RADIATION DETECTOR CIRCUIT

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By

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LIST OF ABBREVIATIONS

AC	Alternating Current
AM-241	Americium-241
DC	Direct Current
etc	Et Cetera
fA	femto ampere
IDE	Integrated Development Environment
I/O	Input/output
I-V	Current-Voltage
keV	kilo electronvolt
LCD	Liquid Crystal Display
mV	millivolt
MΩ	mega ohm
nA	nano ampere
SiC	Silicon Carbide
V	volt
USB	Universal Serial Bus
μSv/h	micro Sievert per hour

LITAR PENGESAN SINARAN

ABSTRAK

Tesis ini memberi tumpuan kepada membina litar pengesan sinaran bersama-sama dengan mikropengawal Arduino Uno. Pada masa kini, radiasi biasanya digunakan dalam beberapa bidang seperti bidang perubatan dan bidang komunikasi. Walau bagaimanapun, radiasi masih berbahaya bagi kita semua jika ia adalah dalam dos yang besar. Oleh itu, litar pengesan sinaran dibina untuk mengesan kewujudan radiasi. Dalam projek ini, AM-241 akan digunakan sebagai sumber radiasi. AM-241 akan mengeluarkan radiasi terutamanya alfa dan fotodiod SiC akan digunakan sebagai pengesan radiasi. Untuk mencapai kejayaan projek ini, litar transimpedance penguat dibina sebagai antara muka antara Arduino Uno mikropengawal dan fotodiod SiC. Selepas itu, voltan keluaran dimasukkan ke mana-mana pin analog daripada mikropengawal Arduino Uno. Arduino Uno mikropengawal diprogramkan untuk mengira nilai seperti voltan keluaran dan arus melalui fotodiod SiC. Semua nilai ini dipaparkan pada LCD dan juga berbanding dengan nilai-nilai yang diukur dengan menggunakan multimeter. Perbezaan antara kedua-dua telah dianalisis dan hampir tidak ada perbezaan. Prestasi fotodiod SiC dan litar transimpedance penguat juga telah dianalisis. Sebab-sebab yang mungkin menyebabkan Am-241 sinaran alfa tidak dapat dikesan oleh fotodiod SiC telah dikemukakan. Namun, sebab utama adalah kekuatan radiasi yang lemah daripada sinaran alfa Am-241.

RADIATION DETECTOR CIRCUIT

ABSTRACT

This thesis is focused on building a radiation detector circuit along with the Arduino Uno microcontroller. Nowadays, radiation is commonly being used in several fields such as medical field and communication field. However, radiation is still harmful to all of us if it is in a large dose. Therefore, a radiation detector circuit is built in order to detect the existence of radiation. In this project, AM-241 is used as the radiation source. AM-241 emits mainly alpha radiation and the SiC photodiode is used as the radiation sensor. To deal with this project, a transimpedance amplifier circuit is built as the interface between Arduino Uno microcontroller and the SiC photodiode. Then, the output voltage is fed into any analog pin of the Arduino Uno microcontroller. The Arduino Uno microcontroller is programmed to calculate the values like the output voltage and the current passing through the SiC photodiode. All these values are displayed on the LCD and also compared to the values measured by using the multimeter. The difference between both has been analyzed and there is almost no difference. The performances of the SiC photodiode and the transimpedance amplifier circuit have also been analyzed. The possible reasons of why Am-241 alpha radiation is undetectable by the SiC photodiode have been revealed. Yet, the main reason is that of the weak strength of the Am-241 alpha radiation.

CHAPTER 1

INTRODUCTION

1.1 Project Background

Radiation was used to describe electromagnetic waves in 1900. Around that time, electrons, X-rays, and natural radioactivity were discovered and included under the term radiation. And today, it refers to the whole electromagnetic spectrum as well as to all the atomic and subatomic particles that have been discover (Nicholas Tsoulfanidi, 2011) while in physics, radiation is referred to the emission or the transmission of the energy in the form of waves or particles through the space or the material medium (Weisstein *et al.*, 2014). Generally, radiation can be categorized into two types, which are ionizing and nonionizing radiation. Basically, ionizing radiation includes X-rays, alpha, beta and gamma and it comes from the nuclei of atoms, the basic building blocks of matter. Nonionizing radiation is the radiation within electromagnetic spectrum with sufficient energy to excite atoms or electrons, but insufficient energy to remove electrons from an atom or to cause ionization (Gayle Woodside *et al.,* 1997).

However, what are the effects of the radiation to all of us? If the radiation is in small dose, it will not harm us because we are actually living with the radioactive materials every day around and inside our body as well as in our environment. But, if it is in large dose, it could be harmful or fatal.

Therefore, radiation detection is very important. Radiation detection has long been of fundamental interest in a wide range of areas such as nuclear forensics and the environmental awareness of radioactive materials (Myeong-Hun Jeong *et al.,* 2015). For example, the Fukushima nuclear accident stimulated citizen scientists to collect and share radiation data across the world (C. J. Sullivan, 2014). A detector/sensor is a device that responds informatively to the phenomena to which it is exposed. Detection of radiation starts with the interaction of the radiation with matter, resulting in a conversion of the energy of the radiation into the generation of photons (light), electrical charge, or heat. There are some works that have used the sensor networks to detect and track the radiation (D. A. Burns *et al*., 2012; A. H. Liu *et al*., 2011). Recently, radiation sensing is being widely applied to the areas such as scientific analysis, safety systems, health care, etc. This results an increasing demand for low cost and reliable radiation sensing devices in the market (Yhang Ricardo Sipauba Carvalho da Silva *et al.*, 2015).

