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UNIVERSITY OF JYVÄSKYLÄ

Measuring Techniques and Systems
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Arduino-Based Scintillation Counter

Final Project

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1. Project Introduction

The following report describes the process of building a scintillation counter for radiation monitoring, using a plastic scintillator, a Silicon Photomultiplier and an Arduino UNO to serve as a processing unit.

1.1 The scintillator counter block diagram is shown in Figure 1.1.

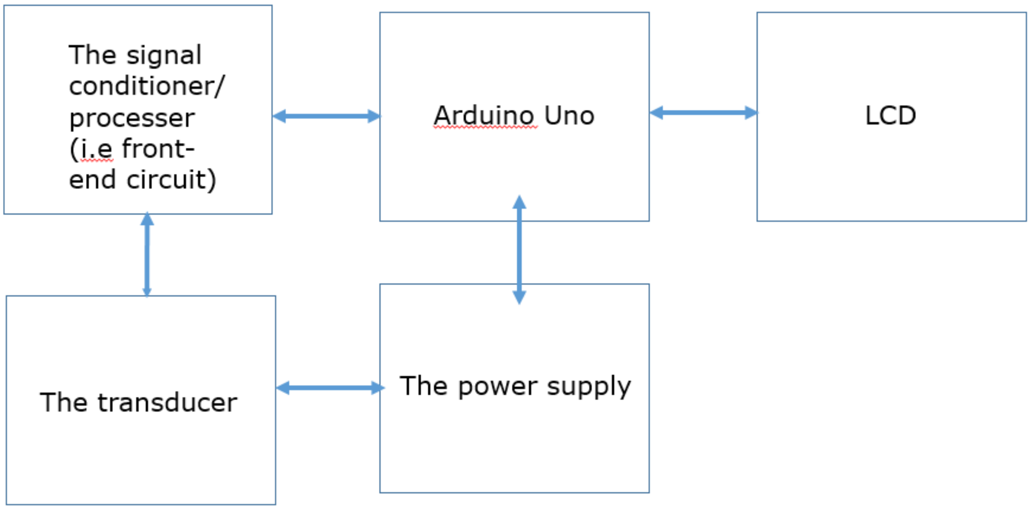

Fig. 1.1 The scintillator counter block diagram.

1.2 The necessary components:

Product	Product No.	QTY	Source	Price (€)
Arduino Uno	782-A000066	1	Link	27,60
Scintillator Crystal		1	JYU Accelerator Laboratory	
Silicon Photomultiplier (SiPM) 1		1	JYU Accelerator Laboratory	
Resistors		1 (10k); 1 (47); 2 (4k7); 1 (15); 5	JYU Accelerator Laboratory	

		(470k); 1 (2k2); 5(1M)		
Capacitors		3 (100n); 1 (1u)	JYU Accelerator Laboratory	
DC-DC Step-Up Converter	XL6009	1	Link	5,98
Rail-to-Rail Operational Amplifier	MCP6021-8-Lead Plastic Dual In-Line (P)	4	Link	1.47 euro x 4
LCD Keypad Shield	375-16X2S HD-01	1	Link	16,49 euro
A piezo buzzer	179-CMI-1 210-5-95T	1	Link	1,34 euro
bunch of wires		1 (Male-Male Connectors), 5 (pin header male connectors)	(Male- Male connectors) link (pin header connectors) link	20 euro
Easy to find stuffs: Cardboard, Glue, Black plastic bags, Holder for SiPM and the Scintillator		1 for each thing		around 5 euro in total
Total				around 100 euro

Table 1.1 List of materials

1.3 The laboratory instruments for testing while developing the product

Laboratory power supply, oscilloscope, other Laboratory connectors, Laboratory cable connection.

The next sections give details about the development steps.

2. Electrical signal generation- Scintillator and Silicon Photomultiplier (SiPM)

This is the transducer part of a scintillation counter, which consists of a scintillator producing photons in response to incident radiation and a photodetector (in our project, we use a silicon photomultiplier) converting generated light into an electric signal. The very main idea of the device lies in the reaction of radiation and scintillator, which produces a series of flashes with different intensities, that are proportional to the energy of radiation. Additionally, the silicon photomultiplier must be reverse biased in order to properly produce a current pulse whenever it is hit/excited by the photon rays (i.e light). Here we actually need a scintillator and SiPM with matching spectral characteristics (i.e the generated light spectrum of the scintillator has its peak matching the peak of the SiPM Photon Detection Efficiency spectrum (see Fig. 2.1)).

