# ISTANBUL TECHNICAL UNIVERSITY

## FACULTY OF SCIENCE AND LETTERS


**Physics Engeering Design I Report**

# Design of a microprocessor based multichannel analyzer for radon detection


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# ABSTRACT

This report describes the design of a microprocessor based multichannel analyzer going to be used for radon detection. A silicon PIN photodiode was used for detecting alpha particles. The main advantages of this design are being low cost and low power consumption. Detector in question is planned to be used in the project related to the prediction of eqrtquakes by measuring radon levels in soil. Radon is a naturally occuring noble gas originated from radioactive decay series of $^{238}$U,$^{235}$U. Since it lacks any odor, taste it is impossible for humans to sense. However, it is possible to measure the activity of radon in desired location with modern nuclear instrumentation. Radon gas emissions must concern every household medically because respiration of high concentrations of radon poses great danger to lung health. In order to measure radon activity levels, designing and building a compact, self-sufficient device would be extremely beneficial. Therefore the aim of this study is to utilize modern equipments to detect radioactivity and gather relevant data. Data acquisiton from the silicon PIN photodiode is achieved with a pulse amplifying circuitry and a microcontroller unit. This data then displayed simultaneously for nuclear spectroscopy for radon gas.

# ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my advisor Prof. Dr. Cenap Ş. ÖZBEN for guiding me in the steps of this work.

Osman Doğukan Kefeli

# CONTENTS

## ABBREVIATIONS

| | |
|---|---|
| $\alpha$ | Greek letter minuscule alpha |
| $\beta$ | Greek letter minuscule beta |
| $\gamma$ | Greek letter minuscule gamma |
| $\mu$s | Micro Second |
| $MCA$ | Multi Channel Analyzer |
| $MeV$ | Mega Electron Volt |
| $Ra$ | Radium |
| $Rn$ | Radon |
| $ROI$ | Region Of Interest |
| $Th$ | Thorium |
| $U$ | Uranium |

# INTRODUCTION

Radiation is the release of energy in the form of moving waves or streams of particles. In nuclear physics there are four main types of radiation and therefore different radiation detection methods. These four main radiation types are heavy charged particles, $\beta$ (beta) particles, $X$ and $\gamma$ (gamma) rays and neutrons. Since the radiation is a form of energy, in nuclear physics this energy is presented in $MeV$ scale. An electron-volt $eV$ is defined as the energy to accelerate one electron in 1V potential. Which the energy corresponds to a few picojoules.

## 1.1 Detection of Radiation

There are various methods for radiation detection. Each technique is used for analyzing different parameters. Detection of radiation can be seperated into four main subclasses with respect to their purposes. First, instinct is to directly detect the existence of radiation process in the environment. This method classifies the existence of the radiation by a threshold parameter and gives a definitive result. Another neccesity is to monitor the radiation with respect to time to get information about source strength. Third method is analyzing the radiation in order to determine the source's type. This can be done by energy spectroscopy methods. Another commonly used procedure is dosimetry. Dosimetry is a technique of measuring and calculating how much radiation a material or living tissue is exposed to, directly or indirectly, to radioactive radiation. In the field of medicine, the amount of radiation given to patients for treatment is measured by dosimetry methods and kept under control.

Radiation characteristics consist of three main classifications. X and Gamma rays interact with the spins of electrons in the target material and cause ionization. On the other hand, heavy ions interact with both target electrons and nuclei and uncharged particles such as neutrons interact with the target nucleus. They are either absorbed or scattered from the target nucleus. Uncharged particles do not scatter from electrons.

The operation of any radiation detector is largely determined by how the radiation to be detected interacts with the detector's material [1]. In order to construct a radiation detection system first of all targeted radiation type must taken into account. Then operating range must be optimized to the target intensity for efficiency.

Radon detection system can be constructed with instrumentation of solid-state silicon detectors. This electronic components are able to detect alpha particles emitted by radon.

## 1.2 Nuclear Spectroscopy

Nuclear spectroscopy used as a quick analytical method for applications like isotope identification [2], nuclear forensics [3], astrophysics [4], medical diagnosis [5] etc. Nuclear spectroscopy includes measurements of gamma rays, charged particles and neutrons emitted from the nuclear reactions or decay of radioactive nuclei. It is mainly utilized with the properties of individual levels such as energy, angular momentum, spin, magnetic and electric moments and transition rates. In nuclear spectroscopy, energy is emitted as beta radiation, alpha radiation or in the form of photons in the gamma-ray range. With the help of mesasurement techniques radiation spectrum of the nucleus is detected in order to identify certain properties to discover the unknown. Instrumentation of electronics to detect the energies emitted by the nuclei have enabled advanced nuclear spectroscopy methods, resulting a more precise enviroment for nuclear data analysis. Further developments have made nuclear physics revolutionary for fields such as nuclear forensics, homeland security, imaging and diagnostics, radiation treatment, material science, art and archaeology. In digital nuclear spectroscopy, the digitizer plays the most important role in the performance of the spectrum analyzer system.