This project implemented the radiation sensor, which is the silicon carbide (SiC) photodiode with the microcontroller such as Arduino Uno. It was expected to detect the radiation and display the values like voltage and current that passing through the SiC photodiode on the LCD.

1.2 Problem Statement

As already known, Arduino Uno always needs an interface to interact with an external circuit. Generally, a voltage divider or a wheatstone bridge acts as an interface between Arduino Uno and external circuit. However, it is not practical in this project as the SiC photodiode is a passive component. Hence, a new interface which is able to interact with both Arduino Uno and the SiC photodiode is needed. Another issue is to ensure that the values like output voltage and the current passing through the SiC photodiode can be displayed on the LCD with minimal error percentage.

1.3 Objectives

The aims of this project are:

- To design a transimpedance amplifier circuit as an interface between Arduino Uno and the SiC photodiode.
- To analyze the performance of the transimpedance amplifier circuit.
- To display the output voltage and the current passing through the SiC photodiode with least error percentage.

1.4 Project Scope

This project focuses on the design of the transimpedance amplifier circuit as the interface to connect Arduino Uno with the SiC photodiode. Then, the Arduino Uno microcontroller should be able to display the output voltage of the transimpedance amplifier circuit and the current passing through the SiC photodiode on the LCD.

1.5 Project Organization

Overall, this project contains five chapters. In Chapter 1, it consists of the overview of this project, problem statement, objectives, project scope and project guidelines.

Chapter 2 summarizes the literature review for the design of the interface between Arduino Uno and external circuit. The process of designing the interface with required components will be further discussed within this chapter.

Chapter 3 is about the methodology of this project, the project flow, the project plan and the software and hardware needed. The flow chart of the design will be discussed in this chapter and the components that will be used to implement the hardware will be described.

Chapter 4 presents the results of the experiment and discussion. Analysis of the overall circuit will be shown in this chapter. All the analyzed data will be further discussed in this chapter.

Chapter 5 is the last chapter and it will be the conclusion part. In this chapter, a conclusion that concludes this project will be discussed. Besides, a brief statement of successfulness and future possible development will be reviewed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the theory of designing the interface between Arduino Uno and the SiC photodiode will be discussed. Arduino Uno, radiation source, radiation detector, the interface circuit between Arduino Uno and the SiC photodiode and the safety precautions when handling the radioactive substances will be explained throughout this chapter.

2.2 Arduino Uno

What is an Arduino Uno? Arduino Uno is a microcontroller board that has 14 digital input/output pins, 6 analog inputs, a 16MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It can simply connected to a computer by using a USB cable or power it with an AC-to-DC adapter or a battery to get started. It is the first board in the series of USB Arduino boards and the reference model for the Arduino platform. Therefore, it is the most used and documented board for the whole Arduino family as it makes things easier due to the simplified version of C++ and the already made Arduino microcontroller (atmega328 microcontroller (P. D. Minns, 2013)) that we can program and reprogram at any time. It has been used frequently in microcontroller (A. M. Gibb, 2010) programming due to its user friendly or easy to use setting. The labeled Arduino Uno Board is shown in Figure2.1 below.

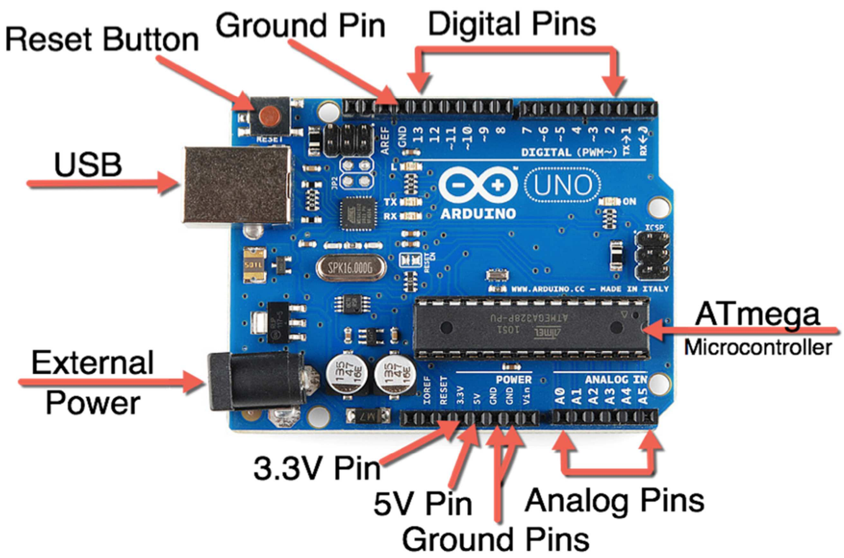

Figure2.1: Labeled Arduino Uno Board

Basically, Arduino can be classified into two parts: hardware and software. For the hardware part, it consists of many components that combine together to make it work and the main components on the board are:

- USB Plug: The first part of Arduino. It is used to upload the program to the microcontroller and has a regulated power of 5volts which also power the Arduino board.
- External Power Supply: This is only used to power the board and has a regulated voltage of 9 to 12 volts, mostly if the USB plug does not provide sufficient power for anything you have programmed it to do.
- Reset Button: Reset the Arduino in case another command has uploaded.
- Microcontroller: This is the device that receives and sends information or command to the respective circuit.
- Analog Pins (0-5): These are analog input pins from A0 to A5.

