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Arduino Based Geiger Muller Counter with SMS Alert System

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Abstract: ***Geiger Muller counter for detection of ionizing radiation was constructed mainly with GM tube and counting system to count tube output radiation signals. The counting system which is one of the important parts of the Geiger Muller counter and it was built with Arduino Uno microcontroller board. Arduino Uno board was used for input pulse signal detection and pulse counting processes by programming with Arduino C language. In this research SD card data logging shield was used to save the measured counts and relevant radiation dose with time stamp. The information of radiation dose (μSv), count per minute (CPM), gained from pulse detecting and counting system was displayed on LCD. One LED flashes and buzzer beeps whenever radiation signals were detected. In addition, GSM module sent SMS to mobile phone according to the program sketching in the Arduino board when Arduino based GM counter detect limited radiation dose rate. In this research firstly function generator (GWINSTEK AFG – 3051) was used instead of GM Tube to feed input signal to pulse detecting and counting Arduino Uno board in order to confirm the program for the detection of input signal which is corresponding to the radiation event. Secondly GM counter high voltage (HV) power supply (≈400 - 506V) was developed for detection of ionizing radiation and counting system in order to count tube output signals. High DC voltage needed for LND-712 was built as high DC voltage bias supply to the anode of GM tube. Pulse counting system was developed to proceed the electric signals, which is generated by GM tube. The counting system detects the signal from the GM tube and the information of radiation dose (μSv), count per minute (CPM), gained from pulse detecting and counting system was displayed on LCD. Arduino, not only open source programmable device but also small the size and design, will give profit on the design and size of radiation detector for the purpose of portable institutional and field inspection of radiation survey meter.***

Keywords: Geiger Muller Counter, Ionizing Radiation, Arduino, Radiation Dose, Count per Minute

1. Introduction

Nowadays, the need to use radioactive sources has been increasing in every country and Myanmar also; therefore radiation safety system, actuate and sensitive detection devices in several institutes, research laboratories, personal radiation monitoring and field of radiation protection essentially need radiation detection instruments. Among the radiation monitoring devices, Geiger Muller counter generally called Geiger counter is a class of radiation detectors which are based on the phenomenon of ionization [1], [2].

The GM counter is a handy device which may be used for counting alpha particles, beta particles, and gamma rays, although with varying degrees of efficiency. The sensitivity of the GM tube is such that any particle capable of ionizing a single atom of the filling gas of the tube will initiate an avalanche of electrons and ions in the tube.

Although most radiation detectors were ordinarily used to detect the sense of radiation, modernized radiation detectors are considered not only for the detection but also scrutiny and sending the information of hazarded radiation area where people should not always stay and monitor this area. One attempt to protect the environment from the increasing of potentially environmental radiation hazards because of an impact of radiation release around nuclear facilities is by a continuous monitoring of the environmental radiation in real time. In this research, GM counter has designed as a nuclear radiation detector with warning system for the application of the radiation field.

The design is based on Arduino program and combined with SD card data logger shield as shown in Figure 1. Arduino is a small microcontroller board and flexible programmable hardware platform designed for artists, designers and the makers of things. Since Arduino is not only open source programmable device but also small size and compact design, Arduino based GM counter can be designed for the purpose of portable institutional and field inspection of radiation survey meter.

Actually, the core language Arduino C is subset version of standard C and another difference between Arduino C and standard C is that the underlying compiler for Arduino C is actually the open source C++ compiler [3]. Thus, electronic and other devices in real world can be controlled by linking with Arduino board dependent of the program uploaded in Arduino microcontroller [4], [5].

