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Design and Fabrication of a Dosimeter for Measuring Ionizing Radiation

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Abstract: This article presents the results of a research on design and fabrication of a dosimeter for measuring ionizing radiation using detector Geiger-Muller. The microcontroller ARM STM32F103 – based device is programmed with some working modes. The collected signal from the detector is converted, displayed on LCD and restored in external memory. The device can also be interfaced with a computer via serial port for transferring data. Through measuring level of radiation in natural environment and a source of artificial radioactivity, testing operations and surveying Poisson distribution, it shows that our device operates stably, fits to the theory and it can be used for radiation safety monitoring application as well as a laboratory equipment.

Keywords: Radiation measurement equipment, Geiger-Muller counter.

1. Introduction

Nowadays, the need to use radioactive sources has been increasing in Vietnam; hence, the requirements of radiation safety are very necessary. There are several institutes, such as Institute for Nuclear Science and Technology (INST), Nuclear Research Institute (NRI) that can produce or repair nuclear electronic equipment in general or radiation measurement devices in particular. Through surveys we have found that, the majority of the devices has been imported and they are expensive. This leads to a lack of initiative, reliance on imported technologies as well as being money – consuming.

In the other hand, with the development of semiconductor technology, many integrated circuits with low power, low price, high customization ability via programming are launched. These advances allow the design and fabrication of measurement devices with low cost, compact size and high performance.

This article presents the results of designing and fabricating a portable dosimeter using Geiger – Muller tube [1][3] in combination with a microcontroller and some integrated circuits.

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2. System design

Block diagram

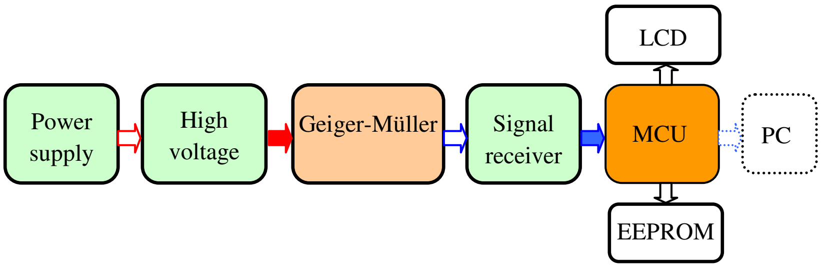

Figure 1. Block diagram.

When the system works, a DC power is connected to a high voltage converter. Through the converter, a DC high voltage several hundred volts is created and fed to the Geiger–Muller tube (LND7121). When 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 [2][3]. The ionization is amplified within the tube by Townsend avalanche phenomenon to produce an easily measured detection pulse. The pulses are detected, and shaped by an external circuit [3] and then they are received and digitized by a microcontroller unit (MCU). The converted data are displayed on a liquid crystal display (LCD), stored in external memory electrically erasable programmable read-only memory (EEPROM). The system also supports a serial connection for transferring data to a computer (PC).

Circuit diagram

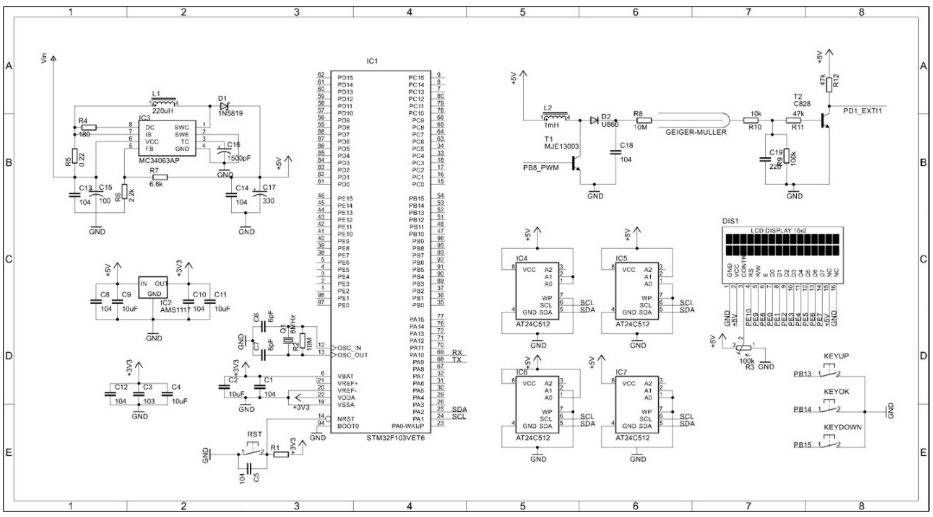

Figure 2. Schematic of the system.