- Digital I/O Pins: These are the digital input, output Pins 2 to 13.
- Digital and Analog Ground Pins
- Power Pins: 3.3 and 5 volts power pins.

While for the software part, it is called Arduino Integrated Development Environment (IDE). The labeled IDE is shown in Figure2.2 below.

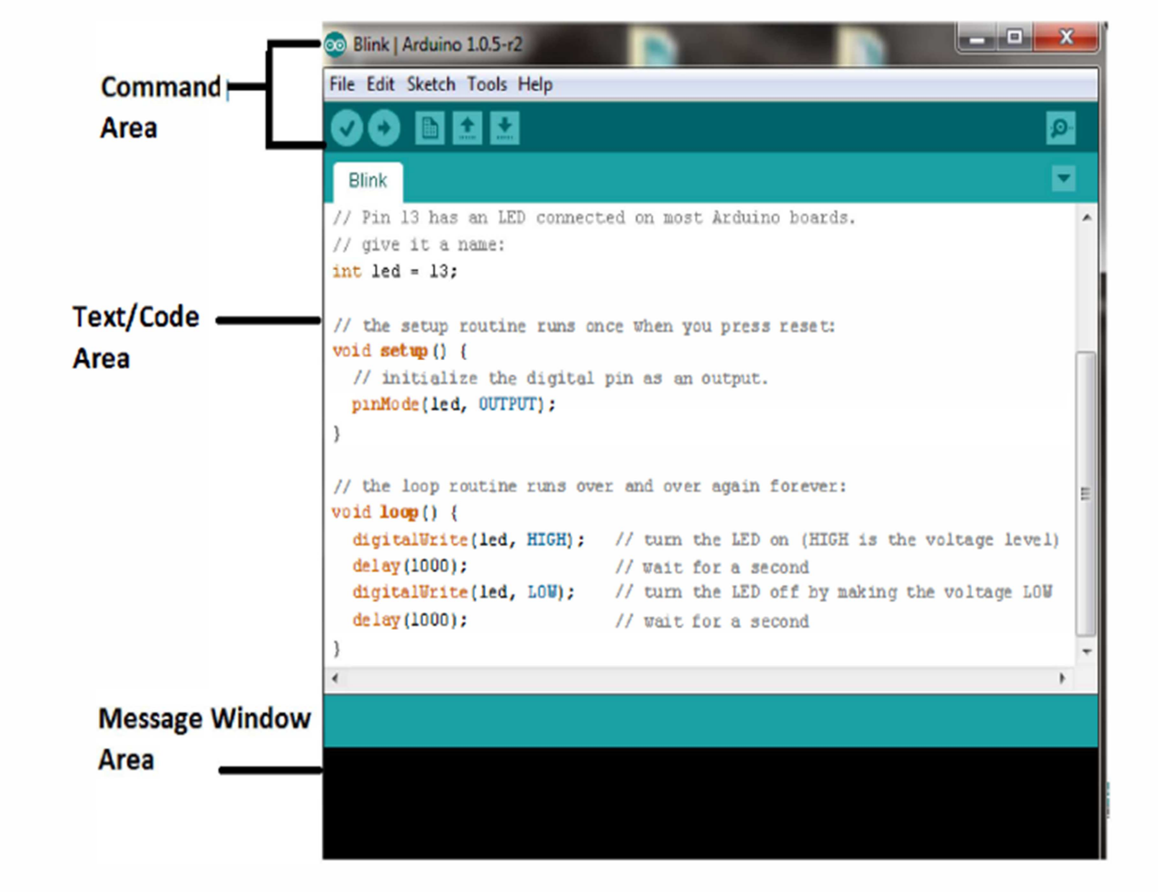

Figure2.2: Labeled IDE

This is a set of instructions that informs the hardware of what to do and how to do it. The Arduino IDE can also divide into three main parts, which are:

- Command Area: This is the area where you have the menu items such as File, Edit, Sketch, Tools, Help and Icons like Verify Icon which is for verification, Upload Icon for uploading the program to board, New, Open, Save and Serial Monitor used for sending and receiving data between the board and the IDE.
- Text Area: This is where you write your code or also known as sketch. A simplified version of C++ programming language is used to make it easier. There are two main parts when writing the code, which are:
    a) The setup function: All the variables that intended to use have to be initialized and assigned before the setup. This is where the initial condition of all variables is set and the preliminary code will only run once.
    b) The loop routine: This is the loop that will run or execute the code again and again.
- Message Window Area: This shows message from the IDE in the black area, mostly on verification on the code.

Figure2.3 below shows the technical specification of Arduino Uno.

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Figure2.3: Technical Specification of Arduino Uno

2.3 Radiation Source

2.3.1 Americium-241(AM-241)

AM-241 is the most common isotope of americium and it is radioactive. It can be easily found in ionization type smoke detectors. It has a half-life of about 432.2 years. AM-241 is an alpha emitter with a weak gamma ray byproduct. Alpha particles are energetic nuclei of helium. The production of alpha particles is normally termed as alpha decay. Alpha particles consist of two protons and two neutrons that bounded together to a helium nucleus. This made them to be relatively large and carry a double positive charge. Thus, they are not very penetrating and a piece of paper can stop their penetration. Alpha particles can only travel for a few centimeters as they end up deposit all their energies along this short path. The main α-particles have an energy level of approximately 5.4keV. Due to its low penetration of alpha radiation, it only poses a health risk when ingested or inhaled.