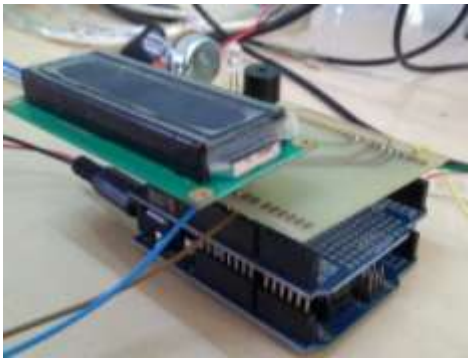

Figure 1: Arduino counting system fixed with data logger shield

2. Radiation Counting System Design

Arduino based GM counter was designed by considering the detection of radiation with alert and warning system for radiation protection. This GM counter provides radiation measurement data and the level of radiation exposure in the radiation field. Authorized users can access the radiation dose on the environment and can respond immediately the public and occupational worker for radiation protection. On the other hand, this counter is also designed to see the information of radiation dose (μSv), count per minute (CPM) displayed on LCD and data saving system. One LED flashes and buzzer beeps whenever radiation signals are detected in order to use as portable radiation detector. Related information of dose rate measured from the radiation detectors is important to send the public or authorities for radiological protection. The block diagram of Arduino based GM counter is shown in Figure 2.

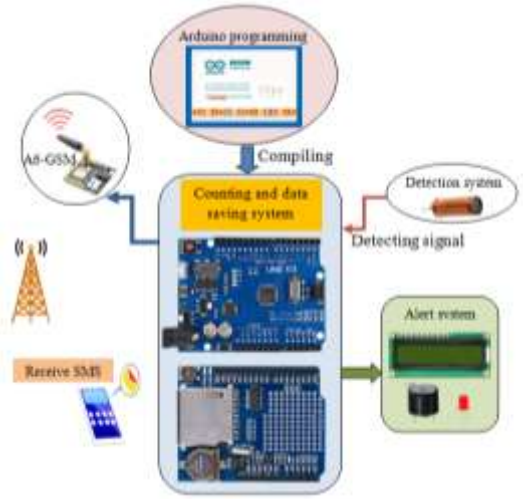

Figure 2: Block diagram of Arduino based pulse counting system

This system is able to send radiation warning SMS to authorized user as related information of dose rate when the limited dose rate is detected by the counter. In addition, all detail measurements of dose rates are collected and saved in SD card with time stamp. Thus, GM counter can be upgraded as a fairly sufficient radiation detector for radiation protection when GM tube is united with flexible programmable counting system, Arduino Uno interface board.

3. Experimental Works of Developed GM Counter

3.1 Programming Arduino C

Arduino is a main component of the counter and microcontroller based board which is supported on the visionary concept of open source hardware and software. It is needed to write sketch or program which is then compiled and uploaded to the microcontroller. The sketch is written in C programming language and the written sketch is verified and compiled by using Arduino IDE.

The main program is to verify the program used in Arduino based GM counter by detecting the signal from the function generator and to save, display and to test alert system with respect to the count rate and dose rate. The program has been sketched in Arduino to define the conversion factor to convert from the output pulse count per minute (CPM) to radiation dose rate ($\mu Sv/hr$). The conversion factor mainly depends on the specification of the Geiger tube. In this research, LND-712 GM tube is intended to use in Arduino based GM counter. In this experiment function generator is used instead of GM Tube output signal to feed input signal to pulse detecting and counting Arduino Uno board.

Actually, signals with various frequencies from the function generator are detected and these signals are converted as count per minute and radiation dose rate to display on the LCD. Besides, the program has to save the measured data in SD card by using data logger shield.

After sketching the program in Arduino 1.6.9, verifying step was firstly done. Defined Arduino input pin is connected to the function generator output. Function generator output is connected with the GWINSTEK GDS-1102A-U digital storage oscilloscope to know and adjust the output wave form of the function generator. Figure 3 shows the complete experimental setup of the pulse counter to verify the input signal is reliable with CPM, dose rate, saving measurement data in SD card, blinking LED and beeping.

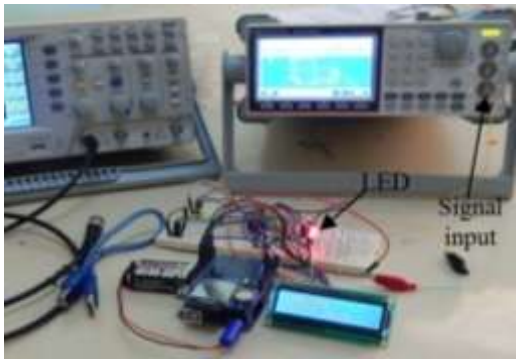

Figure 3: Setup, measurement and testing Arduino Uno output

3.2 Development of High Voltage Bias for GM Tube

Many portable radiation monitors include a GM tube, a simple, two-terminal (anode and cathode), gas-filled detector that generates a pulse each time a radiation event (photon or particle) impinges on the tube's sensitive volume. One problem with GM tubes, however, is their high bias voltage, which is 1000V depending on the tube design and the mixture of gases used [6].