## 1.3 Single Channel Analyzer

Single channel analyzers have been used for measuring pulse amplitude. Single channel analyzer has two adjustable voltage tresholds and produces an output logic pulse depending on the conditions that its input signal falls within the two pre-set treshold levels [6].

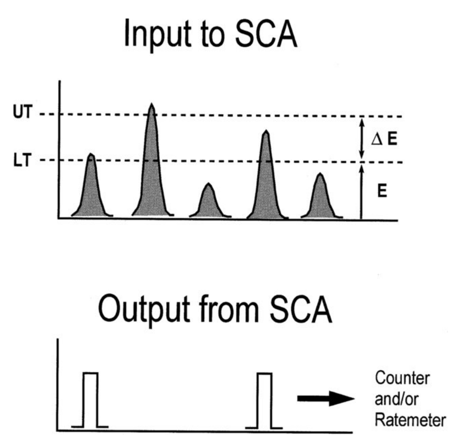


**Figure 1.1:** Pulse height analysis in a single-channel analyzer [7].

Figure above shows that pulses that yields between lower threshold (LT) and upper treshold (UT) digitized as a TTL pulse by the single channel analyzer. This is a good practice for counting the rate of a certain radiation that has known characteristic energy.

However, when it is important to measure the corresponding energy of each pulse, this process must be done for every small $\Delta E$ energy range covering from the ground up. For this purpose multi channel analyzers evolved and utilized from the single channel analyzers. In principle a MCA, equivalent to many independent single channel analyzers consists of conitinous arranged windows [8]. Due to rapid advancements in semiconductor and integrated circuit technology, today's spectrometry system generally includes an analog-to-digital converter (ADC) for digitizing the input pulse.

## 1.4 Multi Channel Analyzer

The multi channel analyzer (MCA) system consists of several key principle components. These are simply data acquisition module, processing and storage unit, an analog-to-digital converter and a visual display module. MCA scans each energy channel that the system is capable of measuring. Records the number of pulse counts for each energy and logs the data in attainable format for determining the nuclide in nuclear spectroscopy system.

The ADC conversion unit utilizes the electrical analog signals to equivalent bytes to make sense in digital interface for further computational analysis.

Multi channel analyzer operates in two different modes. First one is pulse height analyzer mode, input pulses are mapped to bins by their amplitudes. Each bin represents an energy range and this its precision depends on the analyzer's resolution. Second mode is the multi channel scaler mode, where pulses are sorted according to the time of arrival. MCA in design provides a visual display for realtime monitoring of the pulse height spectrum. Graph displayed on the screen provides the number of counts vs. channel number, basically a histogram of the number of counts vs pulse height. Number of pulse heights are analyzed with upper and lower level discriminators that can be adjusted manually.

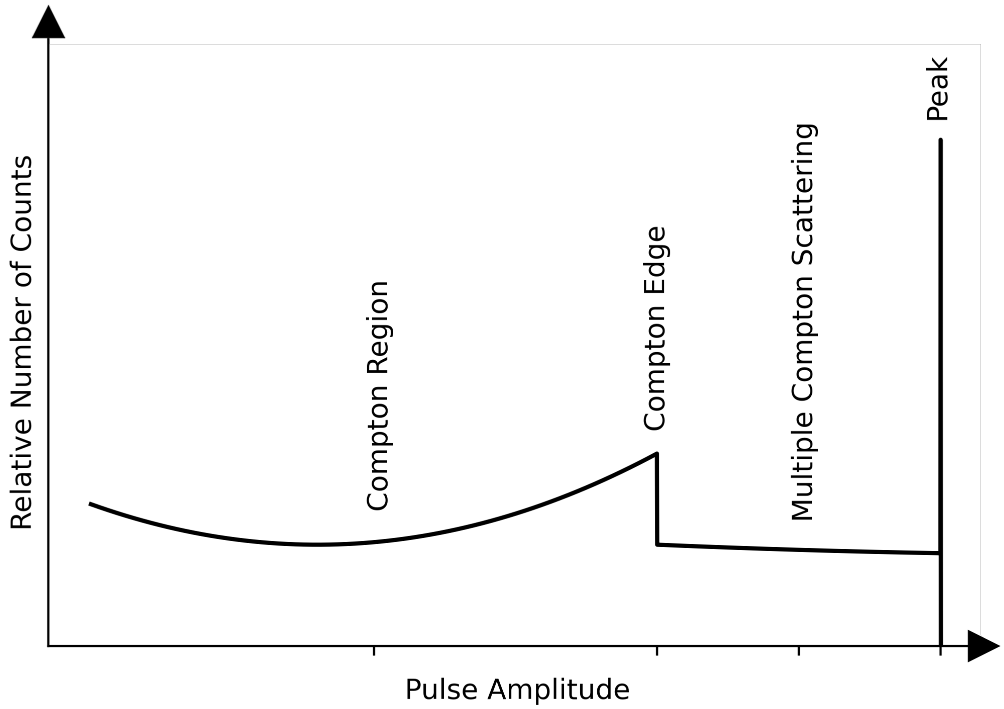


**Figure 1.2:** Ideal spectrum of a multi-channel analyzer.

Pulse height spectrometry examines the amplitudes of signals being received from the detector. This spectrometry describes how energy is transferred in a crystal. Pulse heights are generated from photoelectric interaction within the crystal that creates a charge proportional to incident particles energies that are deposited in the crystal structure. Ideally its expected to see energies piled up at a certain energy. When compton scattering occurs inside the detector only a part of the energy is deposited in the crystal. The energy deposition from Compton scattering events depends on the defection of the scattering.