2.4 Radiation Sensor

2.4.1 Silicon Carbide (SiC) Photodiode

The SiC has good thermal stability and it is expected to be one of the particle detection materials used at high temperature (I. Ishikawa *et al.,* 2008). The detector characteristics like ohmic contact, Schottky contact, p-n junction and pin junction have been examined to develop a SiC radiation detector. SiC based semiconductor radiation detectors and electronic circuits are presently developed for the uses in high-temperature and high radiation conditions where the conventional semiconductor detectors cannot adequately perform. SiC is a better radiation detector as it has higher band gap energy and radiation resistance. The wide band gap energy and low intrinsic carrier concentration allow SiC to maintain semiconductor behavior at much higher temperature than silicon, which in turn permits SiC semiconductor detector functionality at much higher temperature than silicon detectors. Semiconductor detectors work well even at high temperatures, when the dark current is low enough so that its associated noise is acceptable for the particular application. Moreover, as the temperature increases, the dark current increases and also the parallel white noise component with the consequent worsening of the energy resolution capability

(Bertuccio G *et al.,* 1997). SiC radiation detectors are radiation resistant detectors, which means that the detector's parameters are not or very little affected by exposure to radiation. Materials like SiC lead to a detector capable of operating in high radiation fields (F Nava *et al*., 2008). A SiC photodiode is shown in the Figure2.4 below.

Figure2.4: SiC Photodiode

2.5 Interfaces between Arduino and External Circuit

In order to connect the SiC radiation detector with the Arduino Uno microcontroller, an interface is needed. In this project, a transimpedance amplifier circuit will be used as the interface circuit between the SiC sensor and the Arduino Uno.

2.5.1 Transimpedance Amplifier

Transimpedance amplifier is commonly a current-to-voltage converter. It is most often implemented using an operational amplifier. Transimpedance amplifier can be used to amplifier the current output of the sensors including photodiodes, photo detectors, Geiger-Muller tubes, etc to a usable voltage. Generally, current-to-voltage converters are used along with the sensors that have a current response that is more linear than the voltage response. Transimpedance amplifiers are one of the most critical front-end blocks at the receive-path of the electrooptical interface determining the whole optical link performance such as their speed and sensitivity (Majid Rakide *et al.*, 2016). A simplified transimpedance amplifier is shown in Figure2.5 below.

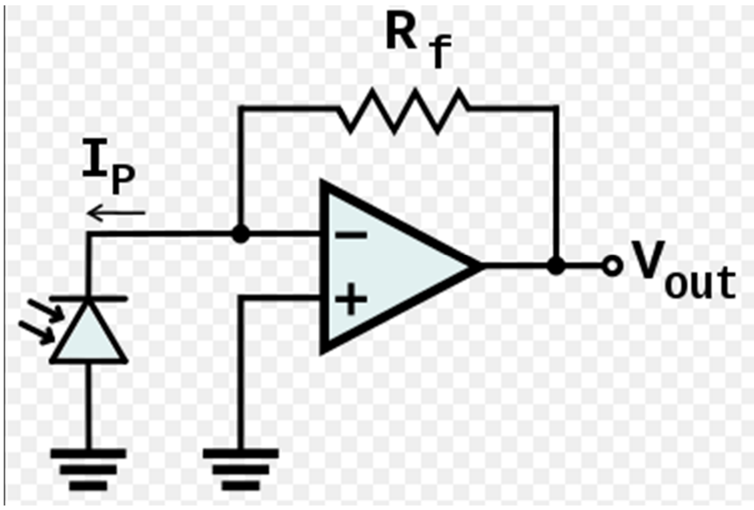

Figure2.5: Simplified Transimpedance Amplifier

2.6 Safety Precautions

Safety precautions are needed when handling radioactive substances. There are some safety precautions that can be applied, which are:

- The radioactive sources are kept in a sealed container unless they are being used in experiment or demonstration.
- The radioactive sources have to be returned to the sealed container immediately after the experiment or demonstration is finished.
- No radioactive substances should be handled with bare hands. They should be handled with tongs or forceps to keep a distance from the radioactive substances.
- The radioactive substances should be kept at arm's length, pointing away from the body when carrying out the experiment or demonstration.
- Protective clothing has to be worn when dealing with the radioactive substances.
- The exposure time to the radioactive substances has to be kept as short as possible.
- The radioactive substances should always be kept as far as possible from the eyes.
- Hands must be washed after handling the radioactive substances for the experiment or demonstration and definitely before eating.
- The experiments involving radioactive substances have to be carried out in the laboratory surrounded by the thick wall with lead.
- The radioactive waste must be sealed and buried deep in the ground to prevent leakage of the radiation.

2.7 Summary

In this chapter, the background of the interfaces between Arduino Uno microcontroller and the external circuit, which is the transimpedance amplifier circuit, is being reviewed. Besides, the basics of the Arduino Uno and the backgrounds of the radiation source and the radiation sensor are also reviewed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the flow chart of the experiment and the overall project flow with brief descriptions will be explained. The components that will be used for hardware implementation will be discussed in this chapter too.

The design, the planning, the performance and the evaluated process of the project will also be discussed. All the data and information that have been collected will follow the design that was planned before. After obtaining the resources successfully, the implementation processes of this project are conducted. Methodology is organized to ensure that this project is going to be done smoothly and effectively.