According to the specification of LND-712 GM tube used in Arduino based GM counter, it operates in the voltage range of 450-650 V [7]. Therefore, step up switch mode power supply (SMPS) with nine stage voltage multiplier is firstly built to bias the GM tube. The schematic circuit diagram of high voltage bias supply for LND-712 is shown in Figure 4.

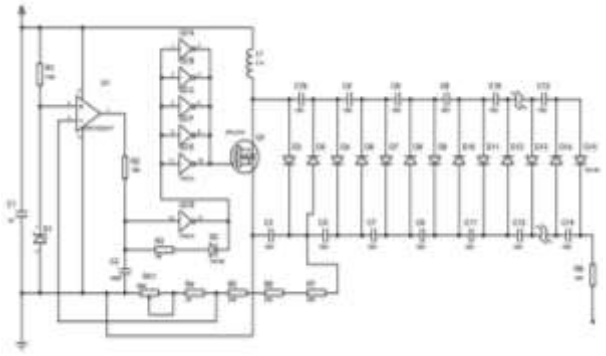

Figure 4: Schematic circuit diagram of high voltage power supply

The circuit diagram for this HVPS shown in Figure 4 is based on switch mode (boost) power supply (SMPS). This power supply uses pulse width mode (PWM) DC to DC boost converter which is based on switch mode power supply. In the circuit, power MOSFET IRFL-4310 is used in power switching. A switching converter operates in the principle of continuously turning on and off a semiconductor switch. Turning on means MOSEFET in saturation and turning off means operating in cut off current. Driving the semiconductor switch to saturation and cut off is made possible through a PWM controller. 74HC14 hex inverters with schmitt trigger inputs and MAX4162 chip control the on/off stage of the switch by PWM with 200 kHz frequency [8]. When the PWM is high MOSFET Q1 saturates, the switch Q1 will turn on and this time the inductor L1 will charge as shown in Figure 5(a). When diode D3 will be reversed biased, the load will rely only to the charge on the capacitor C3. When the PWM signal is low shown in Figure 5(b), Q1 will cut off. The inductor will resist a sudden change in current thus it will reverse its polarity to support the same current direction.

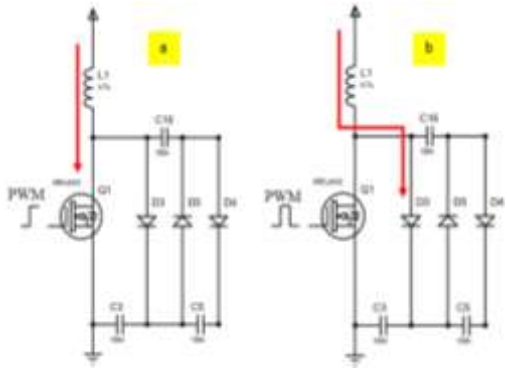

Figure 5(a): Current direction when the PWM is high
(b): Current direction when the PWM is low

D3 will be forward biased and C3 will replenish its charge and the load will drive its power from the input. The reversal in the polarity of the inductor creates a voltage level of higher than the input boost effect.

Then the out voltage is multiplied up to 506V at no load condition. The high voltage output is conducted to the anode of the GM tube through 10MΩ resistor. The circuit is powered by a 9V battery but regulated at 5V supply and is also powered for counting system and alert system are also powered. The composition of these ICs on the printed circuit board including pulse shaper is shown in Figure 6.

Figure 6: High voltage power supply PCB for GM tube

3.3 Composition of Pulse Shaping

When high voltage DC power is connected to a Geiger–Muller tube (LND 712), an ionizing radiation strikes the tube; some molecules of the fill gas are ionized, either directly by the incident radiation or indirectly by means of secondary electrons produced in the walls of the tube.