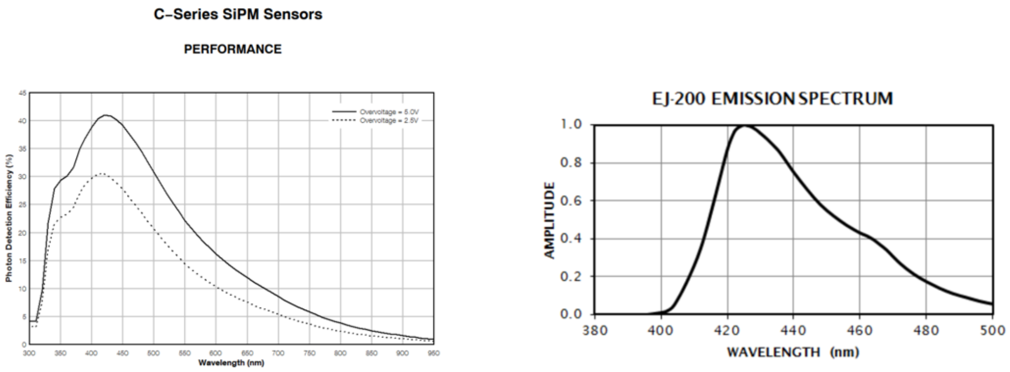

Fig.2.1 Generated light spectrum of the scintillator (the right-hand side spectrum) and the SiPM Detection Efficiency spectrum (the left-hand side). Source: [1], [2]

We used an Eljien Ej-200 plastic scintillator with a peak wavelength emission of 425 nm. To match our scintillator, we have selected a SiPM MICROFC-60035-SMT from Onsemi; this SiPM can be found in 1, 3 and 6 mm single cell or array configurations. The peak emission of this sensor is at 420 nm, which is desirable to match our scintillator. Our SiPM model is 6*6mm. To maximize the collected signal (i.e minimize losses of produced light), we also wrapped the scintillator in highly reflective material and optically coupled it to the SiPM through a lightguide (Fig. 2.2) . By doing so we increased the amplitude of the signal amplitude by order of magnitude from units of mV to tens of mV.

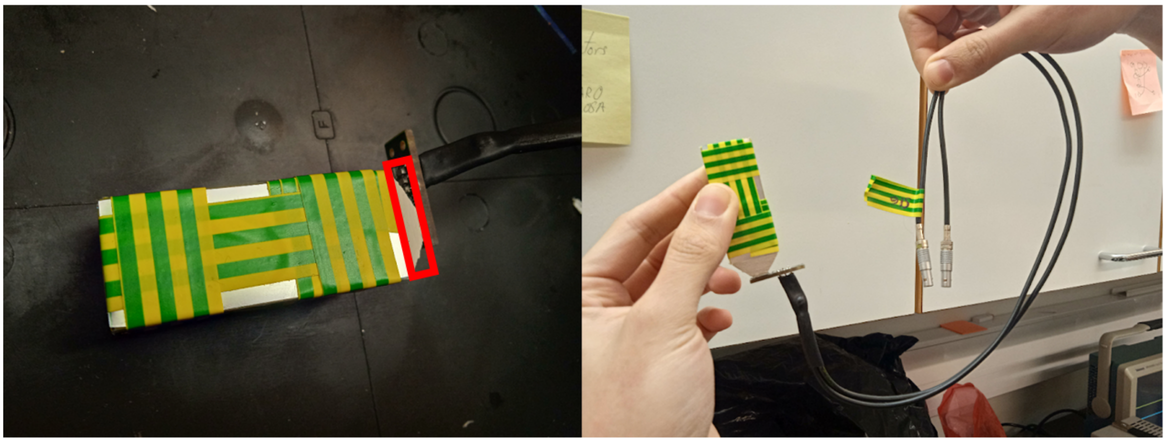

Fig. 2.2 Scintillator wrapped in reflective material and optically coupled with SiPM. The lightguide for optical coupling is indicated by the red box.

3. Analog signal conditioning

Our SiPM was already on a carrier board (i.e the readout board, see Figure 3.1). In such a layout, that readout signal is in the form of negative pulses. The required readout from the Arduino requires 0-5V range of voltage.