### 1.4.1 Analog to Digital Converter

Since measuring radiation is done by converting deposited energies into voltages and radiation energies are proportional with the induced voltages in the detector, one must precisely measure analog signals. Data acquisition systems are used to detect these analog signals and convert them to digital form [9]. An ADC converts continuous analog signal to discrete digital signal.

### Resolution

The ADC resolution referred as the lowest incremental voltage that creates a change in the digital output. The resolution of the converter is also defined as the number of different values that converter is able to output. Number of discrete values usually power of two. For example an ADC with 8-bit resolution can encode an analog signal to 256 levels

$$(2^8 = 256)$$

. Therefore digital output signal must be in range of 0-255, an unsigned 8-bit integer. The smallest incremental voltage can be expressed with respect to reference voltage. For example with a 3.3 $V$ reference voltage, the resolution of an 8-bit ADC is

$$\frac{3.3V}{2^8} = 12.890625mV$$

With this property the ADC has a quantization error. This error is determined by the least significant bit (LSB) of the ADC, and in the example, ADC has a quantization error of 1/256 of the total signal range which means that original analog input value can be 12.890625 $mV$ lower.

### Sampling Rate

Analog signals are continuous and it is required to digitize to a discrete value at a certain time. Sampling rate is defined as the how fast a new digital value is sampled from the continuous analog signal. The Nyquist-Shannon sampling theorem [10] tells that sampling rate should be higher than twice of the frequency of the signal to trust the generated signal. The ADC clock of Atmega328P is 16 MHz divided by a 'prescale factor'. The prescale is set by default to 128 which leads to 16MHz/128 = 125 KHz ADC clock. Since a single conversion takes 13 ADC clocks, the default sampling rate is around 9600 Hz [11].

### Conversion Time

Practical ADC cannot make an instantaneus conversion. Input value must be held constant for a interval of time. This time is specified as the *conversion time.* Integrated ADC modules contains an embedded *sample and hold* circuitry inside to provide the conversion time. How fast can an ADC measure is determined by this quantity.

## 1.5 Silicon PIN photodiodes

A photodiode is similar to a PN junction diode in that it generates electric current using voltage as the energy source, but PIN (P-Intrinsic-N) photodiodes generate electrical signal using both voltage and light.

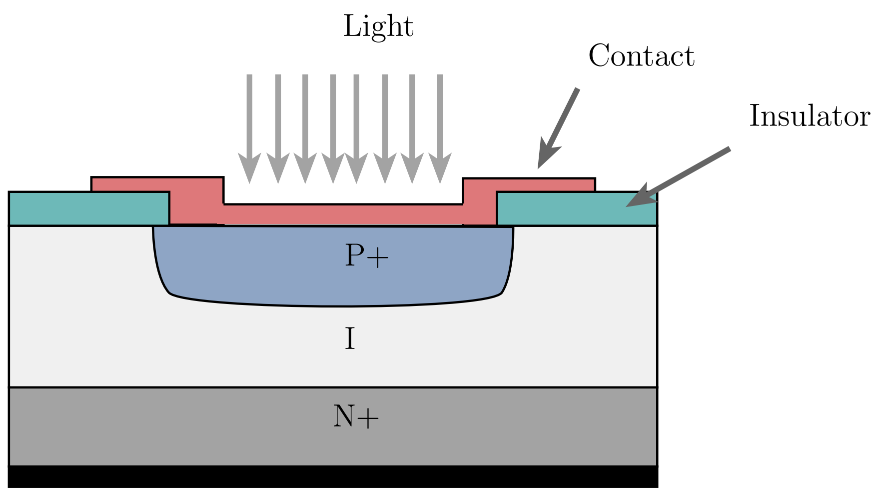


**Figure 1.3:** PIN photodiode structure [12].

A moderate reverse bias is used to operate the photodiode. This prohibits any carriers from entering depletion layer, therefore no current will flow. When a photon hits the intrinsic region, it can interact with an atom in the crystal lattice, dislodging one electron. A hole-electron pair is created in this method. Under the influence of the electric field, the hole and electron will travel in opposite directions across the intrinsic region, causing a tiny current to flow. The size of the current is found to be related to the amount of light that enters the intrinsic region. The more light, the greater the numbers of hole electron pairs that are generated and the greater the current flowing.

## 2.1 Microcontroller Unit

To analyze the full spectrum, values received from ADC component must be stored in some sort of device. A simple ATmega based microcontroller device have been used. For convenience sake a simple Arduino that is available and also relatively cheap can be used.