3.2 Flow Chart

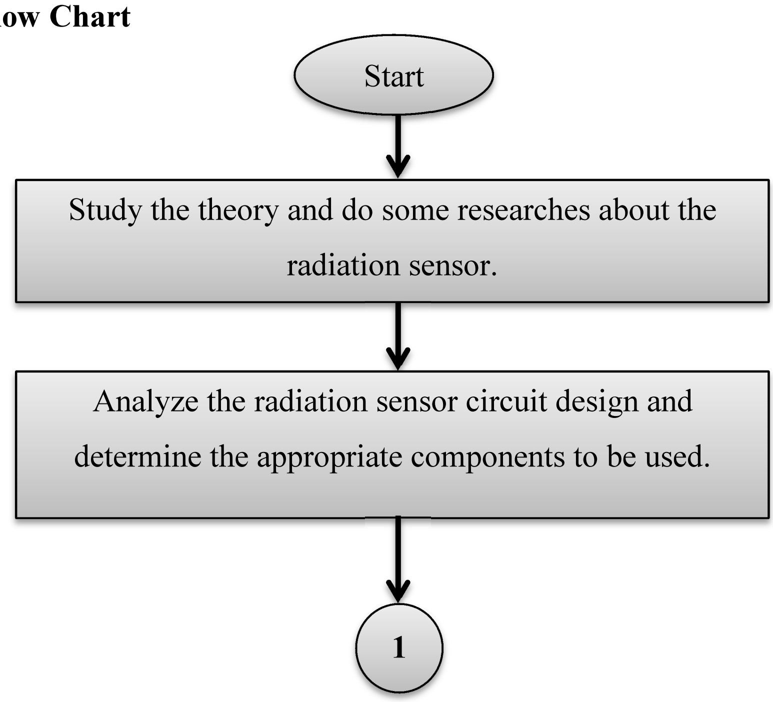

Figure3.1: Flow Chart of The Overall Project Development

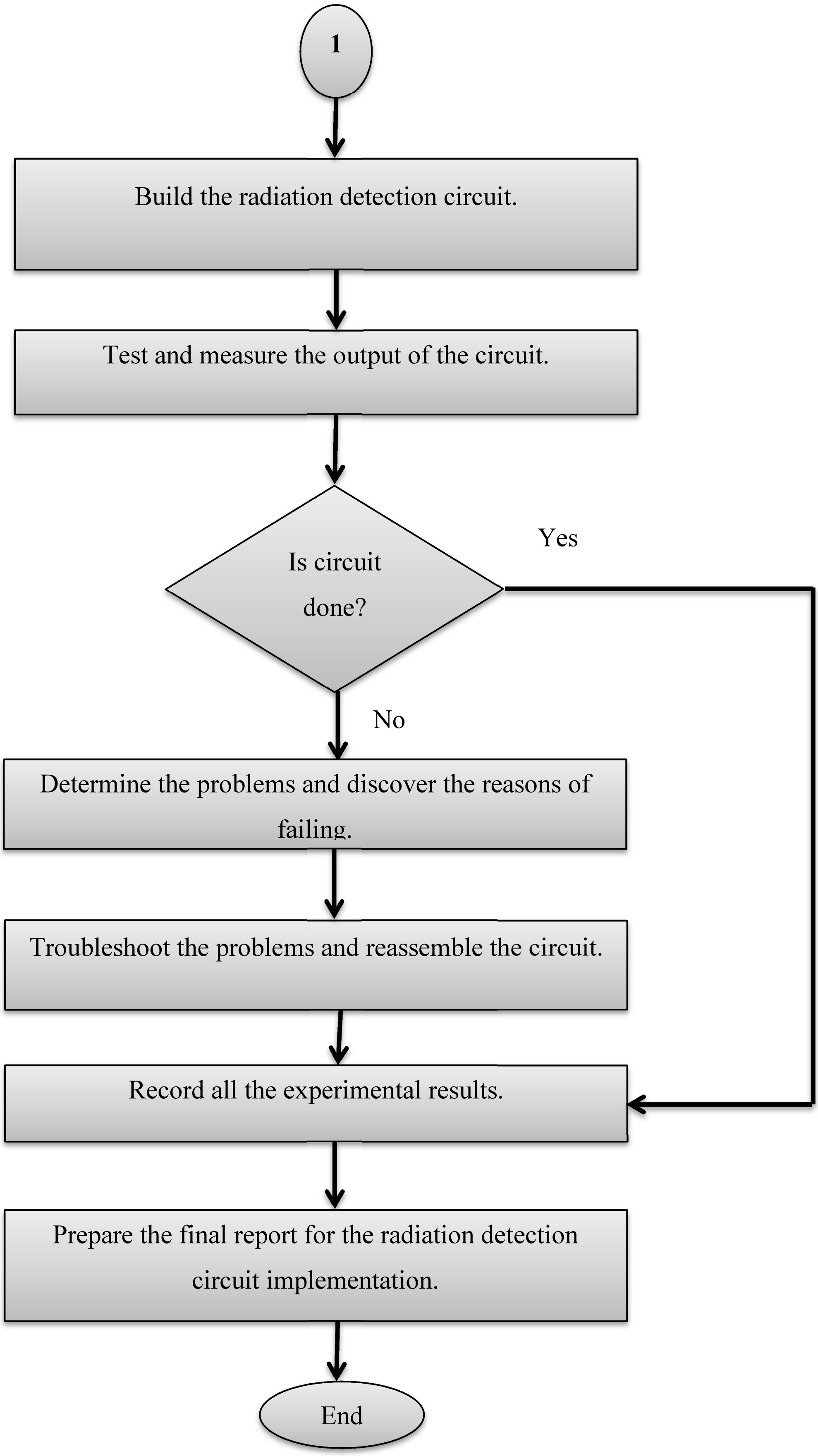

Figure3.1: Flow Chart of The Overall Project Development (cont)