This creates positive charged ions and electrons, known as ion pairs, inside the tube. The strong electric field created by the tube's electrodes accelerates the positive ions towards the cathode and the electrons towards the anode [9], [10].

The ionization is amplified within the tube by Townsend avalanche phenomenon to produce an easily measured detection pulse. The pulse produced at the output of a radiation detector has to be modified or shaped for better performance of the counting system. In this case the Arduino program has been defined that the signal from the GM tube has to be digital read pin of the Arduino based pulse counting system.

Therefore, schmitt trigger 4093 NAND gate was applied in pulse shaping circuit to turn a short input pulse into a square pulse. Figure 7 shows the circuit diagram of pulse shaper and the output is connected to the external interrupts pin 2 of the Arduino board. This pin configure to trigger an interrupt on a low value, a rising or falling edge, or a change in value according to the attach interrupt function in the program.

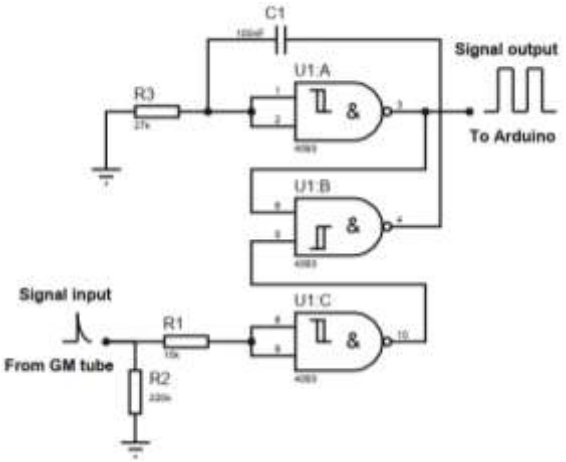

Figure 7: Schematic circuit diagram of pulse shaper

3.4 Testing Arduino Based GM Counter with Radiation Source

In the Arduino based GM counter, rechargeable 9V battery is applied to supply all components used in the counter such as HV supply for GM tube, counting system, radiation alert system that is sending SMS, audible and visible components. The output voltage range of HV bias supply (425 to 506 VDC) is sufficient to operate LND-712. The experimental set up of Arduino based GM counter is shown in Figure 8.

Figure 8: Experimental set up of Arduino based GM counter

In this case, HV bias supply is powered through 5V regulator IC 7805. After confirming the HV power supply 10 μCi Cs-137 radioactive source is positioned by varying the distance between source and GM tube. The distances measured in centimeter between GM tube and radiation source are 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 18, 21 and 25 cm respectively. Dose rate measurement is carried out for two minutes for every distance. This step of experiment is to read all measurement data directly on the counter and to save the data in the SD card.

The data saving in the SD card is then analyzed with respect to the measured distances. While measuring the radiation source for every distance, buzzer and LED properly perform as various levels of radiation dose (CPM) which is programmed in microcontroller.

Next step is testing to send SMS which is warning level of radiation dose by using GSM module. In this case the warning SMS for limited radiation dose is sent to the fixed phone number.

4. Results and Discussion of Arduino Based GM Counter

4.1 Verifying Program with Function Generator of Pulse Counting System

Square waves with various frequencies are fed to Arduino pulse counting system as input signal. The counting results are shown in Table 1. From the table, it is clearly seen that the input square wave with lower frequencies 1 Hz and 10 Hz are correctly detected by the pulse counting system. And then the higher the frequencies of the wave the pulse counting system detect the larger errors between the detected and expected counts. But the maximum error does not exceed 0.3% although changing the duty cycle of the wave. In most cases of measurement, a percent error or difference of less than 10% can be acceptable because of systematic error, random error and personal error. If the measured counts and expected counts show a difference of more than 10% error, there is a great possibility that some mistake has occurred. By seeing these results saved in SD card, the program properly works to detect and convert the signal into count per minute for Arduino based GM counter.