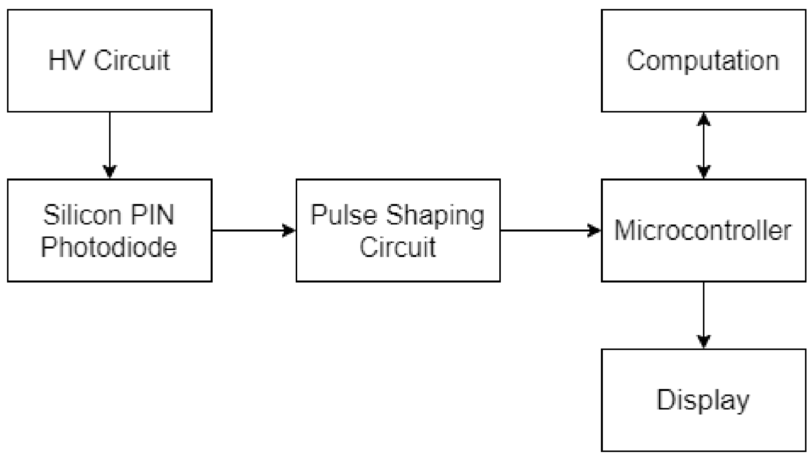


**Figure 2.1:** Block diagram.

Values obtained from the ADC can easily be stored, operated according to the needs and also spectrum histogram can be displayed for real-time analysis.

## 2.2 Pulse Amplifier Circuit

To read the incoming signal generated from silicon PIN photodiode, it must first be amplified. The amplified signal passes through a comparator and gives the read signal to the microcontroller when input pulse is above the pre-determined noise level. Microcontroller is able to read the analog signal that is outputted from the peak-holder circuit.

Pulse acquisiton system operates as follows, firstly the storage capacitor of the peak-detector is discharged. Then continously reading and waiting for a high signal from the LM311 comparator. When high signal is acquired from comparator, output signal is immediatly read and capacitor is discharged by a reset pulse applied to IRF840 MOSFET's gate, therefore a consecutive pulse can be read. Reading in the voltage of the capacitor is equal to the maximum voltage of the incoming pulse.

## 2.3 Peak Holder Circuit

To retrieve the low and narrow pulse, a peak sample holder circuit must be utilized. With the peak-holder part of the circuit it is possible to hold and extend the short-width pulse's height and read the analog voltage with the microcontroller.

Since the capacitor voltage can be discharged with the reset pulse generated from the microcontroller that delivered to the MOSFET's gate, microcontroller can read consecutive pulses.