Figure3.1 shows the flow chart of the overall planning for this project. This project is carried out based on Figure3.1 in order to archive or fulfill all the objectives. Before kick start this project, a plenty of theories and researches about the radiation sensor circuit have been studied. Then, the radiation sensor circuit design has been analyzed and the most appropriate components to be used in this project are determined among all these theories and researches. A radiation detection circuit is built and the output of the circuit is tested and measured. If the circuit is able to achieve the objectives of this project, all the experimental results are being recorded. If the circuit cannot achieve the purposes of this project, the problems and the reasons of failing are determined. After troubleshoot the problems, the circuit is reassembled. Then, all the outcomes of the project are recorded. Lastly, a final report for this project is prepared.

3.3 Overall Circuit Design

For a simple overall circuit design, there are three main parts of the circuit that must be connected with each other to get the expected outcomes. The overall circuit design is shown in Figure3.2 below.

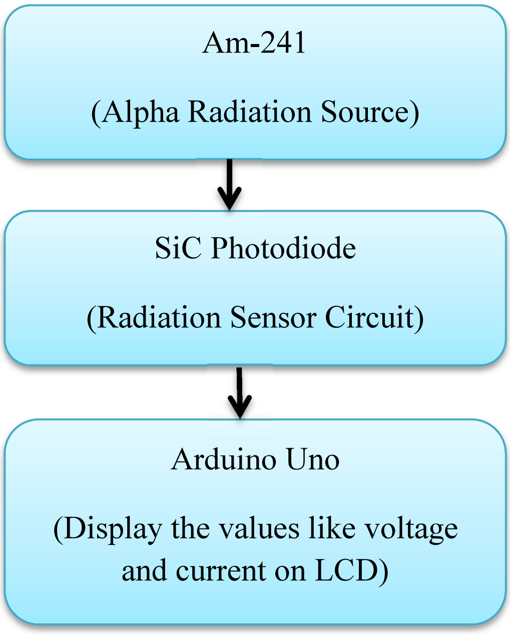

Figure3.2: The Overall Circuit Design

3.4 Circuit Description

3.4.1 Transimpedance Amplifier

In this project, a transimpedance amplifier is used as the interface between the SiC photodiode and the Arduino Uno. Figure3.3 below shows the schematic design of the transimpedance amplifier used in this project.

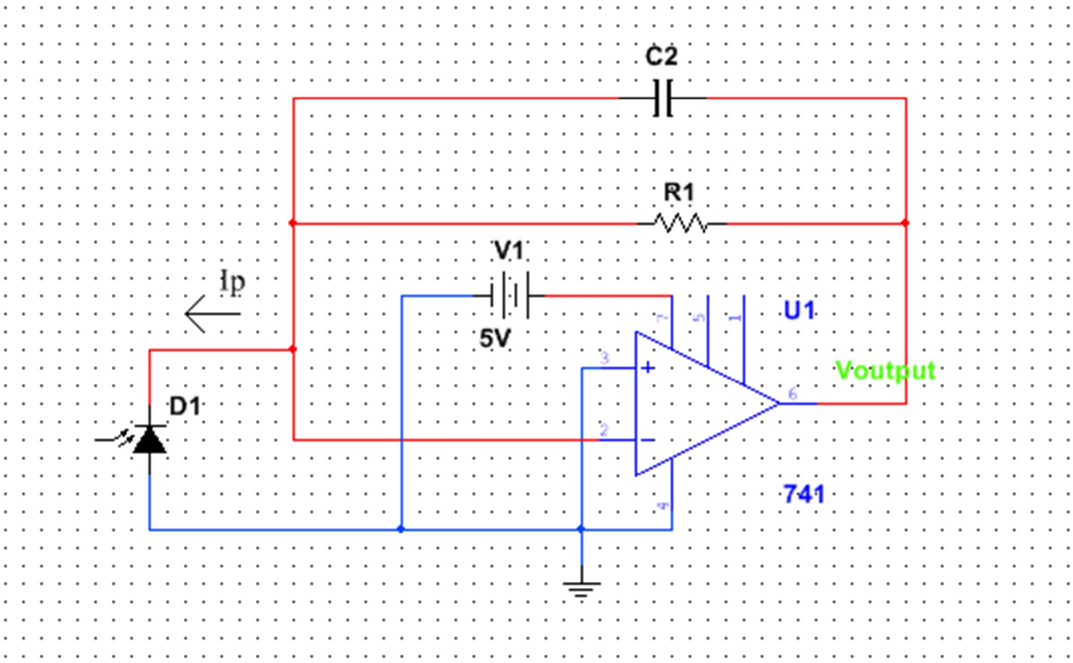

Figure3.3: The Schematic Design of The Transimpedance Amplifier

The transimpedance amplifier has low impedance to the SiC photodiode and isolates it from the output voltage of the operational amplifier. Based on the Figure3.3, the feedback resistor, R1 of the transimpedance amplifier has a very high resistance. This is because the gain of the transimpedance amplifier is set by this resistor and has a value of -R1 as the amplifier is in an inverting configuration. Besides, the large value of R1 is to allow the output to feedback into the input and simply max out the output at 5V at all the time. Hence, the DC gain of the transimpedance amplifier can be represented by the equation3.1 below:

