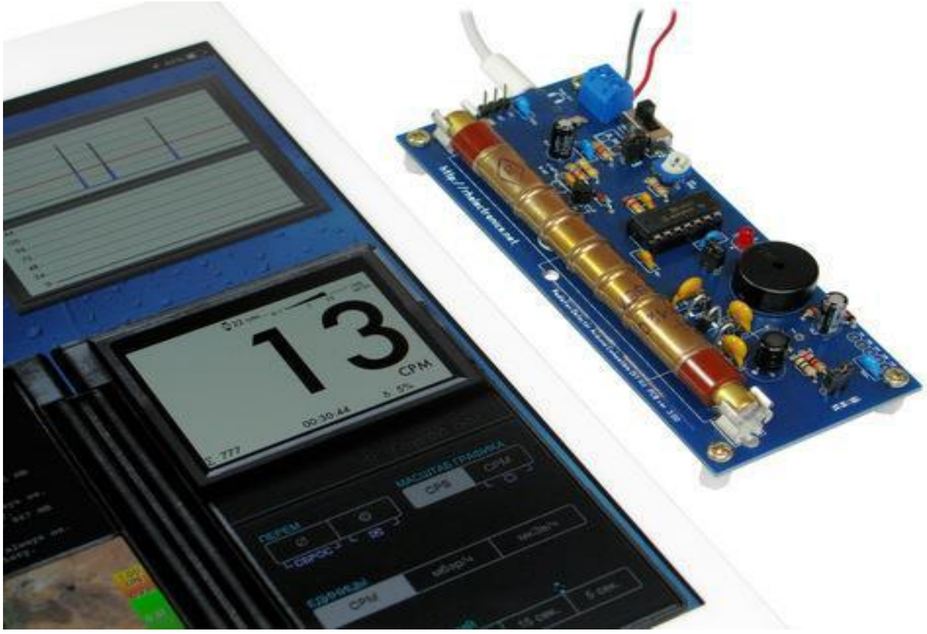
Separating & Detecting Beta and Gamma

By placing shields of different materials in front of the GM tube we can filter out some radiation. For instance placing a paper shield in front of the GM tube would block all the Alpha radiation. The Geiger counter would now only detect beta and gamma radiations. If we place a thin metal shield in front of the GM tube that would effective block the alpha and beta radiation, allowing the detection of gamma radiation. [13]

GEIGER BOT COMPATIBILITY

The board is fully compatible with iPhone / iPad Geiger Bot application. Kit comes with installed TRRS socket and we can use 4-strip Apple audio cable to connect the devices to Geiger bot.

Figure-9: Geiger bot[6]



Because audio output has fixed 1ms pulse duration, we recommend to use Geiger-bot for monitoring background and testing low radioactive sources only. For high speed count please use a microcontroller with INT connection.
To set up right connection settings, please navigate Geiger counter -> Custom GM Tubes -> I/O Settings. The following settings can be used for Arduino Geiger Kit third edition:
Auto-Adjust: OFF; RMS Window: 1; Delay Window: 18; Volume Threshold: 10000; Sample Rate: 22050; Disable Measurement Mode: OFF; Hysteresis Filter: 0; Input Polarity: Negative Only; Wavelet Filter: OFF; Input Gain Control: 0.50; Ultrafast Rates: OFF. [6].

APPLICATION

Geiger- Muller counter is used in different fields. They are.Nuclear facilities around environmental radiation detection.

i. The soil surface radiation pollution detection.
ii. Agricultural radiation pollution detection.
iii. Ore, building materials radioactive detection
iv. Personal dose monitoring alarm.
v. Industrial X, gamma NDT radiation detection.
vi. Radiation medical treatment place radiation detection.
vii. Cobalt source, electronic accelerator irradiation place radiation detection.
viii. Radioactive radiation laboratory detection. [12].