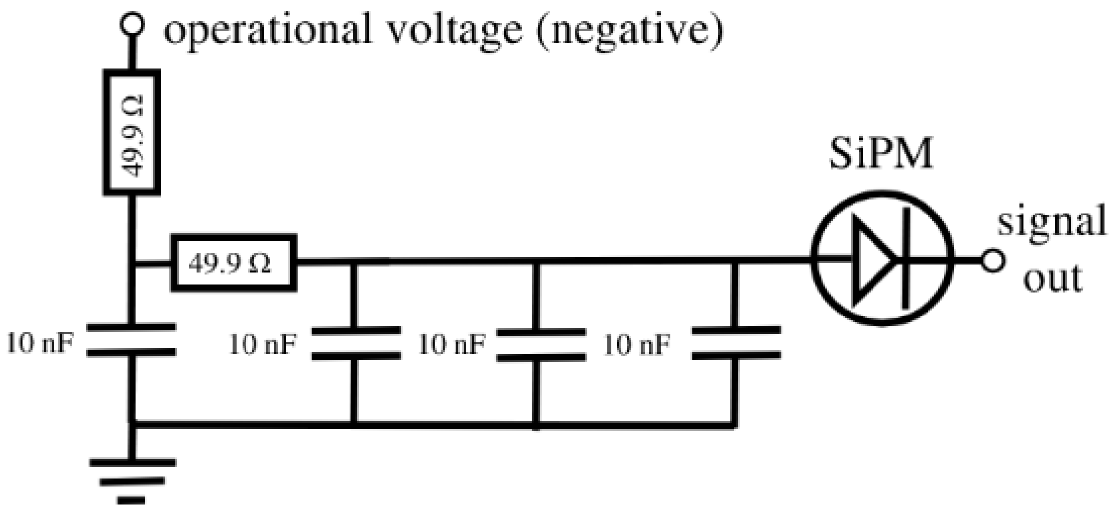

Fig 3.1 The SiPM readout board (i.e bias circuit) [3]

In order to get a tolerable signal for the Arduino, we have to invert and amplify the initial one and get rid of noise. It requires the circuit of high-pass filter and inverting amplifier (Fig. 3.2). We used a series of resistors to get good enough gain, because we didn't have a resistor with a large enough value of resistance. The real breadboard model of the circuit is (Fig. 3.3).

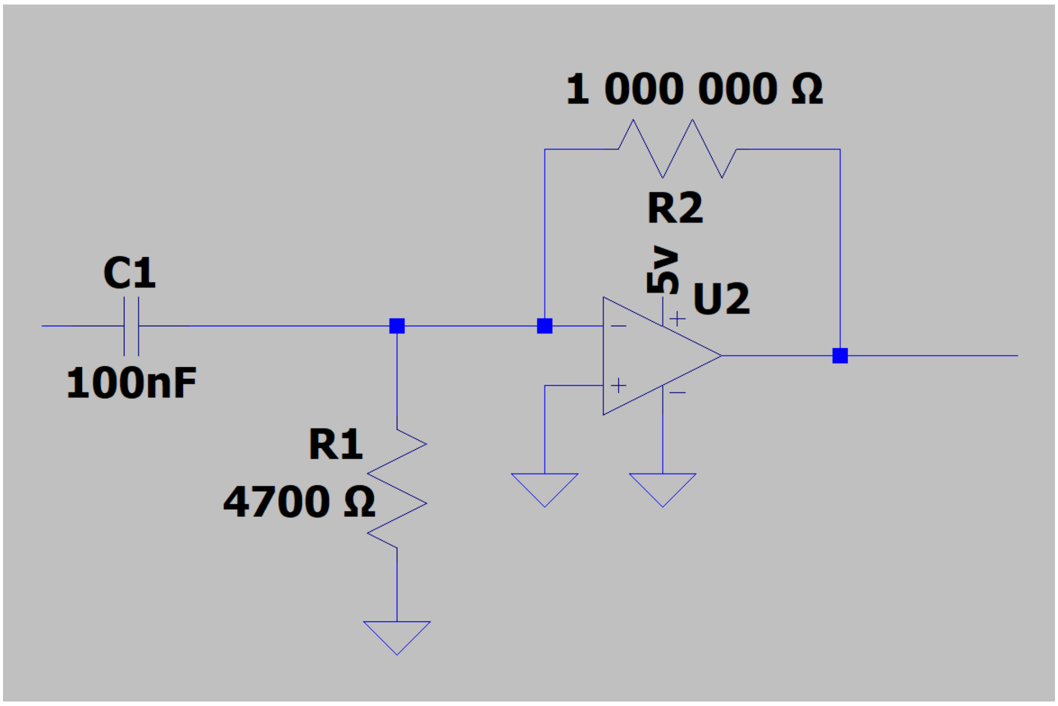

Fig. 3.2 Filter + inverting amplifier circuit. R2 is realized by a series of resistors. The opamp is MCP 6021.