Table 1: Counting pulses with various frequencies and duty cycles

Frequency (Hz)	*Duty cycle (%)*	*Measured Counts (CPM)*	*Average measured counts (CPM)*	*Expected Counts (CPM)*	*Error (%)*
1	20	60	60	60	0
	50	60			
	80	60			
10	20	600	600	600	0
	50	600			
	80	600			
50	20	2994	2994	3000	0.2
	50	2994			
	80	2994			
100	20	5988	5988	6000	0.2
	50	5988			
	80	5988			
1k	20	59844	59845	60000	0.26
	50	59844			
	80	59844			
10k	20	598170	598174	600000	0.30
	50	598176			
	80	598170			

4.2 Bias Supply Measurement

A typical result of SMPS bias supply voltage for GM tube is 506V at no load condition. The high voltage output is conducted to the anode of the GM tube through 10MΩ resistor. When high voltage bias supply is conducted to the GM tube by connecting 10MΩ resistor, the voltage drops to 335V. After continuous measurement of radiation for 35 minutes, then the output voltage of bias supply measured with 10MΩ resistor drops to 483V as shown in Figure 9. As a result, the voltage drop after measuring 35 minute is still in the operating voltage rage of LND- 712 GM tube (450V - 650V). Therefore high voltage bias supply is fitting to power LND-712 GM tube. The circuit is powered by a 9V alkaline battery but regulated at 5V supply and is also powered for

counting system and alert system are also powered. By using this high voltage bias supply Arduino base GM counter continuously measures the radiation source with all electronic components in intense radiation. This measurement takes about 2 hours and 14 minutes and Figure 10 shows the count rate measured with 9V alkaline.

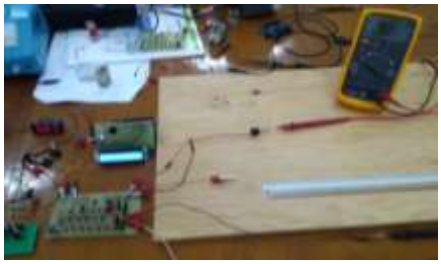

Figure 9: Output voltage of bias supply measured with 10MΩ resistor drops to 483V

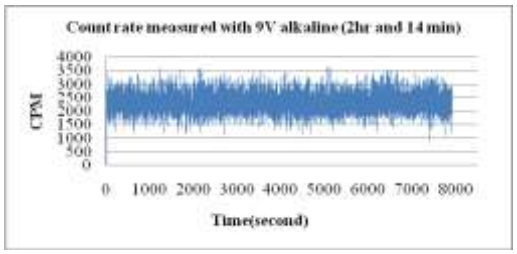

Figure 10: Count rate measured with 9V alkaline battery within 2 hours and 14 minutes.

4.3 Pulse Shaper Output

After powering HV to the GM tube, the output signal of the tube is shaped into digital pulse by using pulse shaper circuit in order to feed as the input signal of Arduino counting system. In this case digital input voltage range of Arduino is 3.3V to 5V and the digital read mode pin has been defined by the program for Arduino based GM counter. Therefore, the output signal from LND-712 GM tube is modified by pulse shaper. Figure 11(a) shows the GM tube output pulse and Figure 11(b) shows the result of 5V output the pulse after passing through the pulse shaping circuit. Thus, the property output signal of pulse shaper is acceptable range of Arduino counting system.

Figure 11: (a) Output pulse from GM tube, (b) output pulse after passing through the pulse shaping circuit

4.4 Measurement of Data Analysis

Table 2 shows the saved data in the SD card for all measurements of Arduino based GM counter when Cs-137 source is placed at various distances. When these measured results are graphed, count rate decreases with increasing the measured distances shown in Figure 12. According to the result of the measurement, the count rate goes fall (decrease) when the source is far from the GM counter. The result follows the principle of controlling harmful ionizing radiation exposure time, distance and shielding.

