Computer Based Radioactivity Measurement with Acquisition and Monitoring Radiation Data Using LabVIEW

A thesis submitted to Electrical and Electronic Engineering Department of Bangladesh University of Engineering and Technology in partial fulfillment of the requirement for the degree of Bachelor of Science (B.Sc.) in Electrical and Electronic Engineering (EEE)

By

Masudul Hassan Quraishi
Department of EEE
Student no: 0706007
Session: 2010-11

&

Md. Aminul Hoque
Department of EEE
Student no: 0706042
Session: 2010-11

Under the supervision of

Dr. Mohammad Jahangir Alam

Professor

Department of Electrical and Electronic Engineering

Bangladesh University of Engineering and Technology (BUET)

Dhaka, Bangladesh

Declaration

This is to certify that this thesis work on **Computer Based Radioactivity Measurement with Acquisition and Monitoring Radiation Data Using LabVIEW** has been carried out by the authors under the supervision of Professor Dr. Mohammad Jahangir Alam, Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh and it has not been submitted elsewhere for award of any degree or diploma.

Signature of the authors

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Masudul Hassan Quraishi

____

Md. Aminul Hoque

Signature of the Supervisor

____

Dr. Mohammad Jahangir Alam

Professor

Department of Electrical & Electronic Engineering

Bangladesh University of Engineering and Technology (BUET)

Dhaka, Bangladesh

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Last but not least, thanks to God for offering us a bountiful life and giving us enough strength to pass the tests.

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Abstract

This thesis presents preparing high voltage for Geiger counter along with data acquisition and monitoring technique by LabVIEW. The data here is radiation data from GM counter. Radioactive material emits radiate energy. The more radioactive the material is the more energy pulses it emits in a given period. A GM counter detects those pulses and gives a proportional voltage as output. This output voltage is connected to NI DAQ card which is connected to computer. The interface between hardware and computer is done by LabVIEW. LabVIEW is a graphical programming language developed by National Instruments to acquire data, display signals, control devices and automate instruments. In this work, LabVIEW is used to analyze and display live data in the lab as well as at the remote Locations through PC. LabVIEW code counts the number of peaks of the input signal which is proportional to radio activity of a material, in a given period and stores it in the data file. The input data is displayed as plot of count vs. time in the front panel of the LabVIEW while it is being measured.

Data acquisition code stores data according to hours of a day. The amount of hours passed is automatically saved along with the radio activity data of the material being measured. Saved data can be viewed any time by the user from LabVIEW. The LabVIEW applications developed specifically for this work are also described in detail in this thesis.

Chapter 1
Introduction

1.1 Background

Radiation is the energy that comes from a source and travels through some material or through space. Light, heat and sound are types of radiation. But the kind of radiation this thesis is mostly concerned is ionized radiation. Ionized radiation is produced by unstable atoms which contain excess of energy or mass. The importance of detecting natural radiation is that certain radiations are harmful for environment. As ionized radiation is used in diagnosis of diseases, medical and scientific researches and nuclear power plants, detection of radiation is an important task.

The most commonly known types of ionizing radiation are alpha, beta, gamma, X and neutron rays. Radioactive material emits ionizing radiation without having been subject to any external influence. The type of radiation emitted and its associated energy is characteristic for the kind of radioactive substances. Although ionizing radiation has been present in nature throughout man's history, it remained unnoticed until less than 100 years ago [3]. Tools for detecting ionizing radiation were in existence rather early; the phenomenon of thermo luminescence was first described in the 17th century. The gold-leaf electroscope was invented in the 18th century.

The effects discovered in the early research work with X-rays and radioactive materials remain the underlying principles of radiation detection into modern times. Detection instruments have been improved many times over the years and numerous investigators have contributed to a tremendous development.

Over a period of less than a century, nuclear radiation detectors have steadily extended human senses into entirely new realms. A great many reliable instruments for detecting and measuring ionizing radiation are now available, ranging from instruments that are widely used as routine tools in nuclear laboratories, to highly sophisticated complex instrument systems designed for very special applications. They have also served the beneficial application of radiation in medicine, industry and research, and also the control of any hazards that might arise from ionizing radiation.

1.2 Objective of the Thesis

The objective of this thesis project is to implement a cost effective Radioactive Measurement System. It has been implemented using DAQ and LabVIEW to record the data and store in a computer. For making this project cost effective, Geiger Muller radiation detector has been used. The high voltage generation circuit mainly consists of a simple transformer and passive elements such as capacitors, diodes and resistors. The key idea is to develop a cheap hardware which can detect radiation up to a satisfactory accuracy and also to record the data into a secure database with easy access.

Radiation detection and measurement is necessary for a wide variety of people working with radiation in two ways. First, they need to know basic concepts of radiation effects to handle radioactive materials safely and secondly to make research in any field related with radiation. The equipment and laboratory setup needed for radioactivity measurement are expensive and difficult to assemble due to the large variety of the type of experiments that are desirable to cover. First of all, in a basic laboratory, one needs to have gamma, beta, alpha and neutron sources, at least one detector to detect each type of radiation and other supplemental instrumentation to perform experiments [1]. Furthermore shielding and a private secured place are needed due to protect people from the effect of these radioactive sources. Nearly two hundred thousand dollars is needed to construct such a basic laboratory described as above [2]. This project based on LabVIEW is a good, inexpensive and easy to use solution for Radiation Detection and Measurement in the industries, power plants, hospitals or in laboratories.

The whole process can be subdivided into four basic blocks: First of all, the radio activity of particles is measured by a Geiger Muller gas detector. Every radio-active particle radiate energy. One needs to convert this energy into voltage in order to detect the radio activity [1]. For this purpose Geiger Muller gas detector is used. It gives us pulses which is a function of radioactivity of that particle. Radio activity is a function of the pulse genereted by the particle. The more pulse a particle generates at a given time the more radio active the particle is. For example, if particle A gives 10 pulses in 1 hour and particle B gives 1000 pulses in 1 hour, then particle B is 100 times more radio active than particle A.

The pulse from gas detector is then connected to DAQ card NI USB 6009, which is installed in a PC. After that LabVIEW programme is used to make interface between DAQ card and PC to measure radio activity. It measures the pulses for peak. Then it counts the number of peaks for a given time and stores it in the PC. The radio activity of a material is propotional to the number of pulses it generates at a given time. Then recorded radio activity data can be observed at a given month from LabView code and it can also be stored in the PC.

1.3 Thesis Layout

This thesis consists of Seven Chapters. Chapter 1 describes the background and objective of the thesis. Chapter 2 describes the basic mechanism of radiation. Chapter 3 describes different detection techniques. From chapter 4 through to chapter 6 the detailed procedure of radiation detection (Gamma radiation) using Geiger Muller gas detector is described, along with data acquisition through DAQ and LabVIEW is thoroughly discussed. Chapter 7 consists of the application of the thesis project and it suggests the future developments and possibilities of this thesis. Finally this thesis concludes with list of references.

Chapter 2
Familiarization with Radioactivity

2.1 Radiation

Radiation is a process in which energetic particles or energetic waves travel through vacuum, or through matter-containing media that are not required for their propagation. Waves of a massive medium itself, such as water waves or sound waves, are usually not considered to be forms of "radiation" in this sense [3].

Two energies of radiation are commonly differentiated by the way they interact with normal chemical matter: ionizing and non-ionizing radiation. The word radiation is often colloquially used in reference to ionizing radiation (i.e., radiation having sufficient energy to ionize an atom), but the term radiation may correctly also refer to non-ionizing radiation (e.g., radio waves, heat or visible light). Because radiation radiates through space and its energy is conserved in vacuum, the power of all types of radiation follows an inverse-square law of power with regard to distance from its source.

Both ionizing and non-ionizing radiation can be harmful to organisms and can result in changes to the natural environment. In general, however, ionizing radiation is far more harmful to living organisms per unit of energy deposited than non-ionizing radiation, since the ions that are produced by ionizing radiation, even at low radiation powers, have the potential to cause DNA damage. By contrast, most non-ionizing radiation is harmful to organisms only in proportion to the thermal energy deposited, and is conventionally considered harmless at low powers which do not produce significant temperature rise.

2.2 Types of Radiation

As mentioned before, radiation phenomenon can be classified into two main categories:

i. Ionized radiation
ii. Non-ionized radiation

i. **Ionized radiation:** Radiation with sufficiently high energy can ionize atoms. Most often, this occurs when an electron is stripped from an electron shell, which leaves the atom with a net positive charge. Because cells and more importantly the DNA can be damaged, this ionization can result in an increased chance of cancer, and thus "ionizing radiation" is somewhat artificially separated out of particle and electromagnetic radiation, simply due to its larger potential for biological damage per unit of energy.

Ionizing radiation comes from radioactive materials, X-ray tubes, particle accelerators, and is present in the environment. It is invisible and not directly detectable by human senses, so instruments such as Geiger counters are usually required to detect its presence. It has many practical uses in medicine, research, construction, and other areas, but presents a health hazard if used improperly. Exposure to radiation causes damage to living tissue, resulting in skin burns, radiation sickness and death at high doses and cancer, tumors and genetic damage at low doses [3].

Ionizing electromagnetic radiation is that for which the photons making up the radiation have energies larger than about 10 electron volts. The ability of an electromagnetic wave (photons) to ionize an atom or molecule thus depends on its frequency, which determines the energy of a photon of the radiation. Radiation on the short-wavelength end of the electromagnetic spectrum with a wavelength of 125 nm or less is ionizing (lower wavelength means higher frequency and higher energy). This includes extreme ultraviolet, X-rays, and gamma rays [4]. There are mainly three types of ionized radiation: alpha (α), beta (β) and gamma (γ) rays.

a. **Alpha:** Alpha particles are helium-4 nuclei (two protons and two neutrons). They interact with matter very heavily, and at their usual velocities only penetrate a few centimeters of air, or a few millimeters of low density material (such as the thin mica material which is specially placed in some Geiger counter tubes to allow alpha particles in). This means that alpha particles from ordinary alpha decay do not penetrate skin and cause no damage to tissues below. Some very high energy alpha particles compose about 10% of cosmic rays, and these are capable of penetrating the body and even thin metal plates.

Alpha radiation is dangerous when alpha-emitting radioisotopes are ingested (breathed or swallowed). This brings the radioisotope close enough to tissue for the alpha radiation to damage cells. Per unit of energy, alpha particles are at least 20 times more effective at cell-damage as gamma rays and X-rays.

b. **Beta:** Beta-minus (β−) radiation consists of an energetic electron. It is more ionizing than alpha radiation, but less than gamma. Beta radiation from radioactive decay can be stopped with a few centimeters of plastic or a few millimeters of metal. It occurs when a neutron decays into a proton in a nucleus, releasing the beta particle and an antineutrino.

   Beta-plus (β+) radiation is the emission of positrons, which are antimatter electrons. When a positron slows down to speeds similar to those of electrons in the material, the positron will annihilate an electron, releasing two gamma photons in the process. Those two gamma photons will be traveling in (approximately) opposite directions.

c. **Gamma:** Gamma (γ) radiation consists of photons with a frequency of greater than 1019 Hz.[3] Gamma radiation occurs to rid the decaying nucleus of excess energy after it has emitted either alpha or beta radiation. Both alpha and beta particles have an electric charge and mass, and thus are quite likely to interact with other atoms in their path. Gamma radiation is composed of photons, which have neither mass nor electric charge. Gamma radiation penetrates much further through matter than either alpha or beta radiation.

   Gamma rays, which are highly energetic photons, penetrate deeply and are difficult to stop. They can be stopped by a sufficiently thick layer of material, where stopping power of the material per given area depends mostly (but not entirely) on its total mass, whether the material is of high or low density.

ii. **Non-ionizing radiation:** The energy of non-ionizing radiation is less and instead of producing charged ions when passing through matter, the electromagnetic radiation has only sufficient energy to change the rotational, vibrational or electronic valence configurations of molecules and atoms.

Even "non-ionizing" radiation is capable of causing thermal-ionization if it deposits enough heat to raise temperatures to ionization energies. These reactions occur at far higher energies than with ionization radiation, which requires only single particles to ionize. A familiar example of thermal ionization is the flame-ionization of a common fire.