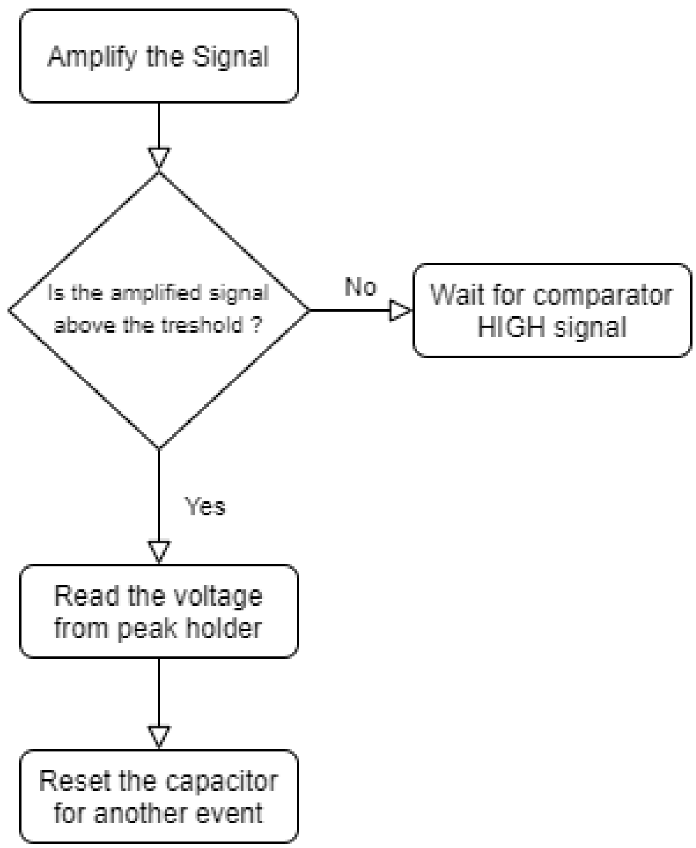


**Figure 2.2:** Flowchart diagram.

**The Schematic**

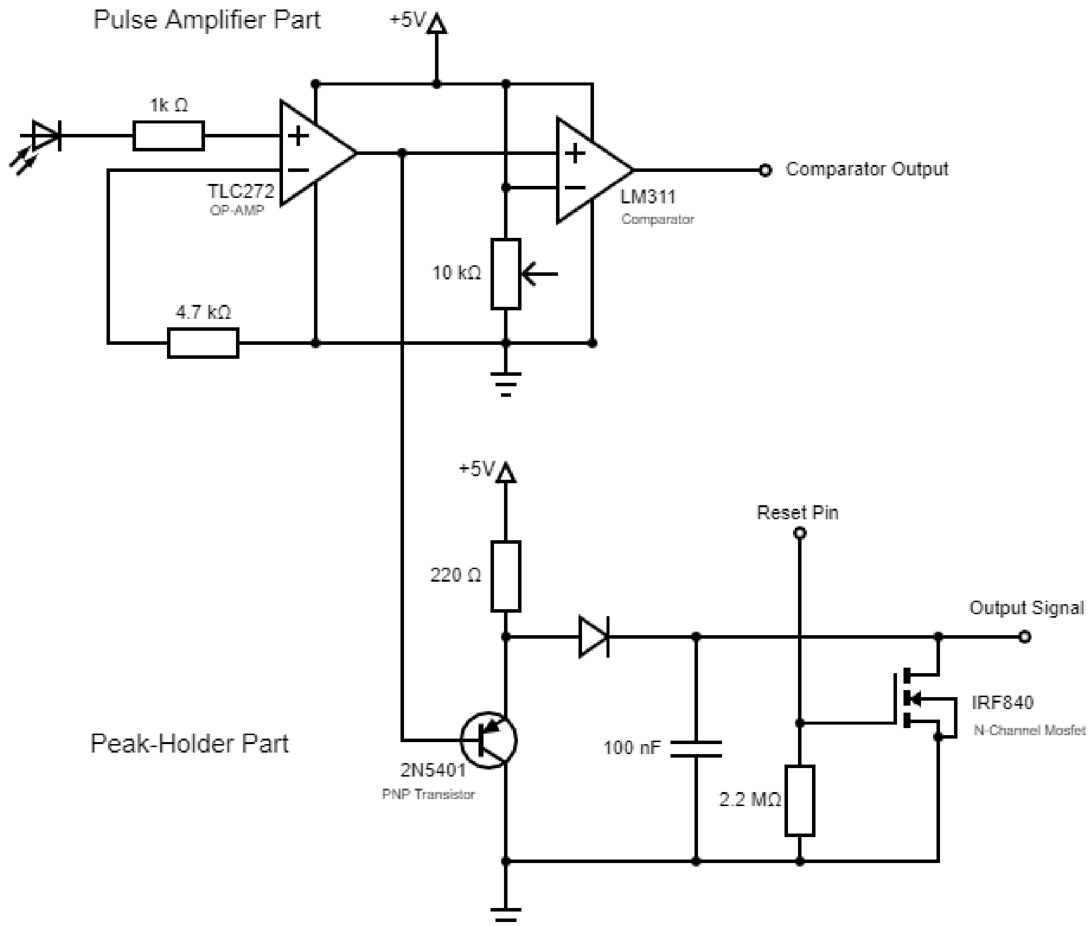


**Figure 2.3:** Pulse Amplifier and Peak Holder Circuit

Microcontroller unit is connected to the circuit to read comparator output and output signal and also attached to the reset pin to discharge capacitor when reading is done.

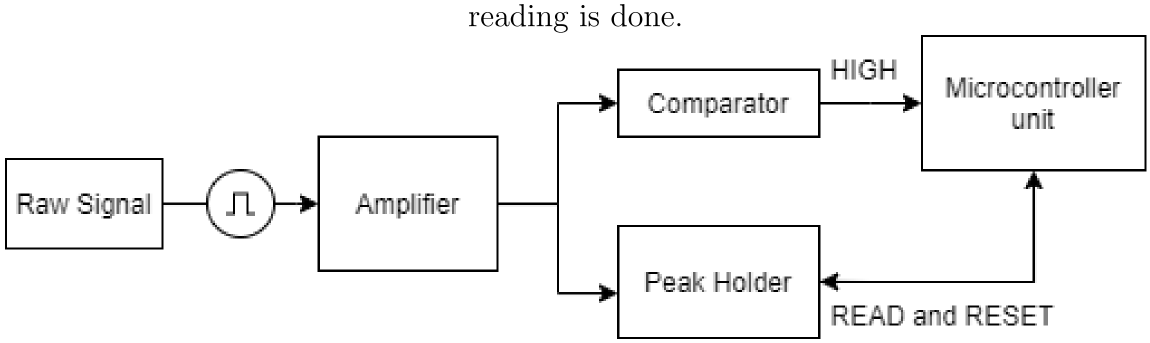


**Figure 2.4:** Circuit diagram.

## 2.4 Data Visualisation

The data were then displayed as histograms which then could be subjected to the traditional analysis to obtain peak parameters and the associated quantities. Visualisation of spectroscopy is an important part in order to get information at first look. In this study an ST7735 TFT LCD panel with SPI communication protocol is used to monitor the histogram of the signals in real-time.

Radiation spectrum does not only contains the source's radiation but also affected by the background radiation of lower energies that are generated from $^{40}$K present in the sand that are used on the walls. So, in order to analyze a certain region two dividers have been set and can be configured by two rotating handles. This allows the specification of the region of interest (ROI). With the help of the microprocessor, divider's corresponding channel numbers and number of pulses that are between the two dividers are displayed at the lower region of the display. In order to use microcontroller computations efficiently, it is important to refresh the spectrum only when a new pulse is acquired.