$$\text{DC gain} = -R1 = \frac{V_{output}}{I_p} \qquad \ldots(3.1)$$

where V_{output} is the output voltage of the transimpedance amplifier, R1 is the feedback resistor and I_p is the induced current. From equation3.1, the output voltage of the transimpedance amplifier, V_{output} can be determined by deriving the equation as below:

$$V_{output} = -I_p \cdot R1 \qquad \ldots(3.2)$$

Since the gain of the transimpedance amplifier is large, the input offset voltage at the non-inverting input of the operational amplifier will act as an output DC offset. This circuit consists of low input signal, high resistance and high gain may causes the output signal to oscillate. Thus, a capacitor, C2 is needed in order to stabilize the output signal. In the circuit shown in Figure3.3 above, the SiC photodiode is connected between ground and the inverting input of the operational amplifier while the non-inverting input of the operational amplifier is also connected to the ground. This then provides a low impedance load for the SiC photodiode, which can keeps the photodiode voltage low.

3.4.2 Exposure of AM-241

After the SiC photodiode has been installed in the transimpedance amplifier circuit, AM-241 is brought towards it. AM-241 is a radioactive substance that will radiate mostly alpha particles which will then be detected by the SiC photodiode. When AM-241 is brought towards SiC photodiode and it detected a radiation, a current will be induced and then being amplified as the output voltage.

3.4.3 Reaction of SiC Photodiode

When the SiC photodiode is exposed to Am-241 alpha radiation, it will absorb the photons or the alpha particles of Am-241. When the photons or the alpha particles are absorbed in the SiC photodiode, the current is induced. This is because when the SiC photodiode is struck by a photon or the alpha particle, which has sufficient energy, an electron-hole pair is created. This mechanism is commonly known as the inner photoelectric effect. The absorption of the photons occurred in the junction’s depletion region of the SiC photodiode. In this region, the holes are moving toward the anode and the electrons are moving toward the cathode. Thus, a photocurrent is induced. The total current that passing through the SiC photodiode is equal to the sum of the photocurrent induced and the dark current. Dark current is a current that is generated in the circuit even there is absence of light. SiC photodiode has a very low value of dark current which is in the scale of femtoAmpere (fA). Therefore, the total current passing through the SiC photodiode is assumed to be the photocurrent induced only.

3.4.4 Arduino Uno Microcontroller

Arduino Uno microcontroller was used because of its simplicity to be programmed, its flexibility and it can be understood easily as well. The output voltage of the transimpedance amplifier, V_{output} is fed into the analog pin of Arduino Uno microcontroller. Figure3.4 below shows how the V_{output} is fed into the analog pin of the Arduino Uno along with the LCD display.

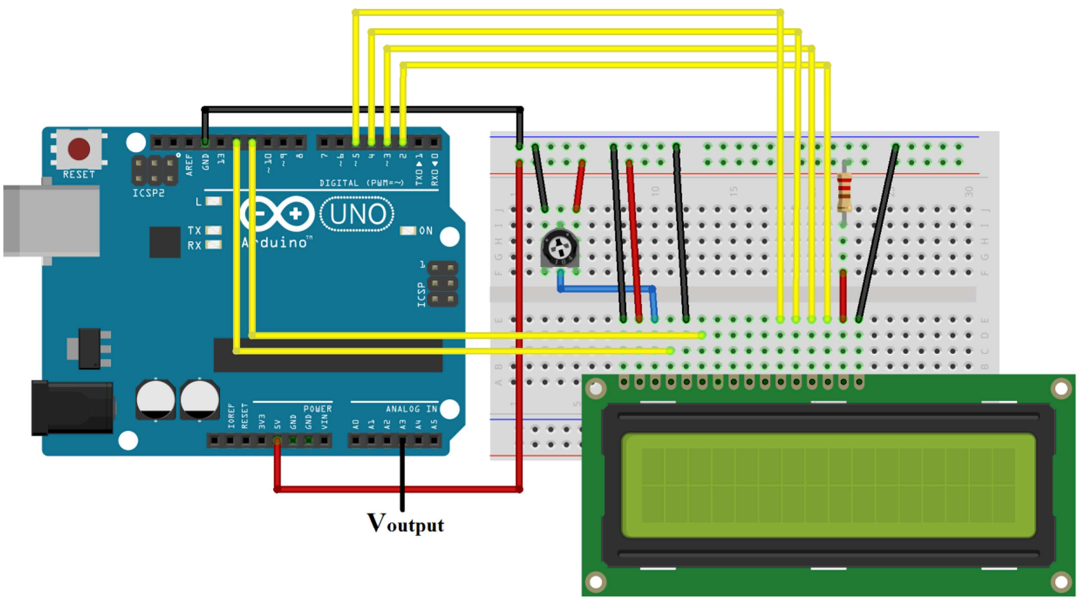

Figure3.4: The Arduino Uno with V_{output} and LCD Display

The analog read of the Arduino Uno microcontroller can produce a value vary from 0-1023, which is equal to 0V to 5V. Arduino Uno microcontroller is used to read the value at its analog pin and programmed to calculate its actual voltage reading which is fed into the analog pin. This actual voltage reading is actually the output voltage, V_{output}

of the transimpedance amplifier. After obtaining this actual voltage reading, the current passing through the SiC photodiode can also be calculated by programming the Arduino Uno microcontroller. All these values are also programmed to be shown on the LCD connected to the Arduino Uno microcontroller.