The electromagnetic spectrum is the range of all possible electromagnetic radiation frequencies. [3] The electromagnetic spectrum (usually just spectrum) of an object is the characteristic distribution of electromagnetic radiation emitted by, or absorbed by, that particular object. An illustration of the electromagnetic spectrum is given below (figure 2.1):

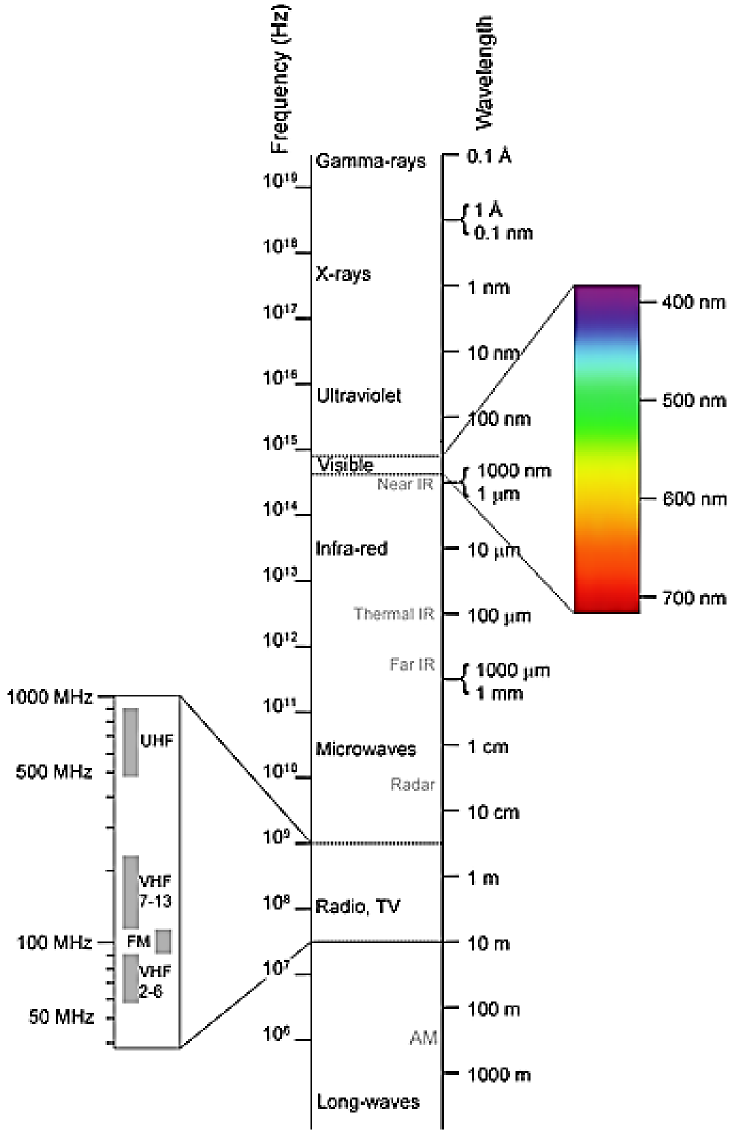

Figure 2.1: Electromagnetic Spectrum

2.3 Historical Background

Electromagnetic radiations of wavelengths other than light were discovered in the early 19th century. The discovery of infrared radiation is ascribed to William Herschel, the astronomer. Herschel published his results in 1800 before the Royal Society of London. Herschel, like Ritter used a prism to refract light from the Sun and detected the infrared, beyond the red part of the spectrum, through an increase in the temperature recorded on a thermometer.

In 1801, the German physicist Johann Wilhelm Ritter made the discovery of ultraviolet by noting that the rays from a prism darkened silver chloride preparations more quickly than violet light. Ritter's experiments were an early precursor to what would become photography. Ritter noted that the UV rays were capable of causing chemical reactions.

Radio waves were not detected first from a natural source, but were rather produced deliberately an artificially by the German scientist Heinrich Hertz in 1887, using electrical circuits calculated to produce oscillations in the radio frequency range, following recipes suggested by the equations of James Clerk Maxwell.

Wilhelm Rontgen discovered and named X-rays. After experimenting with high voltages applied to an evacuated tube on 8 November 1895, he noticed fluorescence on a nearby plate of coated glass. In one month, he discovered the main properties of X-rays that we understand to this day. Henri Becquerel found that uranium salts caused fogging of an unexposed photographic plate, and Marie Curie discovered that only certain elements gave off these rays of energy. She named this behavior radioactivity. In December 1899, Marie Curie and Pierre Curie discovered radium in pitchblende. This new element was two million times more radioactive than uranium, as described by Madam Curie.

Alpha rays (alpha particles) and beta rays (beta particles) were differentiated by Ernest Rutherford through simple experimentation in 1899. Rutherford used a generic pitchblende radioactive source and determined that the rays produced by the source had differing penetrations in materials. One type had short penetration and a positive charge, which Rutherford named alpha and the other was more penetrating with a negative charge, and this type Rutherford named beta. Henri Becquerel shortly proved that beta rays are fast electrons, while Rutherford and a colleague eventually proved that alpha particles are ionized helium. In 1900 the French scientist Paul Villard discovered a third neutrally charged and especially penetrating type of radiation from radium, and after he described it, Rutherford realized it must be yet a third type of radiation, which in 1903 Rutherford named gamma rays.

Cosmic ray radiations striking the Earth from outer space were finally definitively recognized and proven to exist in 1912, as the scientist Victor Hess carried electrometer to various altitudes in a free balloon flight. The nature of these radiations was only gradually understood in later years.

Neutron radiation was discovered with the neutron by Chadwick, in 1932. A number of other high energy particulate radiations such as positrons, muons, and pions were discovered by cloud chamber examination of cosmic ray reactions shortly thereafter, and others types of particle radiation were produced artificially in particle accelerators, through the last half of the twentieth century [5].

Chapter 3

Radioactivity Detection Schemes

3.1 Particle Detector (Radiation Detector)

In experimental and applied particle physics, nuclear physics, and nuclear engineering, a particle detector, also known as a radiation detector, is a device used to detect, track, and/or identify high-energy particles, such as those produced by nuclear decay, cosmic radiation, or reactions in a particle accelerator. Modern detectors are also used as calorimeters to measure the energy of the detected radiation. They may also be used to measure other attributes such as momentum, spin, charge etc. of the particles.

Many of the detectors invented and used so far are ionization detectors (of which gaseous ionization detectors and semiconductor detectors are most typical) and scintillation detectors; but other, completely different principles have also been applied, like Cerenkov light and transition radiation.

3.2 Types of Detectors

The different types of detectors are divided into three groups:

a. Inorganic detectors
b. Organic detectors
c. Gaseous detectors

Gas-filled detectors consist of a volume of gas between two electrodes. In scintillation detectors, the interaction of ionizing radiation produces UV and/or visible light Semiconductor detectors are especially pure crystals of silicon, germanium, or other materials to which trace amounts of impurity atoms have been added so that they act as diodes [6].

Detectors may also be classified by the type of information produced:

a. Detectors, such as Geiger-Mueller (GM) detectors, that indicate the number of interactions occurring in the detector are called counters.

b. Detectors that yield information about the energy distribution of the incident radiation, such as NaI scintillation detectors, are called spectrometers.

c. Detectors that indicate the net amount of energy deposited in the detector by multiple interactions are called dosimeters.

Most of the inorganic scintillators are crystals of the alkali metals, particularly alkali iodides that contain a small amount of an impurity. Examples are NaI(Tl), CsI(Tl), CaI(Na), LiI(Eu), and CaF,(Eu). The element in parentheses is the impurity or activator.

There are other types of detectors used in this purpose as well. An illustration of the classification of radiation detectors is show in the figure below (figure 3.1):

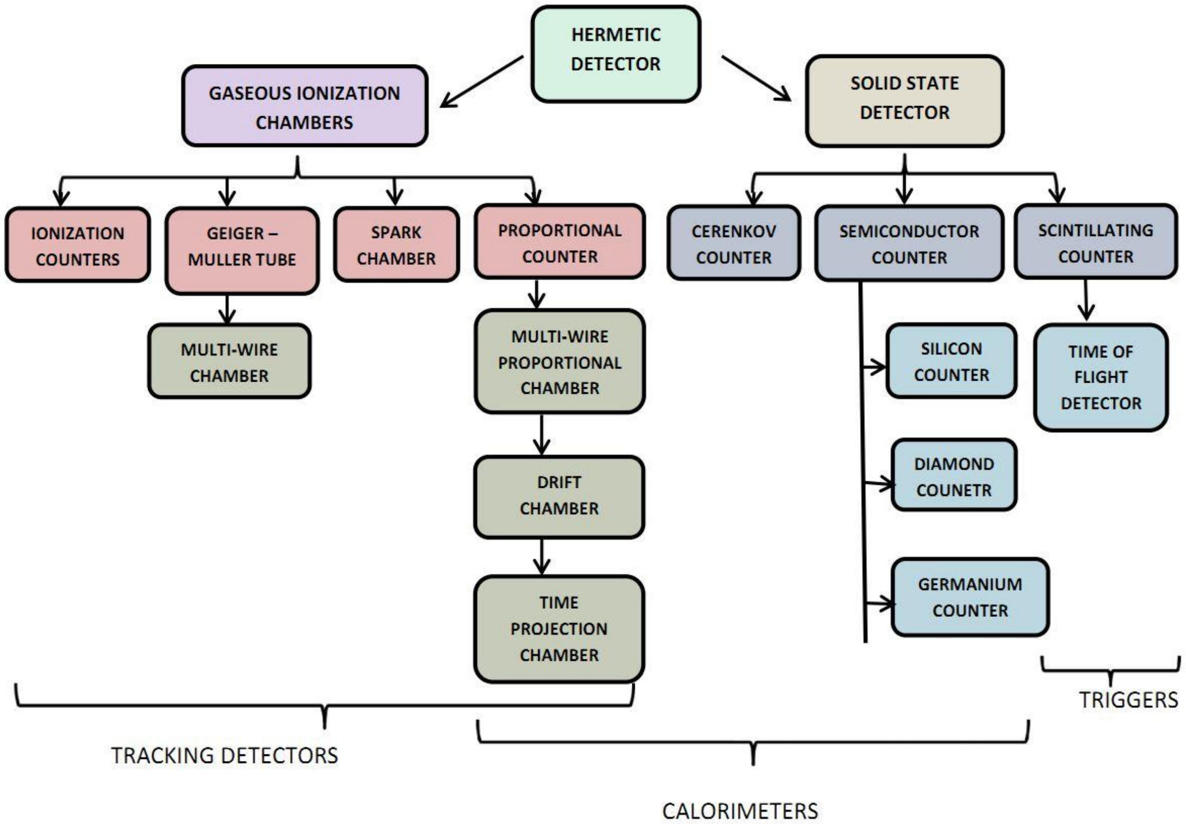

Figure 3.1: Summary of Particle Detectors

3.2.1 Modes of Operation

There are basically two types of modes of operation. They are:

a. Pulse mode

b. Current mode

In pulse mode, the signal from each interaction is processed individually. In current mode, the electrical signals from individual interactions are averaged together, forming a net current signal.

3.2.2 Interaction Rate

The main problem with detectors in pulse mode is that two interactions must be separated by a finite amount of time if they are to produce distinct signals. This interval is called the dead time of the system. If a second interaction occurs in this interval, its signal will be lost; if it occurs close enough to the first interaction, it may distort the signal from the first interaction.

3.2.3 Dead Time

Dead time of a detector system is largely determined by the component in the series with the longest dead time. Detector has longest dead time in GM counter systems. In multichannel analyzer systems the analog-to-digital converter often has the longest dead time. GM counters have dead times ranging from tens to hundreds of microseconds, most other systems have dead times of less than a few microseconds [7].

3.2.4 Paralyzable or Non-paralyzable System

In a paralyzable system, an interaction that occurs during the dead time after a previous interaction extends the dead time. In a nonparalyzable system, it does not happen. At very high interaction rates, a paralyzable system will be unable to detect any interactions after the first, causing the detector to indicate a count rate of zero [1]. Comparison between Paralyzable and Non-paralyzable system is shown in Figure 3.2:

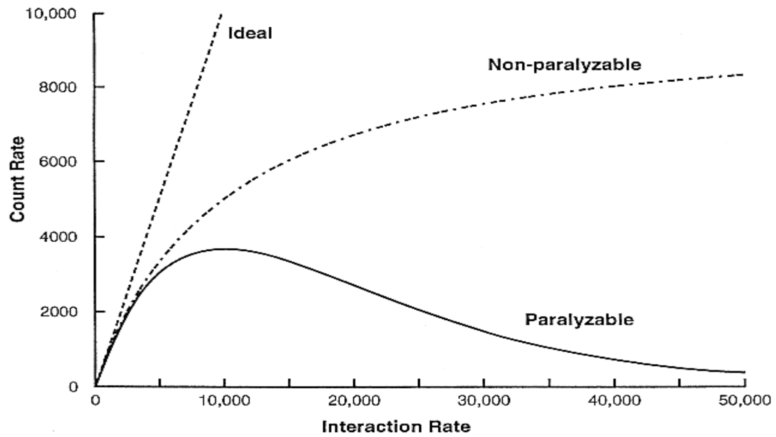

Figure 3.2: Comparison between Paralyzable and Non-paralyzable detectors [1]

3.2.5 Current Mode Operation

In current mode, all information regarding individual interactions is lost. If the amount of electrical charge collected from each interaction is proportional to the energy deposited by that interaction, then the net current is proportional to the dose rate in the detector material. It is used for detectors subjected to very high interaction rates.