Modes of operation

The device is programmed and controlled via the microcontroller unit ARM STM32F103 with three modes, which are “Write to EEPROM”, “Read EEPROM”, and “Clear EEPROM” as described in the left flowchart in the figure 3.

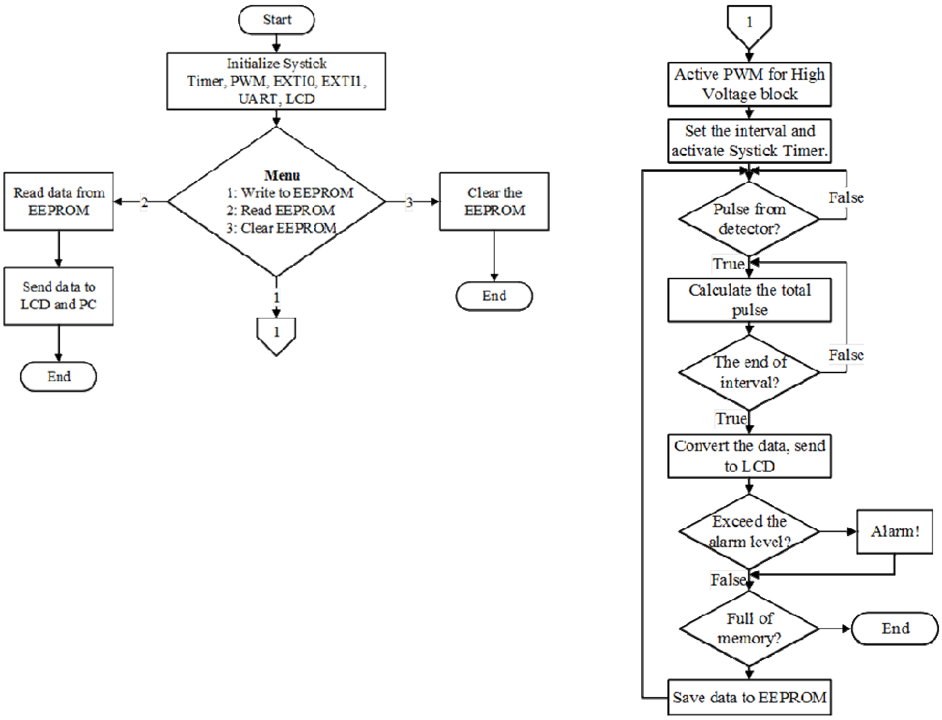

Figure 3. The system flowchart.

When the device is powered up, the system initiates the systick timer for calculating time, the pulse width modulation (PWM) for generating high frequency to the high voltage converter, the external interrupt (EXTI0) for counting the pulse, the UART for communicating with PC and the LCD for displaying information. The device’s working modes are displayed on the LCD, user can select one of the modes via a button.

With the mode “Write to EEPROM”, the whole operations of the system are described in the right flowchart in the figure 3. In this mode, the system measures and writes the achieved data to EEPROM. Firstly, the system activates PWM for generating high voltage then it sets a time interval and activates the systick timer for measuring. Secondly, the pulse from Geiger-Muller detector is detected and the total of pulses is calculated in the time interval. Next, the achieved data is shown on LCD and compared with a safety level for alarm. Finally, the EEPROM’s empty spaces are checked for saving data. The system’s process continues until the memory are full.

With the mode “Read EEPROM”, the data from EEPROM is read and transferred to PC via a serial port.

If the mode “Clear EEPROM” is selected, the whole data in the EEPROM will be cleared completely.

The actual device is shown at the figure 4 with specifications in table 1.

Figure 4. The first version in a working mode.

Table 1. The device specifications.