Table 2: Measurement of dose rate with various distances between Cs-137 source and GM tube

Distance (cm)	*Average dose rate (CPM)*
3	903.5
4	630.5
5	461.0
6	363.5
7	292.5
8	221.5
9	195.5
10	166.0
11	138.0
12	121.5
13	116.5
14	104.5
15	98.5
18	69.5
21	48.5
25	46.0

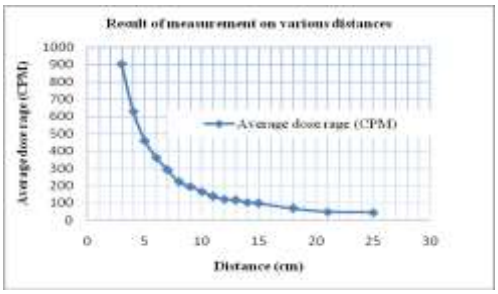

Figure 12: Decreasing dose rate with increasing distance

In the measurement of Arduino based GM counter, considering a point source, a point source of radiation emits in all directions on the source. It follows that the intensity of the ionizing radiation decreases with distance from the source because the rays are spread over greater areas as the distance increases. Any point source which spreads its influence equally in all directions without a limit to its range will obey the inverse square law. The inverse square law is important and can verify as it gives a measure of how the intensity of radiation falls off with distance from a source. Therefore, the saved data is then graphed with inverse square law as shown in Figure 13.

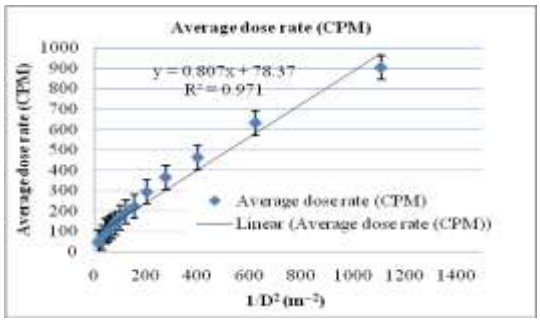

Figure 13: Plotting dose rate following inverse square law of radiation

In Figure 13, linear trend line in the graph shows that how the dose rate data follows the inverse square law of radiation. A trend line, often referred to as a line of best fit, is a line that is

used to represent the behaviour of a set of data to determine if there is a certain pattern. A trend line is most reliable when its R-squared value is at or near 1. Therefore, this graph shows that the count rate saved by counting system verified the right measurement radiation with Arduino based GM counter since R-squared value is 0.976.

4.5 Sending and Receiving SMS to Mobile Phone

There are two ways of connecting GSM module to Arduino for sending SMS, first way is using serial pins of Arduino RX and TX and second way is using two digital pins of Arduino. In any case, the communication between Arduino and GSM module is serial. In this counter, the first method is used for sending SMS. RX pin of GSM module is connected pin 1 named TX of Arduino and TX pin of GSM module to pin 0 named RX of Arduino for serial communication. Serial communication is a process of sending and receiving bytes of data in a sequential manner [5]. One of the main functions, sending alert SMS for limited radiation dose rate is 1404 CPM equivalent to 11.4 $\mu Sv/hr$. This limitation is based on international commission on radiation protection (ICRP) dose limit for public exposure 1 *mSv* in a year [13].

Another result of Arduino based GM counter is sending warning message for limited radiation dose rate and receiving SMS in mobile phone by using GSM module and local mobile network operator. In this case, setting of main program for warning SMS activated after detecting 5 seconds whenever the counter detects the warning level of dose rate. Then, GSM module will automatically send SMS as the information of radiation alert to authorized person through local network. The visual result of this feature in mobile phone is shown in Figure 14.

Figure 14: Visualization SMS from warning system

5. Conclusion

This research and try out of the Arduino based GM counter can be comparable with other ordinary GM counter according to the result of the experiment. In this research paper, development of Arduino based Geiger Muller counter with SMS alert system was carried out to fulfill the need of biasing power supply of GM tube (LND-712). Switch mode power supply (SMPS) is constructed and the high voltage power supply (HVPS) generates the required 500 VDC for GM tube by using 9V battery.

Then, a series of radiation detection experiment was carried out to validate the working accuracy of developed radiation pulse counting system. The detection measurement results proved that the detection system follows the intensity of radiation decreases with increasing of distance between detector and radioactive source. The GSM module was integrated to send SMS to the pulse counting system when the developed system discovers the incoming pulse is beyond the predefine radiation dose limit. It takes five seconds to send SMS warning to the authorized phone number.

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