3.2.6 Spectroscopy

Most spectrometers are operated in pulse mode. Amplitude of each pulse is proportional to the energy deposited in the detector by the interaction causing that pulse. The energy deposited by an interaction is not always the total energy of the incident particle or photon. A pulse height spectrum is usually depicted as a graph of the number of interactions depositing a particular amount of energy in the spectrometer as a function of energy. This is precisely shown in Figure 3.3:

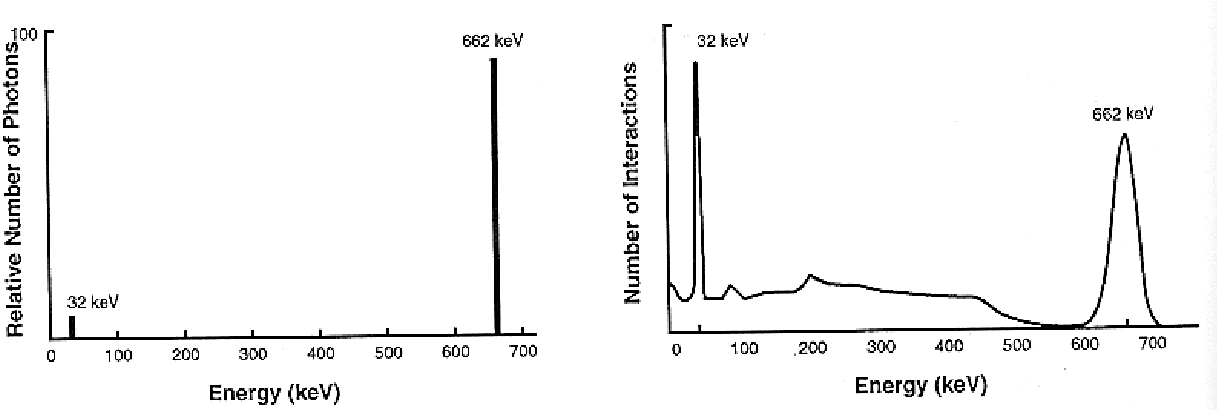

Figure 3.3: Spectroscopy [8]

3.2.7 Detection Efficiency

The efficiency (sensitivity) of a detector is a measure of its ability to detect radiation. Efficiency of a detection system operated in pulse mode is defined as the probability that a particle or photon emitted by a source will be detected in the detector.

$$Efficiency = \frac{Number\ detected}{Number\ emitted}$$

$$= \frac{Number\ reaching\ detector}{Number\ emitted} \times \frac{Number\ detected}{Number\ reaching\ detector}$$

$$= Geometric\ efficiency \times Intrinsic\ efficiency$$

A gamma spectroscopy system consists of a detector, electronics to collect and process the signals produced by the detector, and a computer with processing software to generate, display, and store the spectrum. Other components, such as rate meters and peak position stabilizers, may also be included [8]. The basic block diagram is shown in Figure 3.4:

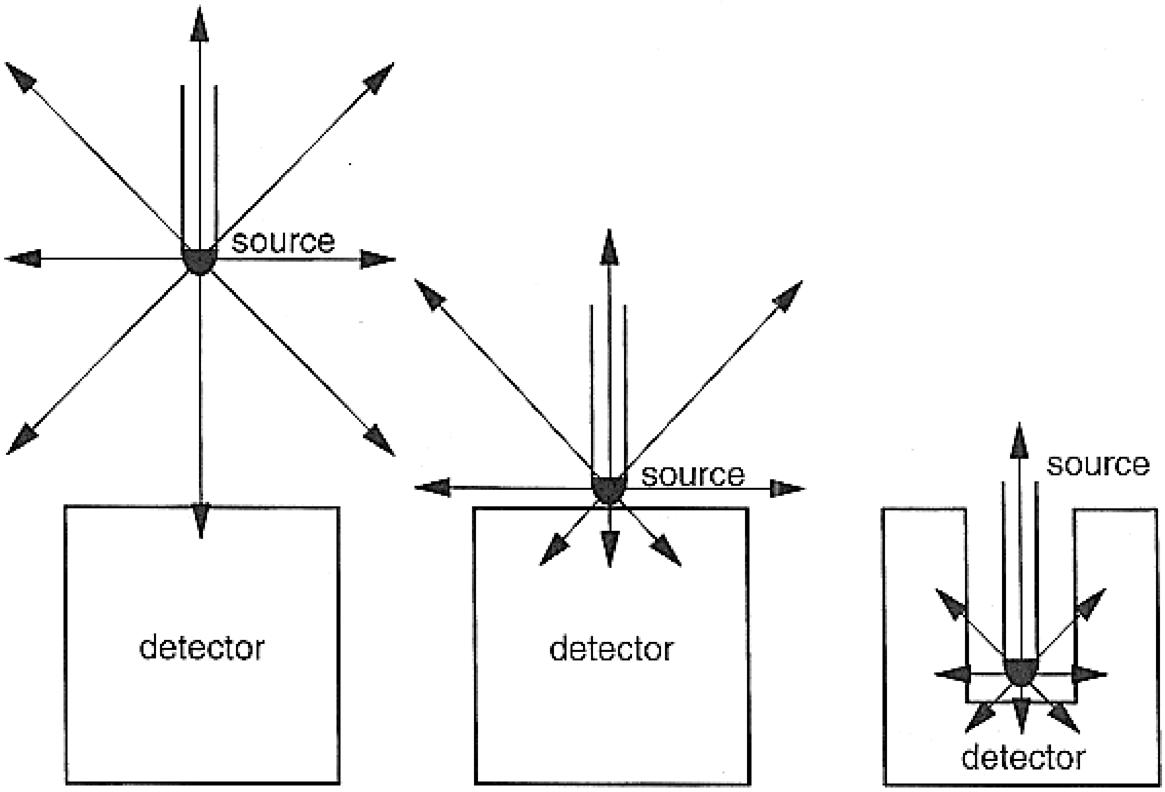

Figure 3.4: Spectroscopy detection [8]

3.2.8 Intrinsic Efficiency

It is often called the quantum detection efficiency or QDE. It is determined by the energy of the photons and the atomic number, density, and thickness of the detector [8]

For a a parallel beam of mono-energetic photons incident on a detector of uniform thickness, intrinsic efficiency can be defined as:

$$Intrinsic\ efficiency = 1 - e^{-\mu x}$$

3.3 Gas-filled Detectors

A gas-filled detector consists of a volume of gas between two electrodes, with an electrical potential difference (voltage) applied between the electrodes. In this detector, ionizing radiation produces ion pairs in the gas. Positive ions (cations) attracted to negative electrode (cathode) and electrons or anions attracted to positive electrode (anode). In most detectors, cathode is the wall of the container that holds the gas and anode is a wire inside the container. This is shown in Figure 3.5:

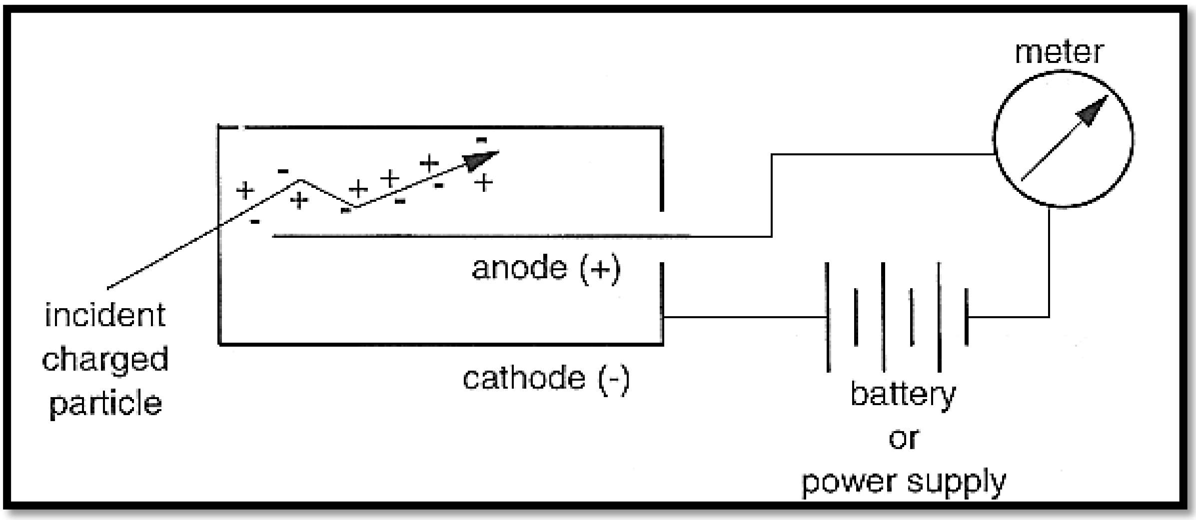

Figure 3.5: Gas-filled detectors

3.3.1 Types of Gas-filled Detectors

Three types of gas-filled detectors are commonly used:

a. Ionization chambers

b. Proportional counters

c. Geiger-Mueller (GM) counters

Type is determined primarily by the voltage applied between the two electrodes. Ionization chambers have wider range of physical shape (parallel plates, concentric cylinders, etc.). Proportional counters and GM counters must have thin wire anode [2].

The various types of gas filled detectors correspond to different operation region as depicted in Figure 3.6. As long as the applied voltage is very low, the field strength is insufficient to prevent recombination. With increasing electric field, recombination becomes less likely and is eventually overcome.

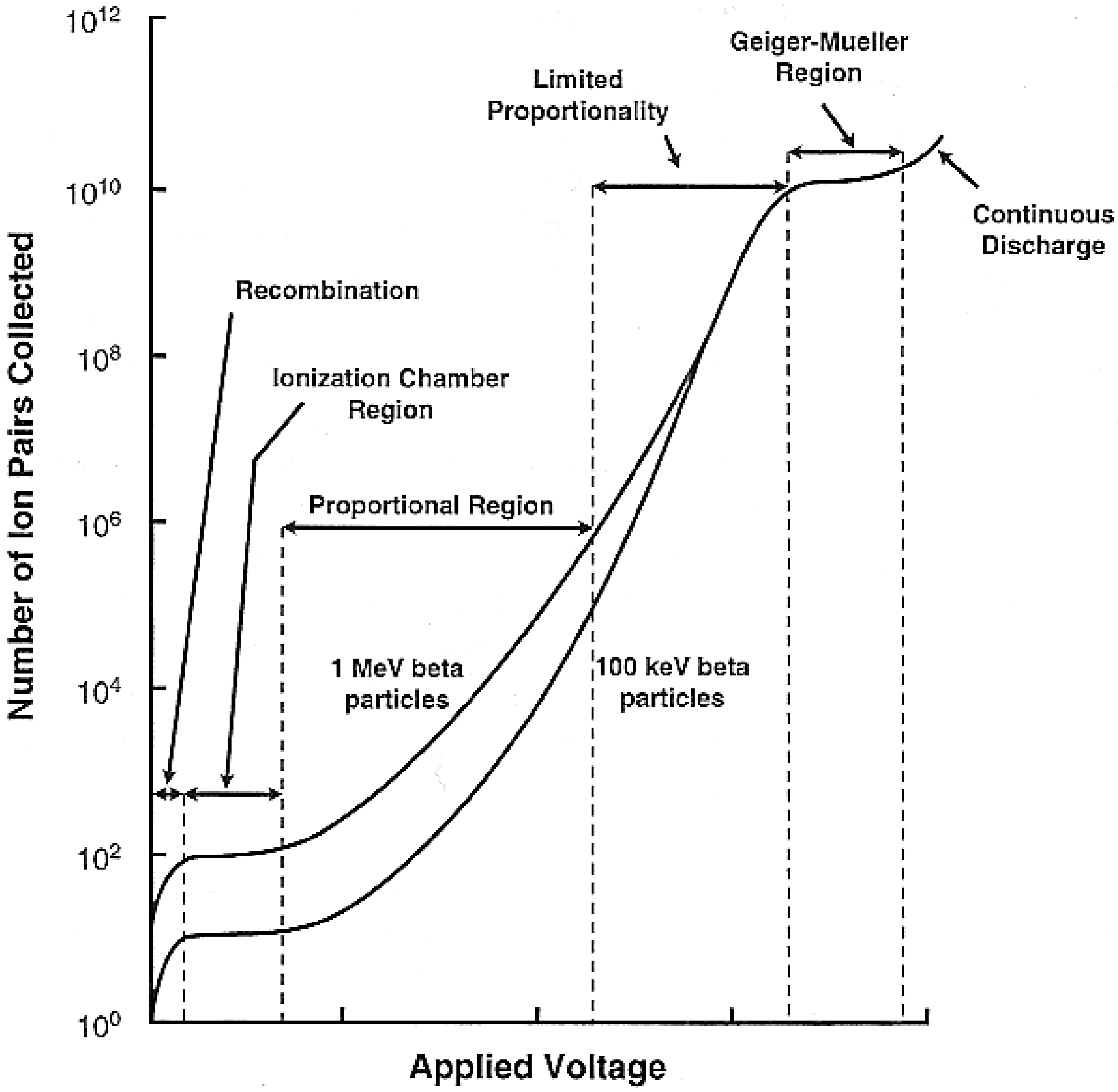

Figure 3.6: Range of different gas-filled detectors [9]

3.3.2 Ionization Chambers

If gas is air and walls of chamber are of a material whose effective atomic number is similar to air, the amount of current produced is proportional to the exposure rate. Air-filled ion chambers are used in portable survey meters, for performing Quality Assessment testing of diagnostic and therapeutic x-ray machines, and are the detectors in most x-ray machine photo timers. But it has low intrinsic efficiencies because of low densities of gases and low atomic numbers of most gases. Ionization Chambers are shown in Figure 3.7:

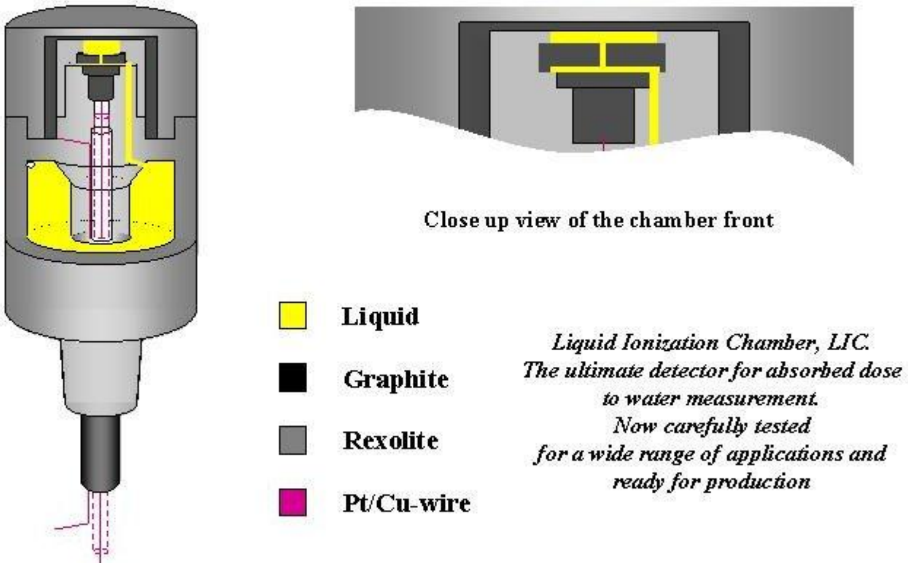

Figure 3.7: Ionization Chamber [10]

3.3.3 Proportional Counters

They must contain a gas with specific properties. They are commonly used in standard laboratories, health physics laboratories, and for physics research. But they are seldom used in medical centers.