## Results and Discussion

Resulting pulses coming from the detector is amplified to be in between 0-5 volts which is which is ADC's reference voltages. Comparator threshold can be set to around 200 mV to eliminate some of the noise. On the peak holder circuit With the right selection of capacitor and a load resistor, it is possible to manipulate a 35 microsecond pulse to decay in 25 miliseconds, that is around 700 times larger. Arduino Mega's microprocessor with the 16 MHz ADC clock of Atmega328P a reading can be executed every 104 $\mu$s.

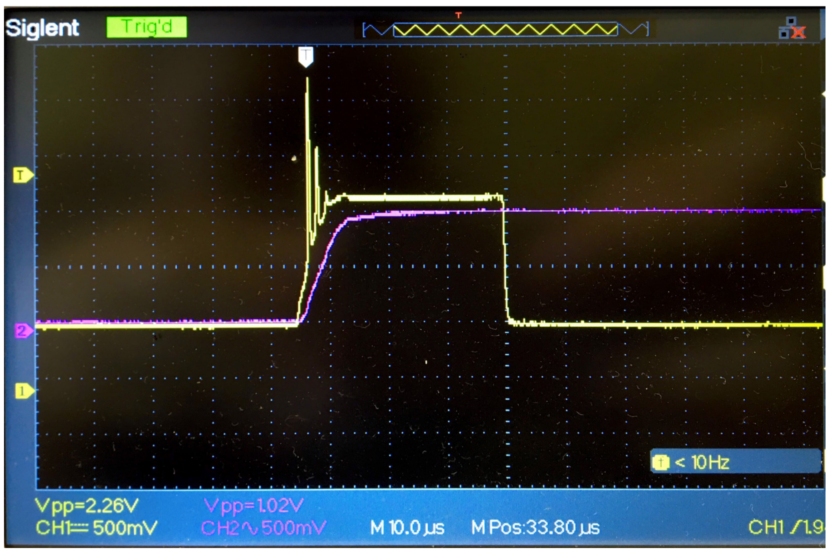


**Figure 3.1:** Incoming pulse (Yellow) and peak-holder output (Purple). Each division is 10 $\mu$s.

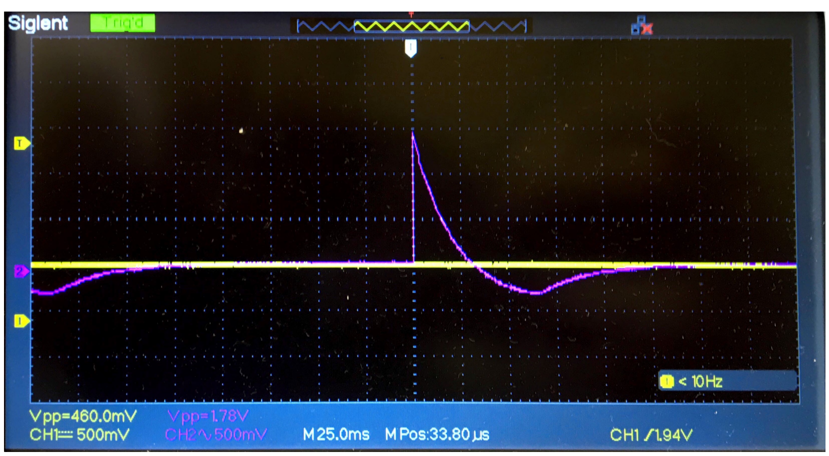


**Figure 3.2:** Incoming pulse (Yellow) and peak-holder output (Purple). Each division is 25 ms.

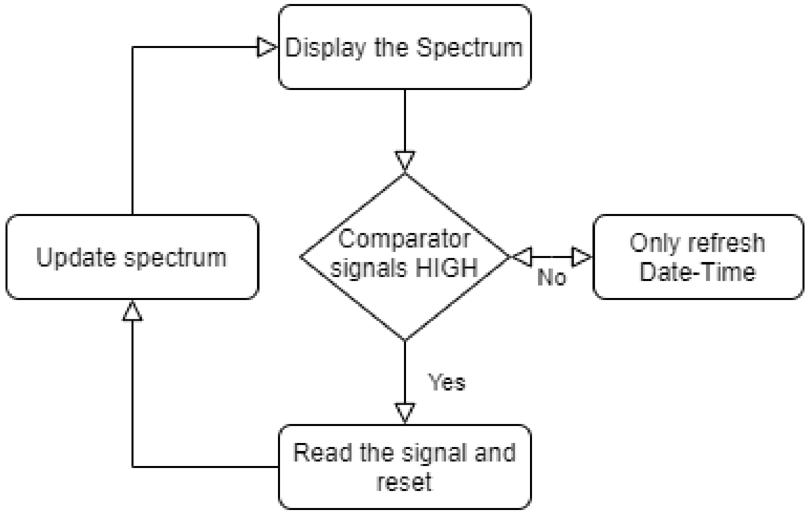


**Figure 3.3:** Flowchart of data acquisiton and displaying block.

It is crucial to refresh the spectrum only when a new pulse is acquired in order to make the most of microcontroller computations.