3.4.5 I-V Characteristic of SiC Photodiode

In order to obtain I-V characteristic curve of the SiC photodiode before and after the alpha radiation for 24 hours, a circuit has been conducted. The schematic design of the circuit is shown in Figure3.5 below.

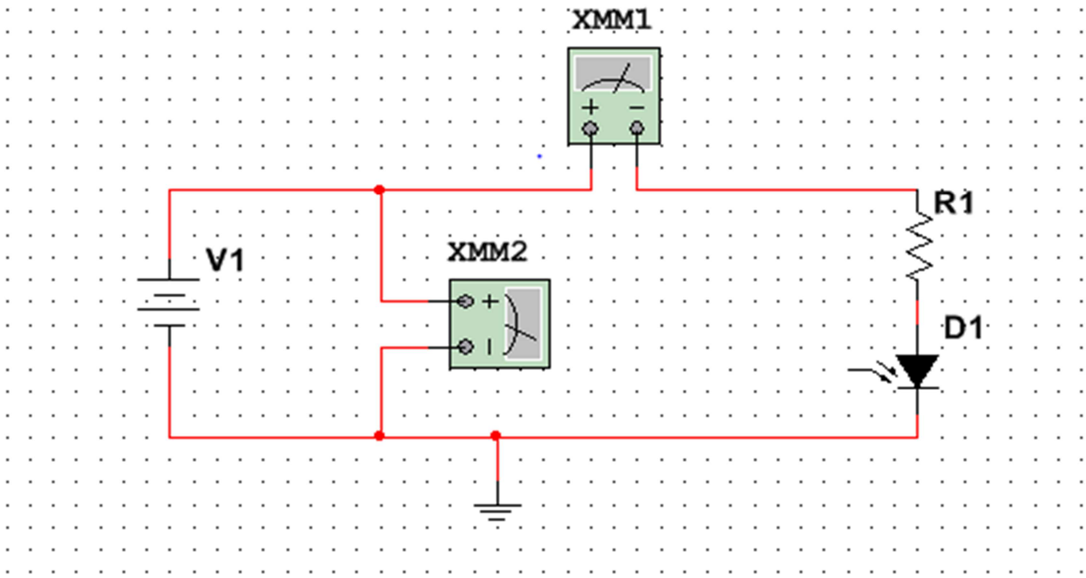

Figure3.5: Schematic Design of The Circuit To Obtain I-V Characteristic of SiC Photodiode

The SiC photodiode is put together with the Am-241 for 1 day, which means that it is exposed to the alpha radiation for 24 hours. This is to observe the difference if there is any after the exposure period. I-V of the SiC photodiode is obtained by using the voltmeter and ammeter in the laboratory.

3.4.6 Measurement of Am-241 Alpha Radiation

A geiger muller counter has been used to determine the strength of Am-241 alpha radiation. It is used to observe the radioactivity of the Am-241. Am-241 is placed directly to the geiger muller counter so that the geiger muller counter can get the results more accurately. The geiger muller counter is connected to the computer. The radioactivity and the ionizing radiation dose of the Am-241 will be displayed on the data logger that has been installed in the computer.

3.5 Input Specification

In order to complete this project, a simple prototype has been built and tested. The prototype is tested under the operating conditions:

- Positive voltage supply, +V = 5V
- Negative voltage supply, -V = 0V
- Room temperature

3.6 Safety Precautions

Since the Am-241 is used in this project and it is radioactive, there are some safety precautions to be applied when carrying out the project. Even though Am-241 is an alpha radiation source and it is not penetrating, safety precautions are still needed to prevent any accident to be happened. Here are some safety precautions that have been applied when dealing with Am-241 throughout this project:

- ➢ Am-241 is kept in a sealed container when it is not being used.
- ➢ Am-241 is returned immediately to the sealed container after being used.
- ➢ Am-241 is handled by using gloves, never with bare hands.
- ➢ The exposure time to Am-241 is reduced to as short as possible.

- ➢ Hands are washed every time after handling the Am-241.

3.7 Calculation

3.7.1 Output Voltage

The analog read of Arduino Uno microcontroller can produce a value of 0-1023, which is equal to 0V and 5V. This value can be calculated using the equation below:

$$V_{out} = (\text{AnalogReadValue}) \left(\frac{5000}{1024} \right) - \text{Offset} \qquad \ldots(3.3)$$

where V_{out} is the actual voltage reading at the Arduino Uno microcontroller. This equation is in the unit of millivolts and there is an offset to subtract to get the actual V_{out} converted by the induced current caused by the radiation.

3.7.2 Current Passing Through SiC Photodiode

After the actual voltage reading is obtained, the current passing through the SiC photodiode or the current induced by the alpha particles can be easily calculated by applying Ohm's Law. Ohm's Law states that the current passing through a conductor is directly proportional to the voltage across it and inversely proportional to its resistance.

$$I = \frac{V}{R} \qquad \ldots(3.4)$$

By applying the equation 3.4 above, the values of V and R are substituted by the V_{out} and R1 respectively and the current passing through SiC photodiode, I_p can be obtained by using the equation below:

$$I_p = \frac{Vout}{R1} \qquad \ldots(3.5)$$