Type of radiation	Gamma
Display	LCD
Interfacing	COM
Memory	4 x 512Kb
Power supply	DC 3.7 – 9 V
Gamma sensitivity Co60	18 cps

3. Results and discussion

Measurement of environmental radiation

With the equipment we have made, we proceed m = 300 measurements at the Department of Computational Physics, Faculty of Physics, Hanoi University of Science. The time for each measurement is one minute. N is denoted as the number of received pulses in one minute. The obtained results are shown below.

$$N_{min} = 11\ cpm$$

$$N_{max} = 46\ cpm$$

$$N = \overline{N} \pm \Delta N = \frac{\Sigma N_i}{m} \pm \frac{\Sigma |N_i - \overline{N}|}{m} = 23.8 \pm 4.76\ cpm$$

$$\frac{\Delta N}{\overline{N}} = 19.98\ \%$$

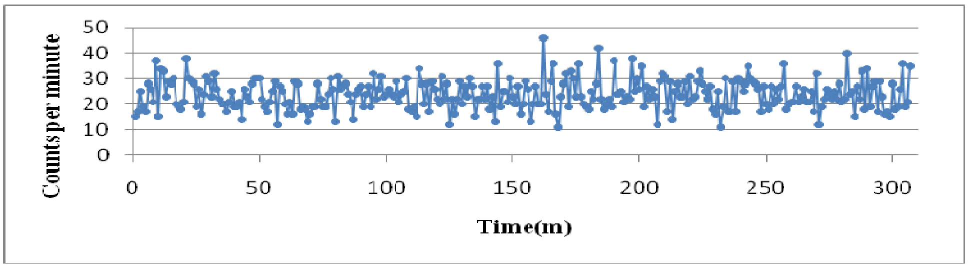

Figure 5. The environment radiation measured in 300 minutes.

The conversion coefficient of Geiger – Muller tube LND7121 is 18 *counts per second* (*cps*) = 1 mR/h [4]. If we consider that in one minute, the counting speed does not change, we have 1080 *counts per minute* (*cpm*) = 1 mR/h, 1R = 2.58 * 10^{-4} C/kg. As for tissue and considering the gamma radiation has the energy from 0.1 MeV to 3 MeV, then the conversion coefficient between exposure dose and absorbed dose is 1R = 0.96 rad [5], 1 rad = 0.0096 Gy. Since the biological effect of each kind of radiation is different in property and energy. Therefore, in order to estimate the danger of radiation, the equivalent dose quantity is used. The relation between equivalent dose and absorbed dose is given by:

$$\mathbf{H} = \mathbf{D} * W_R \qquad (1)$$

Where:

H is equivalent dose absorbed by tissue

D is absorbed dose in tissue

W_R is radiation weighting factor defined by regulation

For the gamma rays $W_R = 1$, so 1cpm = 0.008889 $\frac{\mu Sv}{h}$. Therefore, the equivalent dose of environmental radiation can be caculated. The result is:

$$H = \bar{H} \pm \Delta H = 0.21 \pm 0.04 \ (\mu Sv/h)$$

The result is a little bit less than the environmental radiation in normal condition (2.4 $\frac{mSv}{year}$ or 0.27 $\frac{\mu Sv}{h}$). This can be explained as the following.

The measurement has processed in our laboratory. Therefore, the environmental radiation rays are partially absorbed when they pass though building structures, such as wall, ceiling.

The dead time of Geiger – Muller tube is approximate $10^{-4} s$. In this interval, the tube is not sensitive to an entering radiation. This makes the number of received pulses are not equal to the number of entering radiation; therefore, it reduces the received result. However, in case of measurement of environmental radiation, influence of the factor is negligible because of environmental radioactivity is small.

In the environmental radiation, there is not only gamma radiation but also many other types of radiation such as beta, alpha. The Geiger – Muller tube used in this report is only sensitive to gamma radiation, it does not have an ability to recognize different types of radiation. Therefore, the obtained results are smaller than the actual results.

Moreover, the conversion coefficient of the tube is standardized using Cobalt-60; hence, it always has errors when the tube is applied in the environment where other radiation sources exits.

Measurement of radiation sources

Using the device for measuring Cobalt-60 sources produced by Spectrum Techniques (USA) with the radioactivity is 0.695μ Ci at the experiment time, each measurement was processed in one minute. The total of obtained results was included environmental radiation. After that do the experiment again without the source for receiving the number of radiation from background.

Consider N as the total of obtained radiation, N_2 as the number of radiation from background and N_1 as the number of radiation from Co – 60. N_1 can be calculated by $N_1 = N – N_2$.

The received results are shown in the table 2.