3.3.4 GM Counters

GM (Geiger-Muller) counters also must contain gases with specific properties. Gas amplification produces billions of ion pairs after an interaction, though signal from detector requires little amplification. They are often used for inexpensive survey meters. In general, GM survey meters are inefficient detectors of x-rays and gamma rays. They over response to low energy x-rays. It can be partially corrected by placing a thin layer of higher atomic number material around the detector. A typical GM counter is shown in Figure 3.8.

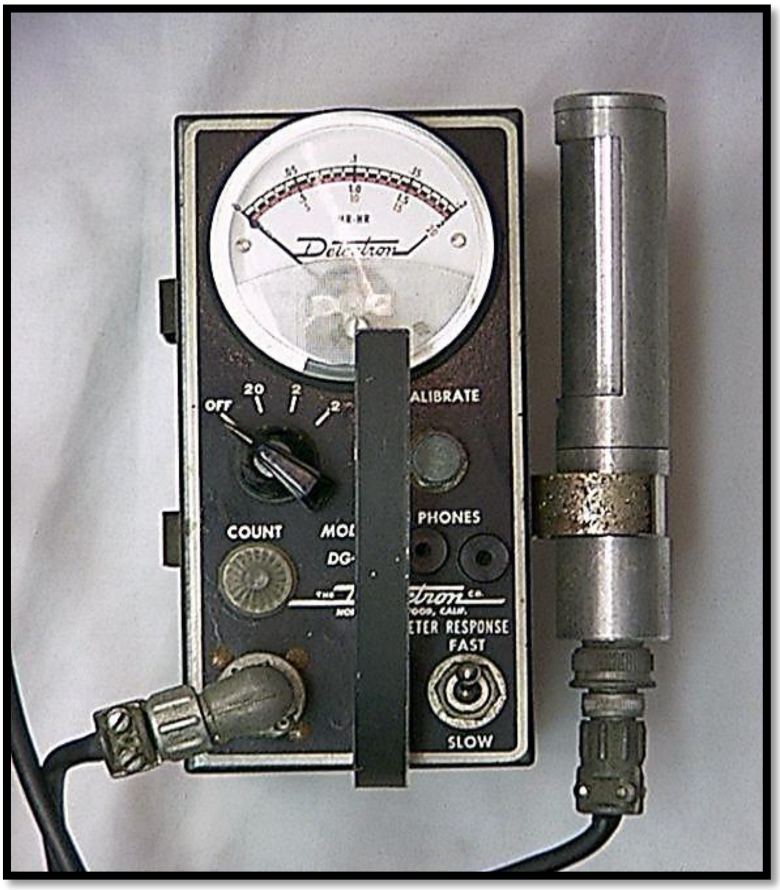

Figure 3.8: Geiger Muller Counter [11]

GM detectors suffer from extremely long dead times. They are seldom used when accurate measurements are required of count rates greater than a few hundred counts per second. Portable GM survey meter may become paralyzed in a very high radiation field. One should always use ionization chamber instruments for measuring such fields.

3.3.5 Working Principle of Most Common Detectors

Radioactivity is a natural and spontaneous process by which the unstable atoms of an element emit or radiate excess energy in the form of particles or waves. These emissions are collectively called ionizing radiations. Depending on how the nucleus loses this excess energy either a lower energy atom of the same form will result, or a completely different nucleus and atom can be formed.

Ionization is a particular characteristic of the radiation produced when radioactive elements decay. These radiations are of such high energy that when they interact with materials, they can remove electrons from the atoms in the material. This effect is the reason why ionizing radiation is hazardous to health, and provides the means by which radiation can be detected [12].

3.3.5.1 Scintillation Detectors

Scintillators are used in conventional film-screen radiography, many digital radiographic receptors, fluoroscopy, scintillation cameras, most CT scanners, and PET scanners [1]. Scintillation detectors consist of a scintillator and a device, such as a PMT, that converts the light into an electrical signal.

The desirable properties of Scintillators are:

i. High conversion efficiency
ii. Decay times of excited states should be short
iii. Material transparent to its own emissions
iv. Color of emitted light should match spectral sensitivity of the light receptor
v. For x-ray and gamma-ray detectors, μ should be large which ensures high detection efficiencies
vi. Rugged, unaffected by moisture, and inexpensive to manufacture

Amount of light emitted after an interaction increases with energy deposited by the interaction. They can be operated in pulse mode as spectrometers. High conversion efficiency produces superior energy resolution.

The basic principle behind this instrument is the use of a special material which glows or "scintillates" when radiation interacts with it. The most common type of material is a type of salt called sodium-iodide. The light produced from the scintillation process is reflected through a clear window where it interacts with device called a photomultiplier tube. The first part of the photomultiplier tube is made of another special material called a photocathode. The photocathode produces electrons when light strikes its surface. These electrons are then pulled towards a series of plates called dynodes through the application of a positive high voltage. When electrons from the photocathode hit the first dynode, several electrons are produced for each initial electron hitting its surface. This "bunch" of electrons is then pulled towards the next dynode, where more electron "multiplication" occurs. The sequence continues until the last dynode is reached, where the electron pulse is now millions of times larger than it were at the beginning of the tube.

At this point the electrons are collected by an anode at the end of the tube forming an electronic pulse. The pulse is then detected and displayed by the instrument. The working principle is illustrated in figure 3.9:

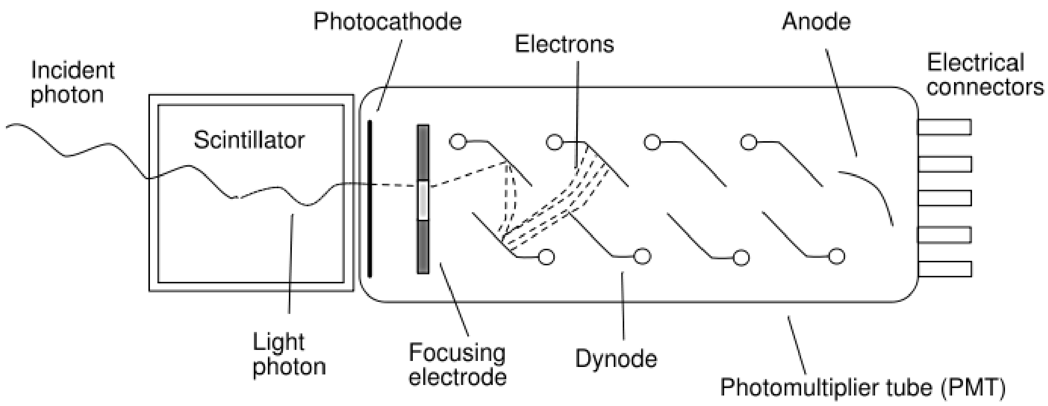

Figure 3.9: Scintillation Counter [13]

3.3.5.2 GM Counters

This instrument works on the principle that as radiation passes through air or a specific gas, ionization of the molecules in the air occurs. When a high voltage is placed between two areas of the gas filled space, the positive ions will be attracted to the negative side of the detector (the cathode) and the free electrons will travel to the positive side (the anode). These charges are collected by the anode and cathode which then form a very small current in the wires going to the detector. By placing a very sensitive current measuring device between the wires from the cathode and anode, the small current is measured and displayed as a signal. The more radiation which enters the chamber, the more current is displayed by the instrument. Many types of gas-filled detectors exist, but the two most common are the ion chamber used for measuring large amounts of radiation and the Geiger-Muller or GM detector used to measure very small amounts of radiation. The schematic diagram of a GM counter is provided below in figure 3.10.

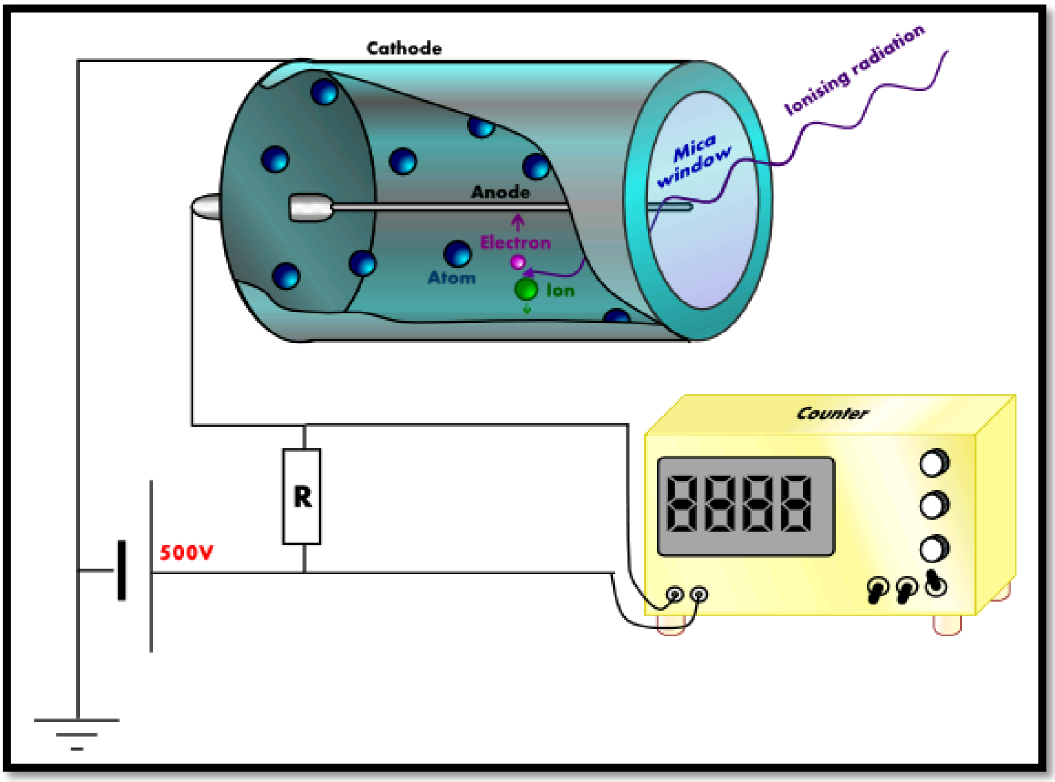

Figure 3.10: Schematic view of the Geiger Muller counter

3.4 Count-rate Effects

If two interactions occur in a detector, separated by a very short time interval, the detector produces a single pulse which is sum of the individual signals from the two interactions. It has higher amplitude than the signal from either individual interaction. Operating a pulse height spectrometer at a high count rate causes loss of counts and misplacement of counts in the spectrum. This phenomenon is shown in figure 3.11:

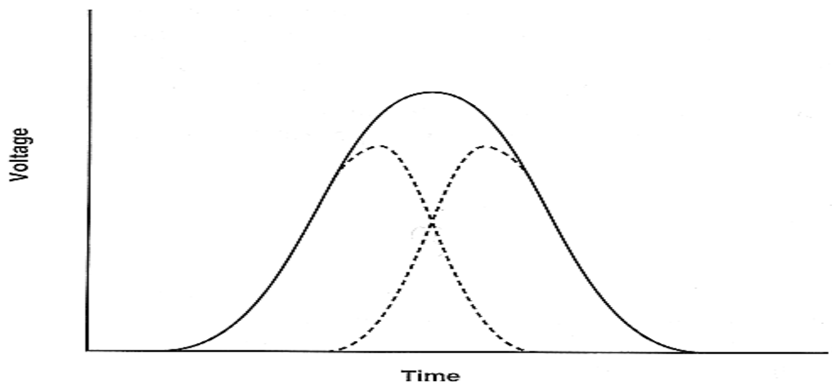

Figure 3.11: Count Rate effects

Chapter 4
High Voltage Generation

4.1 High Voltage for GM Counter

Geiger-Muller counter operates at high DC voltage. The DC voltage is applied at two electrodes of the counter. The counter used in this project has an operating voltage range of 450-650V [21]. The hardware built in the project is basically a DC-DC converter. A 9V DC source is switched and then stepped up to make 500 V DC.