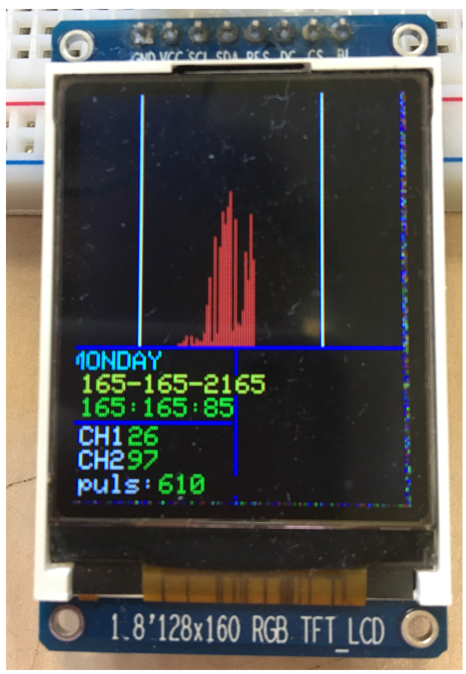


**Figure 3.4:** Layout of LCD display.

Histogram and the adjustable region of interest is seen on the display,

## Conclusion

A multichannel analyzer which utilises a microcontroller as the digitiser, to adequately digitise the amplified pulses from a silicon PIN photodiode based radiation detector has been developed. This work showed that the detector and the instrumentation presented in this study can be used for measuring the alpha radiation of $^{226}$Ra decay. Thus measurements clearly be monitored by a single display. With this design that has minimal and easy to find components, it is possible to produce large amounts of detectors. Which leads to more control over the knowledge of radiation throughout geographic area of interest such as Anatolia's fault lines and possible geodemographic analysis'.