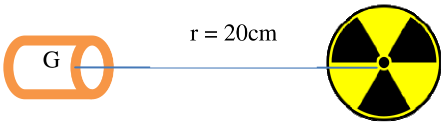

Figure 6. The mode for measuring radiation source Cobalt-60.

Table 2. The experimental result.

Detector	N (cpm)	N_2 (cpm)	N_1 (cpm)	H_1(μSv/h)
G	45.90±5.72	24.20±2.56	21.70±8.28	0.19±0.078
Theory				0.22

The difference between experiment and theory is $\Delta H = 0.0273\ \frac{\mu Sv}{h}$. It is equivalent to 12.398%. For radiation measurements, the result is acceptable.

Survey of Poisson distribution

Measuring with a radiation source Cesium – 137, the radioactive is 170.605 kBq at the experiment time, with 246 continuous measurements. Each measurement was performed in 15 seconds, the obtained results are shown below.

$$N_{min} = 8 = 32\ cpm$$

$$N_{max} = 35 = 140\ cpm$$

$$N = \bar{N} \pm \Delta N = \frac{\Sigma N_i}{m} \pm \frac{\Sigma |N_i - N|}{m} = 19.02 \pm 4.18 = 76.11 \pm 16.72\ cpm$$

$$\sigma = \sqrt{\sum \frac{(N_i - \bar{N})^2}{m-1}} = 5.34 = 21.36\ cpm$$

Since the number of gamma rays from the source is a random quantity and it obeys Poisson distribution, so the gamma rays coming to the sensitive volume of detector is also obeyed the Poisson distribution. In order to verify the reliability and stability of equipment, the result need to be fitted with the Poisson distribution. We conduct the experiment and classify the data into 10 intervals, each interval has 3 counts, beginning from $N_{min} = 8$ to $N_{max} = 35$. The results are presented at the table 3 and figure 7 below.

Table 3. The distribution of obtained radiation from the source

Counting Interval	8-10	11-13	14-16	17-19	20-22	23-25	26-28	29-31	32-34	35
Number of the counts per 15 seconds	5	26	45	60	43	31	16	10	2	2
Frequency(%)	2.08	10.83	18.75	25.00	17.91	12.91	6.66	4.16	0.83	0.83

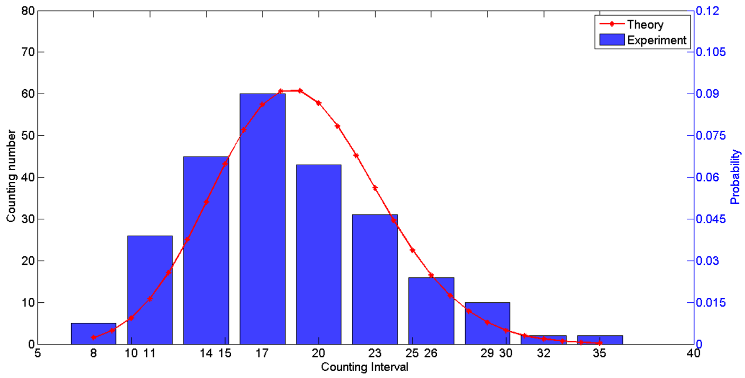

Figure 7. The histogram of counts.

The value $\overline{N}$ = 19 = 76 *cpm* is in the interval at which has the most probability. According to the Poisson distribution, the standard deviation of N quantity is $\sigma = \sqrt{\sum (N_i - \overline{N})^2 / (m-1)} = 5.34 = 21.36\ cpm$. Figure 7 also shows that the result (bars) is relatively compatible with Poisson distribution pattern (dot line). That result is acceptable; however, there is small difference between experiment and theory. This can be explained by the following.

The measurements were performed in normal conditions without shielding. In this experiment, we supposed that the environment radiation is constant, but the radiation background we got above is not constant. This will affect the result.

As mentioned above, the counting tube Geiger-Muller has the dead time. The tube is not sensitive to entering radiation in this time. This makes the number of received pulses are not equal to the number of entering radiation; therefore, it reduces the received result.

4. Conclusion

Through tests on measurement of radiation background, radiation sources, Poisson distribution and working time, it shows that the device works stably, the result on tests fit to theory.

The device has been designed and fabricated portability. It is integrated some functions, such as storing obtained data, PC interfacing. The device can be used for surveying, monitoring radiation as well as a measuring equipment in a laboratory.

Acknowledgements

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