4.2 Equipment Used

Name	Model/Specification
Timer IC	LM555
Transformer	220V-6V Step Down
MOSFET	IRF540
Diode	1N4007
BJT	BC549C
Capacitors	100nF, 10uF, 1000uF
Resistors	5k, 68k, 1M, 100k, 1k
Battery	9V
Potentiometer	100k

Table 4.1: Equipment used in high voltage generation

4.3 555 Timer IC

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. The timer is a very useful precision timing device that can act as either a simple timer to generate single pulses or long time delays, or as a relaxation oscillator producing stabilized waveforms of varying duty cycles from 50 to 100% [14]. For high voltage generation, an output pulse of desired duty and frequency is generated by 555.

4.3.1 Pin Diagram

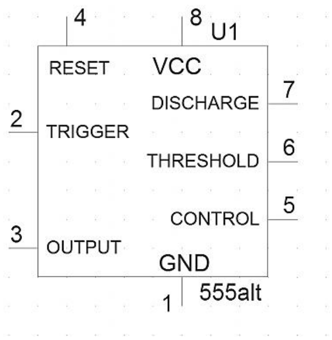

Figure 4.1: Pin diagram of 555 timer IC

4.3.2 Pin Description:

i. Pin 1. − **Ground**, The ground pin connects the 555 timer to the negative (0v) supply rail.

ii. Pin 2. − **Trigger**, The negative input to comparator No 1. A negative pulse on this pin sets the internal Flip-flop when the voltage drops below 1/3Vcc causing the output to switch from a "LOW" to a "HIGH" state.

iii. Pin 3. − **Output**, The output pin can drive any TTL circuit and is capable of sourcing or sinking up to 200mA of current at an output voltage equal to approximately Vcc - 1.5V so small speakers, LEDs or motors can be connected directly to the output.

iv. Pin 4. − **Reset**, This pin is used to reset the internal Flip-flop controlling the state of the output, pin 3. This is an active-low input and is generally connected to a logic "1" level when not used to prevent any unwanted resetting of the output.

v. Pin 5. − **Control Voltage**, This pin controls the timing of the by overriding the 2/3Vcc level of the voltage divider network. By applying a voltage to this pin the width of the output signal can be varied independently of the RC timing network. When not used it is connected to ground via a 10nF capacitor to eliminate any noise.

vi. Pin 6. − **Threshold**, The positive input to comparator No 2. This pin is used to reset the Flip-flop when the voltage applied to it exceeds 2/3Vcc causing the output to switch from "HIGH" to "LOW" state.

vii. Pin 7. − **Discharge**, The discharge pin is connected directly to the Collector of an internal NPN transistor which is used to "discharge" the timing capacitor to ground when the output at pin 3 switches "LOW".

viii. Pin 8. − **Supply +Vcc**, This is the power supply pin and for general purpose TTL 555 timers is between 4.5V and 15V.

4.4 Circuit Diagram:

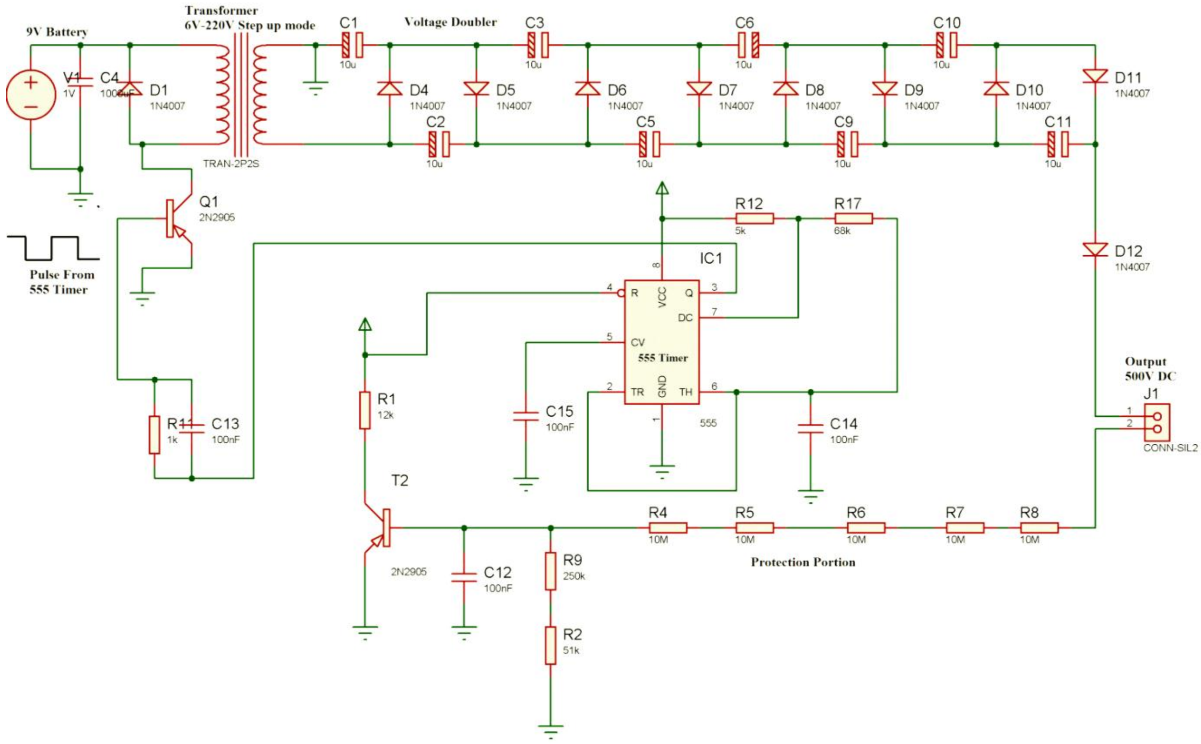

Figure 4.2: Circuit diagram for high voltage generation

4.5 Circuit operation:

4.5.1 Pulse generation for switching:

There are two modes of operation of 555 timer:

i. Monostable mode
ii. Astable mode

In this project timer is operated in astable mode to generate pulse. In this mode the capacitor is charged and discharged between Vcc/3 and 2(Vcc/3). The connection diagram in astable mode is shown in Figure 4.3 and necessary calculation to find the duty and frequency is next to the figure.

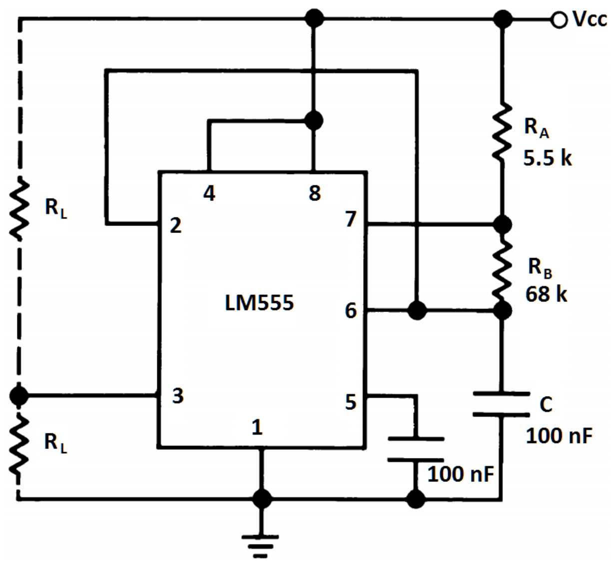

Figure 4.3: Connection of 555 timer in Astable mode

The charge time is given by

$t_1 = 0.693\ (R_A +\ R_B)C$

The discharge time is given by

$t_2 = 0.693\ (R_B)C$

The total period is

$T = t_1 +\ t_2 = 0.693\ (R_A +\ 2R_B)C$

The frequency of oscillation $f\ = \frac{1}{T} = \frac{1.44}{0.693(R_A+2R_B)C}$

The duty cycle is $D = \frac{R_B}{R_A+2R_B}$

By adjusting R_A and R_B the frequency and duty of output pulse can be adjusted.

In the circuit $R_A\ = 5.5\text{k}\Omega$, $R_B\ = 68\text{k}\Omega$, C=100nF

Frequency=146Hz and Duty= 0.48

4.5.2 Stepping up the generated pulse:

The output from 555 timer is used to switch the input 9V supply. Switching is performed by IRF540 MOSFET. The switched output is stepped up via a transformer. A 220V/6V step down transformer is operated in step up mode to achieve amplified pulse.

4.5.3 Voltage multiplier:

Output from the transformer is passed through voltage multiplier circuit for further amplification. [15]

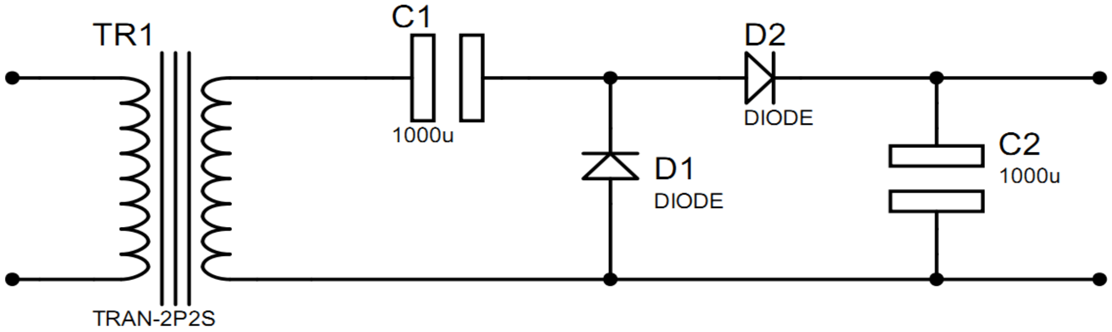

Figure 4.4: Basic voltage multiplier (doubler) circuit

In the voltage doubler circuit shown in figure the first diode rectifies the signal and its output is equal to the peak voltage from the transformer rectified as a half wave rectifier. An AC signal via the capacitor also reaches the second diode, and in view of the DC block provided by the capacitor this causes the output from the second diode to sit on top of the first one. In this way the output from the circuit is twice the peak voltage of the transformer, less the diode drops.

4.5.4 Rectification and final output

The output from voltage multiplier is rectified via a diode rectifier to get the final output of 500V DC.

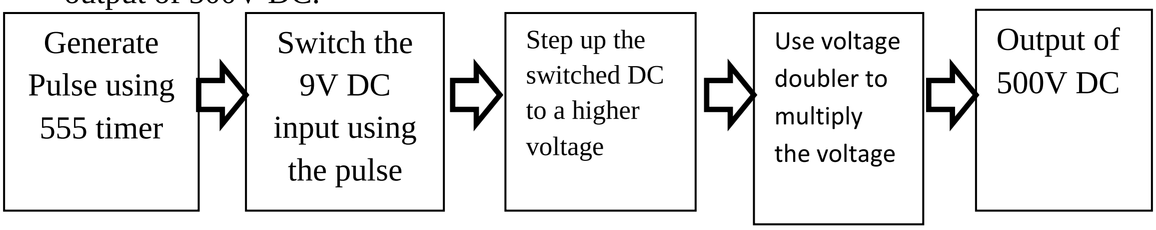

Figure 4.5: Block diagram of high voltage generation

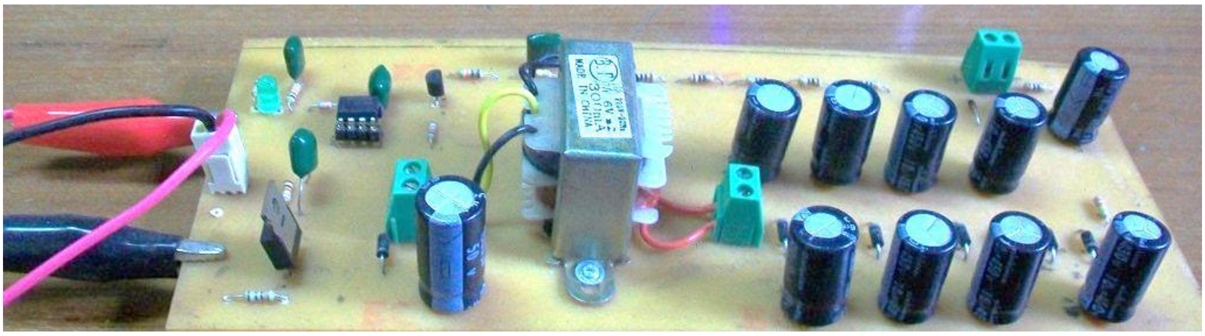

Figure 4.6: Hardware setup for high voltage generation

Figure 4.5 shows the flowchart of high voltage generation process. Figure 4.6 shows the hardware setup for high voltage generation.

4.6 Protection Scheme:

The high voltage board must have a protection circuit for safety. If voltage higher then rated voltage is generated, excess current flow might damage the Geiger counter.