DISCUSSION

As Geiger-Muller counter is not available in our country we have to buy it from other country but in our project we show how we can make GM counter all by ourselves which make the cost of it very less and the detector is also very efficient.
Here the list of the components with their prices are shown below which shows that we build a very low cost Geiger- Muller counter all by ourselves.

Table:1 Cost of each components in dollars ($)

Serial.No	Item	Quantity	Price (in $)
1	PCB 120 x 50 mm	1	2.38
2	1x CD4011 IC	1	0.238
3	1x 2N3904 Transistor	1	0.036
4	1x 10 Ohm Resistor	1	0.012
5	1x 100 Ohm Resistor	4	0.048
6	4x 1K Ohm Resistor	1	0.012
7	1x 2K2 Ohm Resistor	1	0.012
8	1x 4K7 Ohm Resistor	1	0.012
9	3x 47 K Ohm Resistors	3	0.036
10	1x 220 K Ohm Resistors	1	0.012
11	1x 470 K Ohm Resistors	1	0.012
12	1x 4M7 Ohm Resistor	1	0.012
13	1x 10K Trimmer Potentiometer	1	0.0595
14	2x 1N60 Diode	2	0.024
15	1x 1N4148 Diode	1	0.012
16	3x 1N4937 Diode	3	0.107
17	1x Red Led 3.00mm	1	0.012
18	4x 10nF Multilayer Ceramic Capacitor	4	0.238
19	5x 100nF Multilayer Ceramic Capacitor	5	0.262
20	1x 100pF Multilayer Ceramic Capacitor	1	0.012
21	3x 2.2nF HV Multilayer Ceramic Capacitor	3	0.179
22	2x 10uF Electrolytic Capacitor	5	0.119
23	1x Radial Inductor HV Coil 6x8 size	5	0.0595
24	1x Terminal Block Connector	5	0.0595
25	1x Slide Switch On/Off Button	5	0.0595
26	2x Tube Clips for SBM-20	2	0.119
27	1x Piezo Buzzer	1	0.179
28	1x 14 Pin IC Socket	1	0.095
29	1x Male Header 10 Pins	1	0.095
30	3x Jumper Cups	3	0.179
31	4x Standoff M3	4	0.048
32	4x Screws M3 [6]	4	0.048
33	Arduino 400	1	4.76
34	GM Tube	1	10.71
	Total		**20.08**

By using GM Counter use can perform various analysis like-

i. Determination of Pulse Height vs. Ionization Type and Energy:
ii. Determination of Counting Curve and Pulse Height vs. Voltage.
iii. Determination of Beta Attenuation.
iv. Determination of dead Time and Recovery Time [14].

CONCLUSION

Health physics instruments are designed for a number of different applications, such as routine environmental monitoring; monitoring occupational exposure; measuring contamination of surfaces, air, and water; measuring radon and its progeny; medical radiation measurements; and nonintrusive inspection in the context of anti-terrorism and homeland security. In this project we show how we can make a low cost GM counter which can detect all types of radiation. Our hypothesis was about constructing a low cost GM detector which would be user friendly and efficient as well. Our results do support our hypothesis except the fact about low cost. However, the cost is also justified in its own way . The project was based on GM tube as radiation sensor was more costly and hard to get. If GM tube was available in Bangladesh then we could have easily maintained the low cost. The project can be developed by making it more mobile in collaboration with robot, remote controlled wheeler and drone. As Bangladesh is building nuclear power plants, this project has a greater scope and opportunity. It can be used in safety and safeguard of nuclear power plant for controlling fissile materials as well as in specialized military purposes such as NBC warfare.

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We are also thankful to our all department instructors for teaching us the basic knowledge about this project. We also express our sincere gratitude to all the person involved in bringing the project related material all the way from Russia and specially experts from Bangladesh Atomic Energy Commission (BAEC) to help us in developing this project electrically. Finally, we would like to convey our thanks to our colleague's and classmates for encouraging us in every possible way.

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