## Appendix

Working example code:

```
#include <Adafruit_GFX.h>    // Core graphics library
#include <Adafruit_ST7735.h> // Hardware-specific library for ST7735
#include <SPI.h>
#include <RTClib.h>             // include Adafruit RTC library

// Defining SPI Pins for TFT LCD
#define TFT_CS        53
#define TFT_RST        9
#define TFT_DC         8


Adafruit_ST7735 tft = Adafruit_ST7735(TFT_CS, TFT_DC, TFT_RST);
// Initialize RTC module and configure the days
RTC_DS3231 rtc;
DateTime   now;
char daysOfTheWeek[7][12] = {"Sunday", "Monday", "Tuesday", "Wednesday", "Thursday", "Friday", "Saturday"};
char dow_matrix[7][10] = {"SUNDAY", "MONDAY", "TUESDAY", "WEDNESDAY", "THURSDAY", "FRIDAY", "SATURDAY"};


char _buffer[11];
float p = 3.1415926;
int pulslar[128]; // For drawing on LCD
int original_log[128];    // For keeping the original logs of pulses
int toplam_puls;          // To display the number of pulses occurred in the region of interest (ROI)
float faktor=1;         // Multiplying factor for the histogram to not exceed the screen

unsigned long oncekizaman = 0;

byte x_pos[7] = {8, 8, 6, 4, 4, 8, 4}; // 29,29,23,11,17,29,17
static byte previous_dow = 8;
```

```

void setup(void) {
  Serial.begin(9600);
  tft.initR(INITR_BLACKTAB);
  rtc.begin();
  rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
  //pinMode(2, INPUT);
  pinMode(2, INPUT); // comparator çıkışı pin 2
  pinMode(3, OUTPUT);  //reset pulse'ı pin 3

  int tolam_puls = 0;
  for (int i = 0; i < 128; i++)
       {
        pulslar[i] = 0;
       }
  for (int i = 0; i < 128; i++)
       {
        original_log[i] = 0;
       }
  // Use this initializer if using a 1.8" TFT screen:
  tft.initR(INITR_BLACKTAB);      // Init ST7735S chip, black tab
  tft.fillScreen(ST77XX_BLACK);
  tft.fillScreen(ST77XX_BLACK);
  // Drawing the outline of sections for the display
  tft.drawFastHLine(0, 130, 63, ST7735_BLUE);
  tft.drawFastHLine(0, 101, tft.width(), ST7735_BLUE);
  tft.drawFastVLine(64, 100, 59, ST7735_BLUE);
  tft.drawFastHLine(0, 100,  tft.width(), ST7735_BLUE);
  tft.setTextColor(ST7735_WHITE, ST7735_BLACK);     // set text color to white and black background
  tft.setTextSize(1);                               // text size = 1
  //Outline for dividers' value and toplam puls
  tft.setTextSize(1);
  tft.setTextColor(ST7735_WHITE, ST7735_BLACK);
  tft.setCursor(4,132);   // For the first Divider
  tft.print("CH1:" );
  tft.setCursor(4,141);   // For the second Divider
  tft.print("CH2:" );
  tft.setCursor(4,150);    // For the Total pulses between dividers
  tft.print("puls:");
```

```
}

void loop() {
  unsigned long ilkzaman = millis();
  int val = digitalRead(2);
  if (val == 1) {
    int deger = analogRead(A5);   // genliği okuduğum pin A5
    digitalWrite(3,HIGH);
    delayMicroseconds(1);
    digitalWrite(3,LOW);

  Serial.println(deger);
  int toplam_puls = 0;
  now = rtc.now();  // read current time and date from the RTC chip
  tft.setCursor(x_pos[previous_dow], 103);
  tft.setTextColor(ST7735_CYAN, ST7735_BLACK);     // set text color to cyan and black background
  tft.print( dow_matrix[now.dayOfTheWeek()] );


  // print date
  sprintf( _buffer, "%02u-%02u-%04u", now.day(), now.month(), now.year() );
  tft.setCursor(4, 112);
  tft.setTextColor(ST7735_YELLOW, ST7735_BLACK);     // set text color to yellow and black background
  tft.print(_buffer);

  // print time
  sprintf( _buffer, "%02u:%02u:%02u", now.hour(), now.minute(), now.second() );
  tft.setCursor(4, 121);
  tft.setTextColor(ST7735_GREEN, ST7735_BLACK);     // set text color to green and black background
  tft.print(_buffer);

  int Index = map(deger,0,1023,0,127);
  original_log[Index] = original_log[Index] + 1;    // Reads from analog pin and appends to the right channel accordingly
```

```
bool flag=1;
pulslar[Index] = pulslar[Index] + 1;

for(int t=0;t<127&&flag==1;t++){                    // This code is for checking if the pulses exceeded display screen
  if(pulslar[t]>100/faktor){                        // Needs to be optimized.
    faktor=faktor/2;
    flag=0;
    }
    }

unsigned char div0 = map(analogRead(A3),0,1023,0,127); //first divider index between 0-127
unsigned char div1 = map(analogRead(A1),0,1023,0,127); //second divider index between 0-127

for (int i = 0; i < 128; i++){
  tft.drawLine(i,100,i,100-pulslar[i],ST7735_RED);
  tft.drawLine(i,100-int(faktor*pulslar[i]),i,0,ST7735_BLACK);
  //tft.drawLine(div0,100,div0,0,ST7735_WHITE);
  //tft.drawLine(div1,100,div1,0,ST7735_WHITE);
  }


tft.drawLine(div0,100,div0,0,ST7735_WHITE);
tft.drawLine(div1,100,div1,0,ST7735_WHITE);
if( div0 < div1){
  for (int i = div0; i < div1; i++){
    toplam_puls = toplam_puls + original_log[i];
    }
    }
else {
  for (int i = div1; i < div0; i++){
    toplam_puls = toplam_puls + original_log[i];
    }
    }

for (int i = div0+1; i < div1; i++)
```

```
     {
     tft.drawLine(i,100,i,100-pulslar[i],ST7735_RED);
     tft.drawLine(i,100-int(faktor*pulslar[i]),i,0,ST7735_BLACK);
     }
  tft.drawLine(div0,100,div0,0,ST7735_WHITE);


  tft.setCursor(23,132);
  tft.print(div0);
  tft.print("   ");
  tft.setCursor(23,141);
  tft.print(div1);
  tft.print("   ");

  tft.setCursor(35,150);
  tft.print(toplam_puls);
  tft.print("  ");
  unsigned long ikincizaman = millis();
  unsigned long timer=ikincizaman-ilkzaman;
  Serial.println(timer);
}
}


void RTC_display()
{
  char _buffer[11];
  char dow_matrix[7][10] = {"SUNDAY", "MONDAY", "TUESDAY", "WEDNESDAY", "THURSDAY", "FRIDAY", "SATURDAY"};
  byte x_pos[7] = {8, 8, 6, 4, 4, 8, 4}; // 29,29,23,11,17,29,17
  static byte previous_dow = 8;

  // print day of the week
  if( previous_dow != now.dayOfTheWeek() )
  {
    previous_dow = now.dayOfTheWeek();
//    tft.fillRect(11, 55, 108, 14, ST7735_BLACK);     // draw rectangle (erase day from the display)
    tft.setCursor(x_pos[previous_dow], 103);
```

```
    tft.setTextColor(ST7735_CYAN, ST7735_BLACK);     // set text color to cyan and black background
    tft.print( dow_matrix[now.dayOfTheWeek()] );
  }

  // print date
  sprintf( _buffer, "%02u-%02u-%04u", now.day(), now.month(), now.year() );
  tft.setCursor(4, 112);
  tft.setTextColor(ST7735_YELLOW, ST7735_BLACK);     // set text color to yellow and black background
  tft.print(_buffer);

  // print time
  sprintf( _buffer, "%02u:%02u:%02u", now.hour(), now.minute(), now.second() );
  tft.setCursor(4, 121);
  tft.setTextColor(ST7735_GREEN, ST7735_BLACK);     // set text color to green and black background
  tft.print(_buffer);
}
```

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