The high voltage output is fed to input of a BJT. Whenever the current flow exceeds limit, the transistor switches the reset pin of 555 timer to ground. The timer is reset and pulse generation is stopped immediately which sets the high voltage output to zero volts.

4.7 Varying Voltage Output:

Voltage output can be varied a small amount by adding a potentiometer at the output. Output voltage also varies proportionally to input voltage. The high voltage board is particularly built for this thesis purpose only and it is for the specific GM counter model. Therefore varying the voltage in wide range is not necessary. Just a little tuning might be needed to get the counter in its best performance voltage range.

The hardware setup for the counter is ready now. So the counter will produce output pulse in response of radiation field around it. In the next chapters focus will be on the counter interfacing with computer using LabVIEW and acquisition the count data from GM counter to the computer.

Chapter 5

Introduction to LabVIEW and DAQ

5.1 NI LabVIEW

LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a dataflow programming language developed by National Instruments (NI). It can be used to develop sophisticated measurement and control instruments using intuitive graphical icons and connecting wires that resemble a flowchart. LabVIEW also offers powerful integration with hardware devices for analysis and data visualization. LabVIEW runs on Microsoft Windows, UNIX, Linux, or Mac OS. Applications developed for this thesis were programmed in LabVIEW 2009 version.

5.2 LabVIEW Features

LabVIEW application is called a virtual instrument (VI) which has three components:

(i) Front Panel
(ii) Block Diagram
(iii) Connector Pane

5.2.1 Front Panel

Front panel is the user interface of the virtual instrument. Controls and indicators are main part of the front panel.

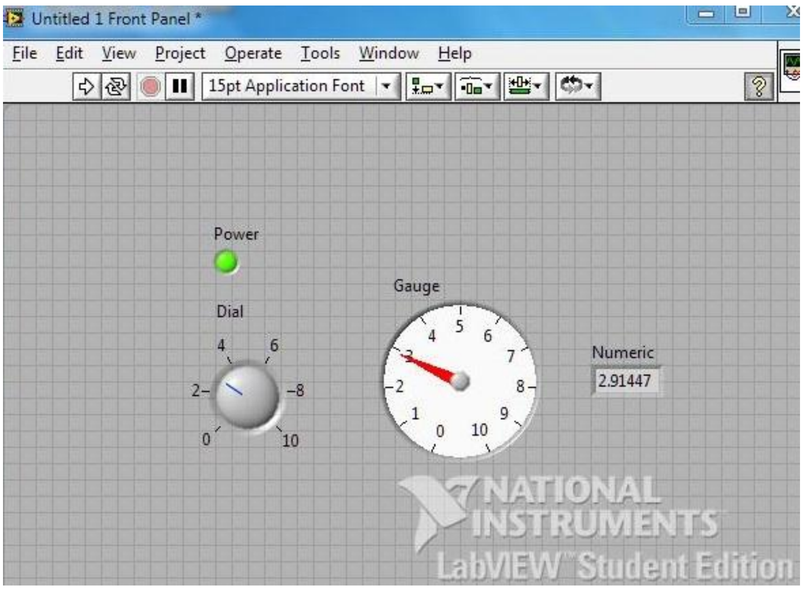

Figure 5.1: LabVIEW Front Panel

Numeric and text control, dials, knobs, gauges, numeric indicator, Boolean and text indicators, graphs and chart features can be added to the front panel. Figure 5.1 shows the front panel of LabVIEW. The value adjusted in the dial is displayed by a gauge indicator and also a numeric indicator.

5.2.2 Block Diagram

A block diagram is where a programmer makes an application structure by connecting various function-nodes using links called wires. Block diagram consists of functions, input, output, and wires. In LabVIEW, all functions have inputs and outputs connections. Inputs can be strings, numbers or signals from devices, and outputs can be strings, numbers or figures. Wires are used to connect different functions.

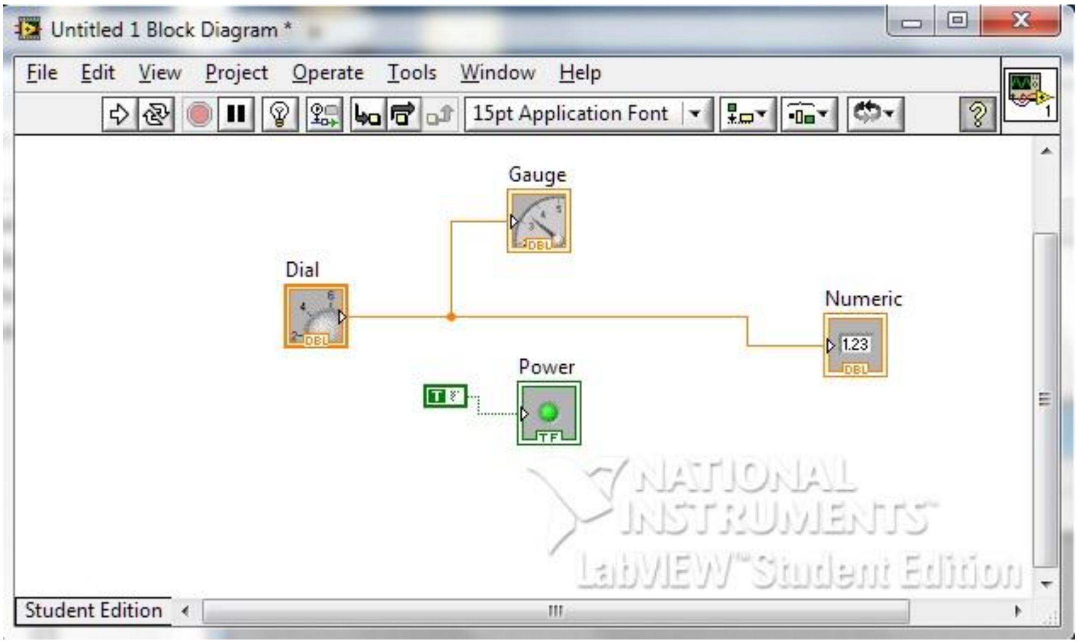

Figure 5.2: Block diagram in LabVIEW

Figure 5.2 shows the block diagram of the front panel shown in figure 5.1. The output from dial control is connected to the inputs of the gauge and numeric indicator. There are a number of functions available in LabVIEW; they can be used in a user friendly graphical environment to implement any algorithm.

5.2.3 Connector Pane

Any LabVIEW application can be set as a connector pane, which can be used as a function in other LabVIEW applications. A connector pane is also called a sub VI. A function is executed once all inputs are available.

5.3 Key LabVIEW Functions Used

Some of the important functions used in the thesis will be viewed in this section.

5.3.1 Elapsed Time

The first time the Elapsed Time Express VI is called, it will begin monitoring time until the specified amount of time has passed. When the Elapsed Time Express VI is called before the specified time has elapsed, the Time has Elapsed output will be FALSE. When the Elapsed time Express VI is called after the specified time has elapsed, the Time has Elapsed output will be TRUE [16]

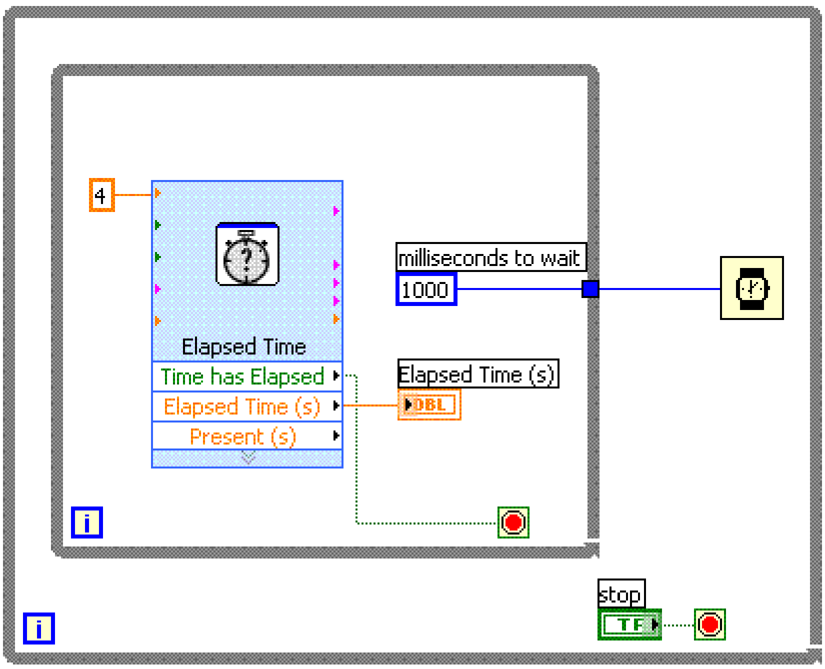

Figure 5.3: Elapsed Time Block

The purpose of the Elapsed Time Express VI is to keep a running count of the time elapsed since the first time it was called.

5.3.2 DAQmx Create Channel (CI Cnt Edge)

This function creates a channel to measure the frequency of a digital signal. Only one counter input channel can be created at a time with this VI because a task can contain only one counter input channel. To read from multiple counters simultaneously, a separate task must be created for each counter [17]

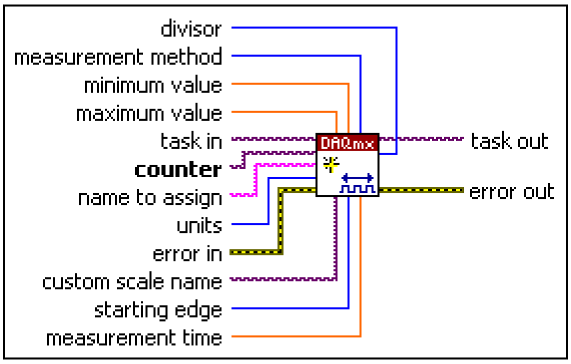

Figure 5.4: Count Edge Block

Here in the channel is created to count the pulse edges from GM counter.

5.3.3 DAQmx Read

DAQmx read function reads the count data from counter block and passes the data to next stage [18]

Figure 5.5: DAQmx read block

5.3.4 Spreadsheet Read and Write

Reads and writes to specific excel or text file. The format, number of rows and file path can be added to the function [19].

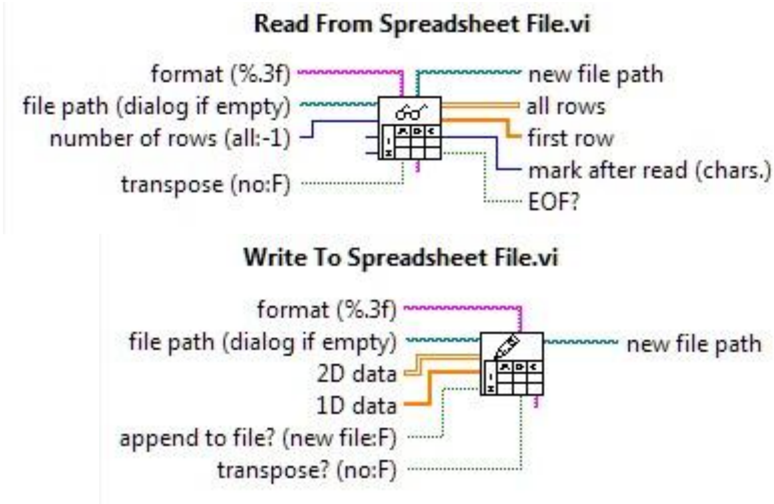

Figure 5.6: Spreadsheet read write block

5.3.5 Build Array

Build array function concatenates multiple arrays or appends elements to an n-dimensional array.

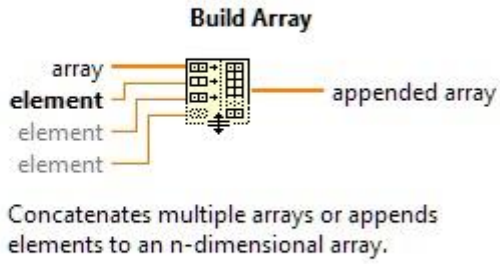

Figure 5.7: Build array block

5.3.6 Build XY Graph

Plots two one dimensional arrays on two axis.

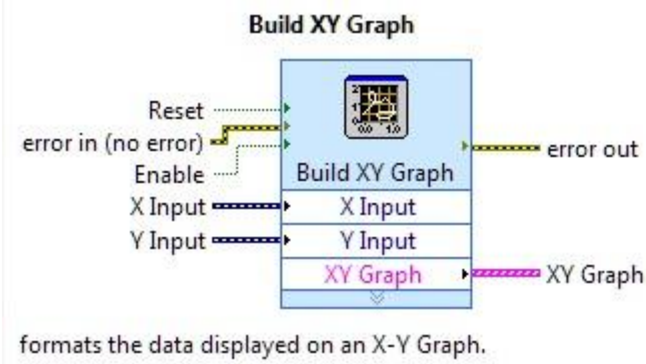

Figure 5.8: Build XY graph block

5.3.7 Arithmetic and Comparison Functions

Several arithmetic and comparison functions are used to set loop conditions. For example: equals to, greater than, less than, addition, divide by etc.

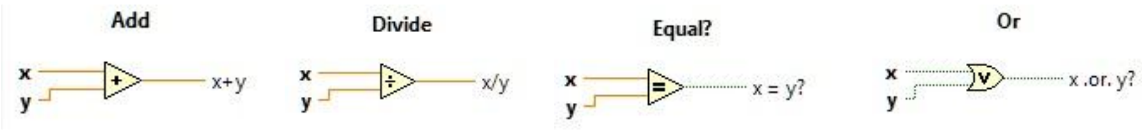

Figure 5.9: Arithmetic and Comparison functions

All these functions described in this section have been implemented to interface the GM counter with the computer, the process will be explained in next chapter.

5.4 Data Acquisition (DAQ)

5.4.1 Meaning of Data Acquisition

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for processing.

5.4.2 DAQ System Features

Some of the key features are:

a. DAQ systems capture, measure, and analyze physical phenomena from the real world.

b. Light, temperature and pressure are examples of the different types of signals that a DAQ system can measure.

c. Data acquisition is the process of collecting and measuring electrical signals and sending them to a computer for processing.

d. Electrical signals come from Transducers.

The building blocks of a DAQ system includes:

a. **Transducer:** A device that converts a physical phenomenon such as light, temperature, pressure, or sound into a measurable electrical signal such as voltage or current.

b. **Signal:** The output of the transducer.

c. **Signal conditioning:** Hardware that one can connect to the DAQ device to make the signal suitable for measurement or to improve accuracy or reduce noise.

d. **DAQ hardware:** Hardware one uses to acquire, measure, and analyze data.

e. **Software:** Application software is designed to help one to easily design and program measurement and control application of data.

5.5 Data Acquisition Card (DAQ Card)

The data acquisition device used in the thesis is NI USB-6009. It is 14-bit, 48 kS/s low cost multifunction DAQ card [20].

5.5.1 Features of NI USB-6009

Some of the attractive features of it are:

a. Small and portable

b. 12-bit input resolution, at 10 kS/s

c. Built-in connectors for connectivity

d. 2 analog outputs (range 0 to 5 V)

e. 12 digital I/O lines

f. 8 single ended inputs (4 differential inputs)

g. Input range ±1 to ±20V

h. The NI USB-6008 and NI is ideal for students.

i. 32 bit counter

j. 5 mA Output current drive

k. 14-bit input resolution, at 48 kS/s

Figure 5.10: NI USB-6009

5.5.2 DAQ Assistant

The DAQ assistant feature in NI LabVIEW is used to access different controls of DAQ card.

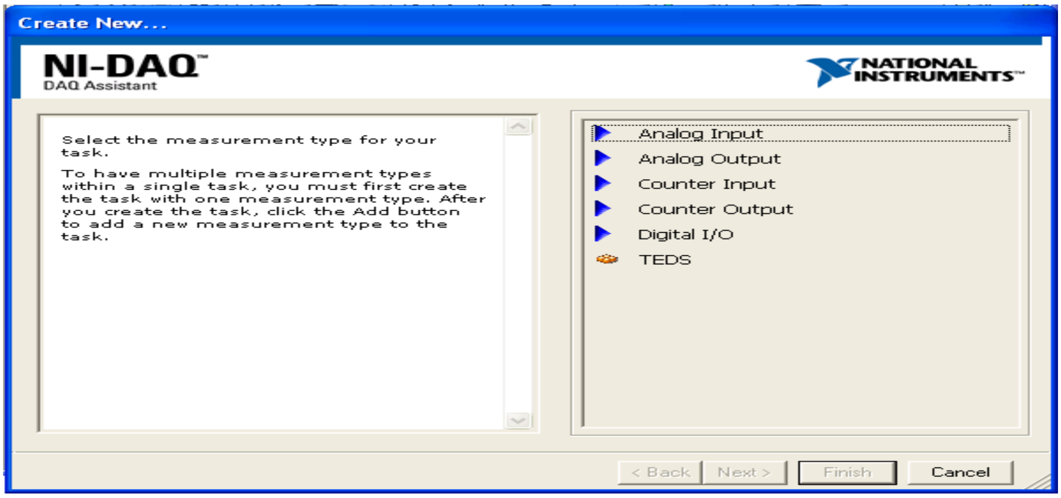

Figure 5.11: NI-DAQ Assistant

From the menu analog or digital I/O, counter I/O can be selected. In the thesis, counter input is used to read the count from GM counter.

Chapter 6

Interfacing Geiger Muller Counter

6.1 Interfacing

Computer interfacing of hardware refers to the communication between the hardware and computer via another device or program. In this section, GM counter (model ZP-1320) will be interfaced with computer with the aid of NI USB-6009 counter and LabVIEW program.

6.2 Applying High Voltage

The recommended operating voltage mentioned in the datasheet of ZP-1320 is 500 V [21]. First the input of 9V DC of the output of high voltage setup [Figure 4.6] is turned on and the output is adjusted to 500V DC. Then the output is connected across ZP-1320.

Figure 6.1: GM counter ZP-1320

6.3 Connecting GM counter with NI USB-6009

NI USB-6009 DAQ card has its digital trigger or event counter input at PFI0 pin. Output from the GM counter is connected to PFI0 pin of DAQ card. The ground of high voltage board and DAQ card must be shorted. When radiation is detected, output pulse from GM counter goes to DAQ card and the count is stored and monitored in computer using LabVIEW program.

6.4 LabVIEW Programming for Data Acquisition and Monitoring

A virtual instrument is created using LabVIEW for proper collection, storage and monitoring of radiation data. Each step in the program is described here in brief.

6.4.1 Elapsed Time Block

Radiation data is measured for 10 minutes in each hour of the day and rest of the time the count is not taken. Total count in these 10 minutes is stored in an excel file. Therefore 24 data in 24 hours of a day is stored in excel file every day.

To ensure that count is taken for only specified 10 minutes, the elapsed time block shown in figure 6.2 is used in the program.

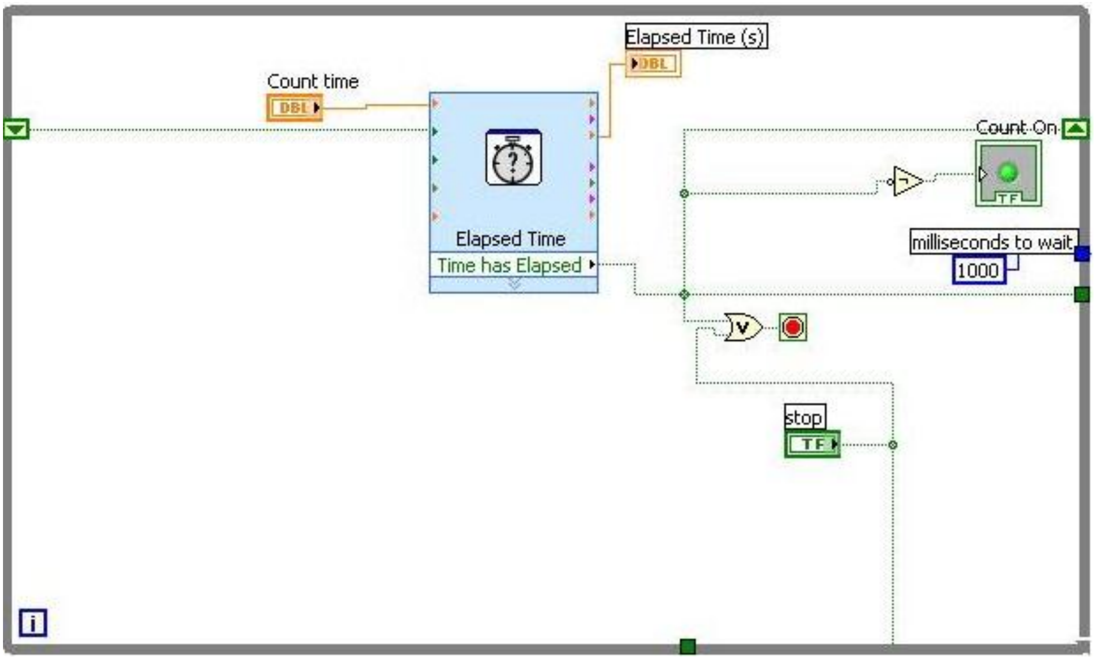

Figure 6.2: Elapsed time block

The input 'count time' indicates the time period when the counter will stay on. This is set to 10 minutes. In 10 minutes the count is taken. When 10 minutes is over, the time has elapsed output is true and the while loop as well as the count taking stops. The count can also be stopped by pressing the stop button before 10 minutes. The milliseconds to wait block is the time to wait for the next count, and it is set to 50 minutes. These parameters can be made variable and controlled from the front panel.

6.4.2 Counter Block

This is portion where the communications between GM counter and computer occurs. Pulse from the counter is taken as input to NI USB-6009. DAQ assistant and DAQmx read functions take the count data and display it as current count.

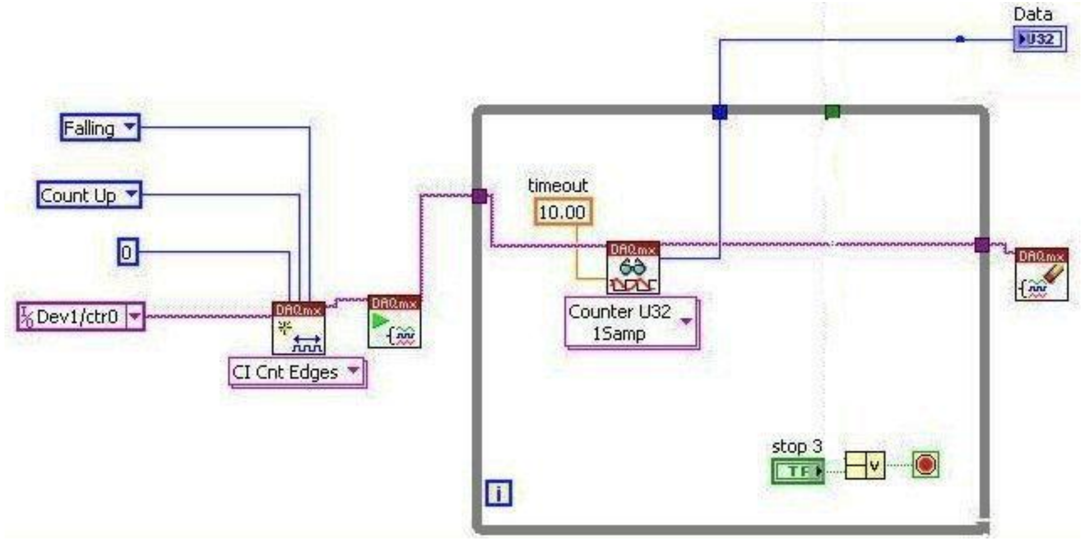

Figure 6.3: Counter Block

Current count is written in a excel file by write to spreadsheet function.

6.4.3 File Read and Plot

Count data written in the excel file is read by the read from spreadsheet function and plotted using the plot XY graph. The plot is viewed in the front panel. Each row from the excel file is read at once and build array function combines them to form an array. The array is sent to the Y plot of XY graph. The X plot is another array with whole number from 1 to 24 indicating 24 hours of day.

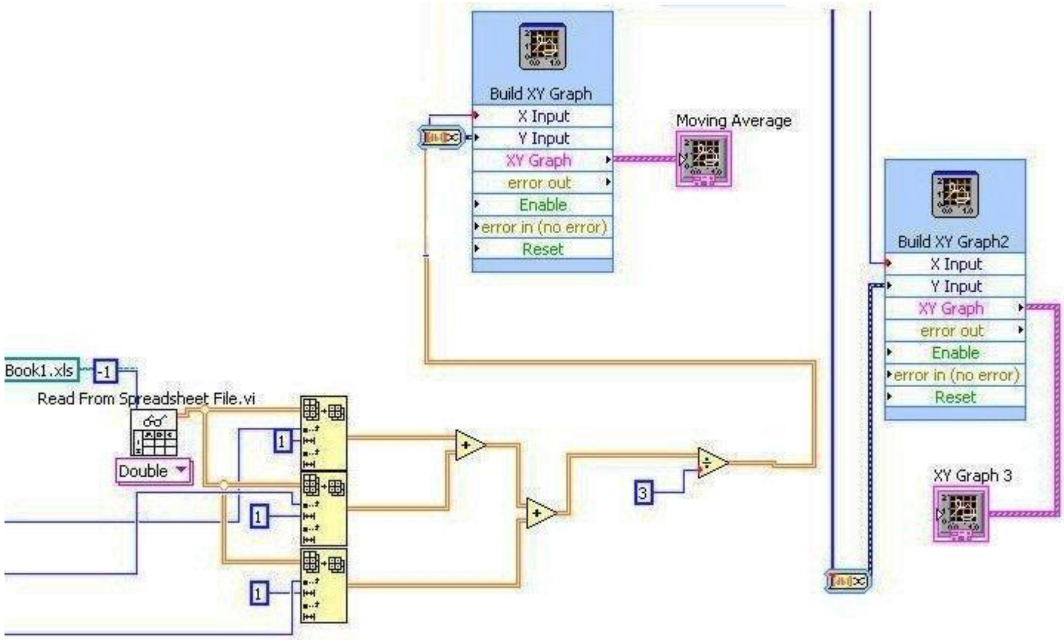

Figure 6.4: Read and Plot Block

A moving average is also plotted taking the last updated 3 values. Moving average plot is useful to comment on the variation in count. Moving average smooths out any fluctuation in count data.

6.4.4 Security Alarm

Count in any hour is compared with a specified value. If it crosses that value, the computer CPU error beep is initialized. The graphical block of alarm is shown in figure 6.5. The alarm duration and frequency can be adjusted in the function.

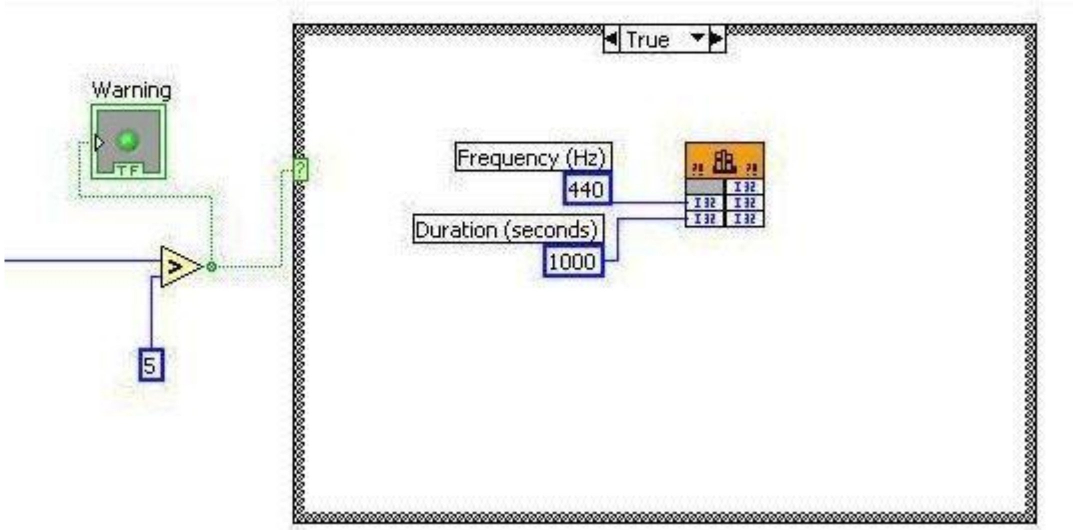

Figure 6.5: Alarm block

All these programming blocks are connected together to create the interfacing environment. The total block is surrounded by a while loop to ensure that the program runs continuously. There is a stop button in the while loop. Whenever the stop button is pressed, the loop condition becomes false and execution is stopped.

6.5 Virtual Instrument

All the blocks described in section 6.4 combine to form the virtual instrument for acquisition and monitoring data. Front panel of this instrument is shown in figure 6.6.

The current count indicator displays the radiation count in the last hour. Hour passed indicator displays the hours passed in the day. On the right side there are two LEDs. The count on LED is turned on when the count is taken in an hour. Warning LED is on when the alarm block is activated.

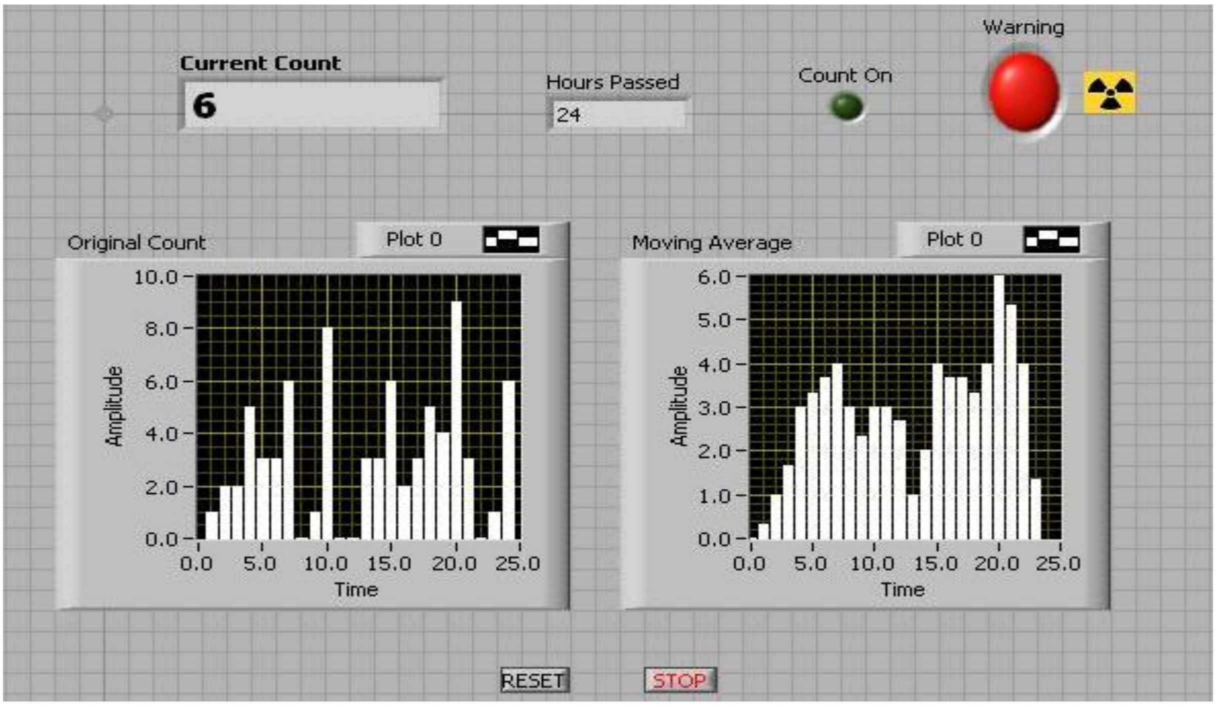

Figure 6.6: Front Panel

The stop button stops taking the count and reset button resets the whole setup.

The two plots of original count and moving average are shown in the front panel. X axis indicates time and Y axis indicates number of count per hour.

Figure 6.7 shows the simplified block diagram of the algorithm.

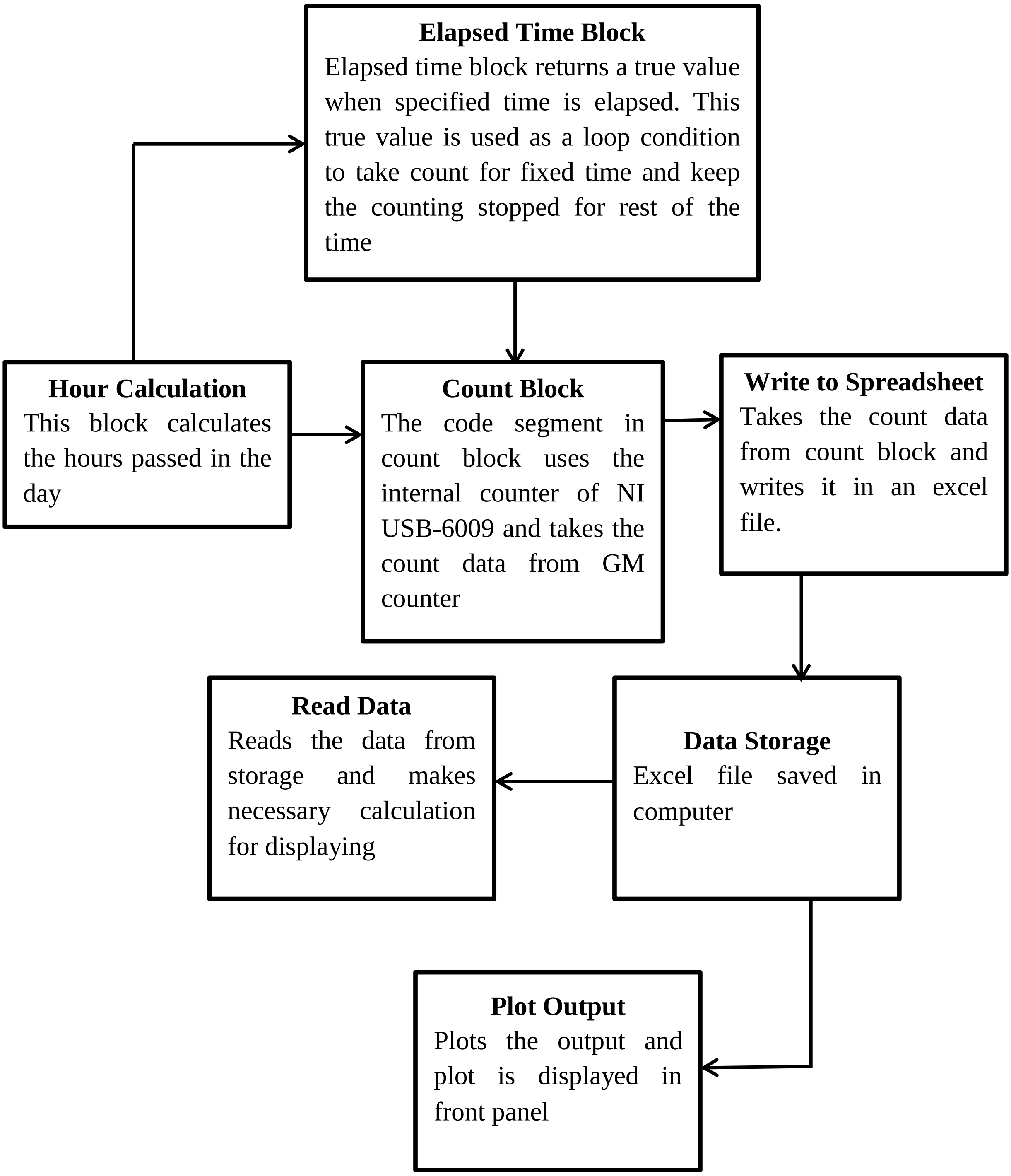

Figure 6.7: Block Diagram of interfacing algorithm

Chapter 7

Conclusion and Suggestion for Future Extension

7.1 Conclusion

To conclude, an inexpensive and easy to use environment for Radiation Detection and Measurement is implemented in our project. Most commonly used detectors, sources and additional instrumentation are modeled in an extensible way. Also the computer resource requirements are kept so low that with a modern personal home computer, one can use this LabVIEW based software efficiently. So the general cost of the necessary detection & measurement is lowered to a computer price, which is easily affordable in the current century. Additionally, in LabVIEW virtual window one can setup experiments which may be impossible to construct in real life. Furthermore, it creates a safe environment for the student, since there is no real radiation risk and also no possible damage risk to the expensive instruments, while learning radiation detection and measurement.

7.2 Applications of the Project

a) Background radiation is the ionizing radiation that the general population is exposed to, including natural and artificial sources. Measuring background radiation is very important and this project can be used to measure background radiation effectively.

b) Nuclear Power Plant (NPP) is the future of world's energy. Establishment of nuclear power plant requires pre and post monitoring of the location. This project can be a vital tool for the purpose.

c) Nuclear accidents can cause long time damage to people around and surrounding environment. Accidents can be minimized using the security alarm used in this project.

d) The archive program can be used to study radiation history of a certain location.

e) Maintenance of nuclear reactor and other machinery can be eased with this tool.

f) After a natural disaster (like Tsunami in Japan) environment is exposed to different types of harmful radiation. Measuring and monitoring becomes important in these situations.

g) The project is easy to handle and very much user-friendly. It can be used in educational purpose to teach students radiation basics. It can also be used to raise awareness among mass people about radiation.

7.3 Limitations and Solutions

a) Our LabVIEW code does not work at very high frequency, because of the resolution limit of NI USB-6009 DAQ card. This issue can be solved by using high resolution DAQ card.
b) To make this project cost efficient, GM counter is used for detection. But actually GM counters are not suitable for high radiation field; they are paralyzed when the count rate is too high. In order to get better results, scintillation detectors may be used.
c) We did not use any noise removal hardware. So because of the external noise, results can be varied a little bit. It can be resolved by using noise removal circuitry between GM counter and NI DAQ card.
d) The high voltage output can be varied to a limited range and can only be used for some fixed detectors working in that range.
e) The GM counter ZP-1320 is capable of detecting gamma radiation only
f) The dead time of GM counter causes error in pulse count.

7.4 Suggestion for Future Work

a) Since this LabVIEW based software is not developed with a professional team of developers and is quite new to this field, there are some bugs to be fixed. However currently it is operational and usable and will be developed in near future for more accuracy and to make it more user-friendly.

b) Neutron activation analysis is used to determine the concentrations, ingredients of a known or unknown material. This requires a nuclear reactor available to irradiate the sample and a radiation detection laboratory to analyze. Furthermore while during such an experiment the experimenter needs to predict the activity of the sample after irradiation. So the neutron activation analysis and spectroscopy module will be added to this project in order to enable activity, dose and spectrum prediction and also simulation, prior to neutron activation experiments. Thus, the experimenter will be able to make changes before irradiating materials to get the best results needed.

c) An online database can be formed in future where radiation data will be stored. Every time the data is stored in the excel file, it will be sent to the online database through internet. A webpage can be made where users can access using a password and monitor the radiation data.

d) Complete wireless control of the instrument can be achieved by internet or Bluetooth or any other wireless means of communication. GM counter and computer setup room will be near the radiated zone and can be controlled from thousands miles away by internet.

e) If DAQ card is not available, then serial interfacing of the hardware can be achieved by microcontroller and RS-232 to USB converter. It will minimize the cost of the total system.

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