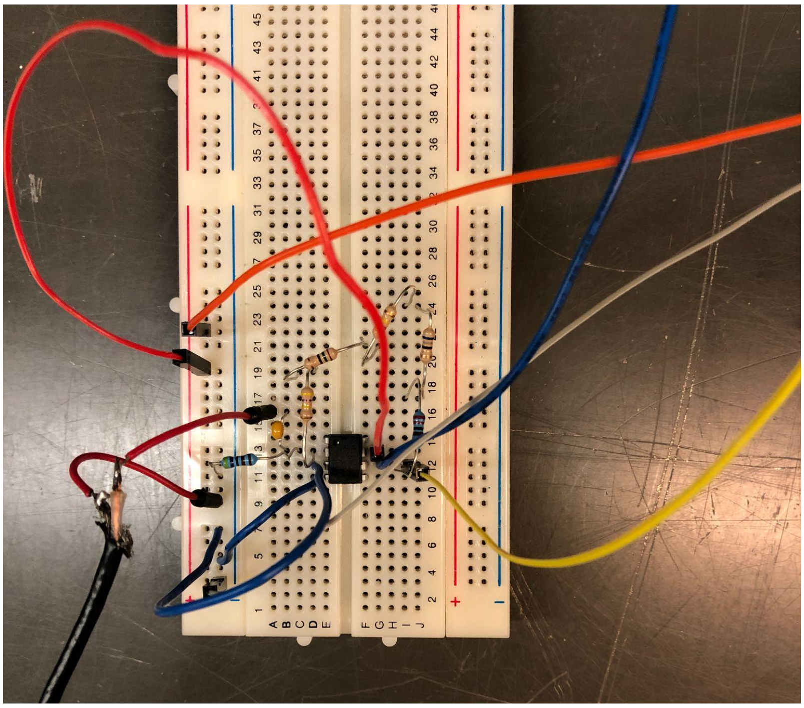

Fig. 3.3 Our analog signal conditioning system. The bread board model of the signal conditioner circuit in Figure 2.2

As a result, we obtained an appropriate signal to pass further to Arduino (Fig. 3.4). In Fig 3.4, The yellow curve is the signal directly from SiPM ; the blue one is the signal after conditioning. We can see that scaling and inverting work as intended, and the duration of the signal is prolonged for Arduino to process it.

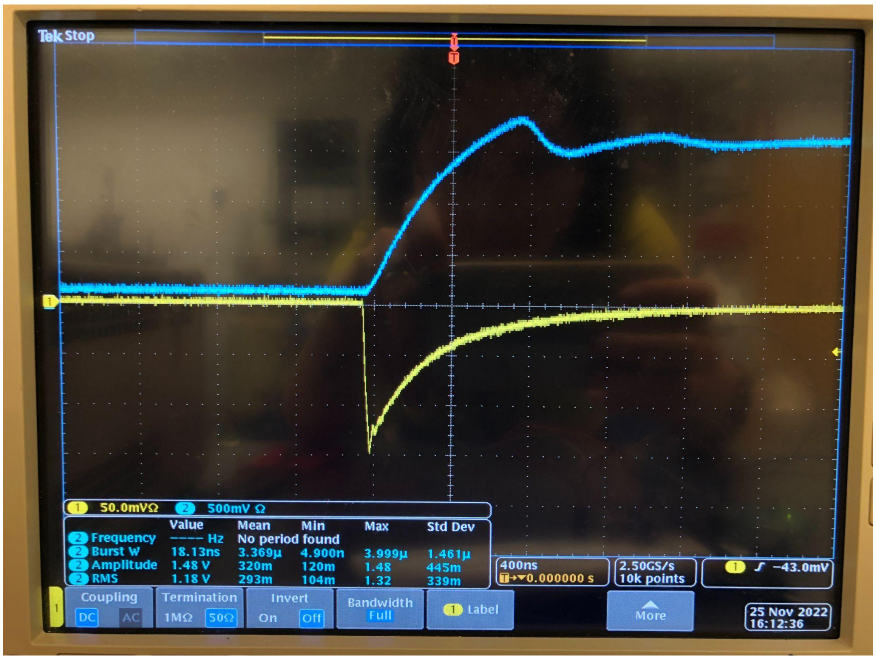

Fig. 3.4 The comparison between the readout signal of the SiPM with and without the conditioning circuit. The yellow: signal directly from SiPM (without the conditioning), blue (with the conditioning): inverted and amplified signal for Arduino

Setup for the testing (the transducer part and the signal processing (i.e signal conditioning)) is indicated in Fig. 3.5

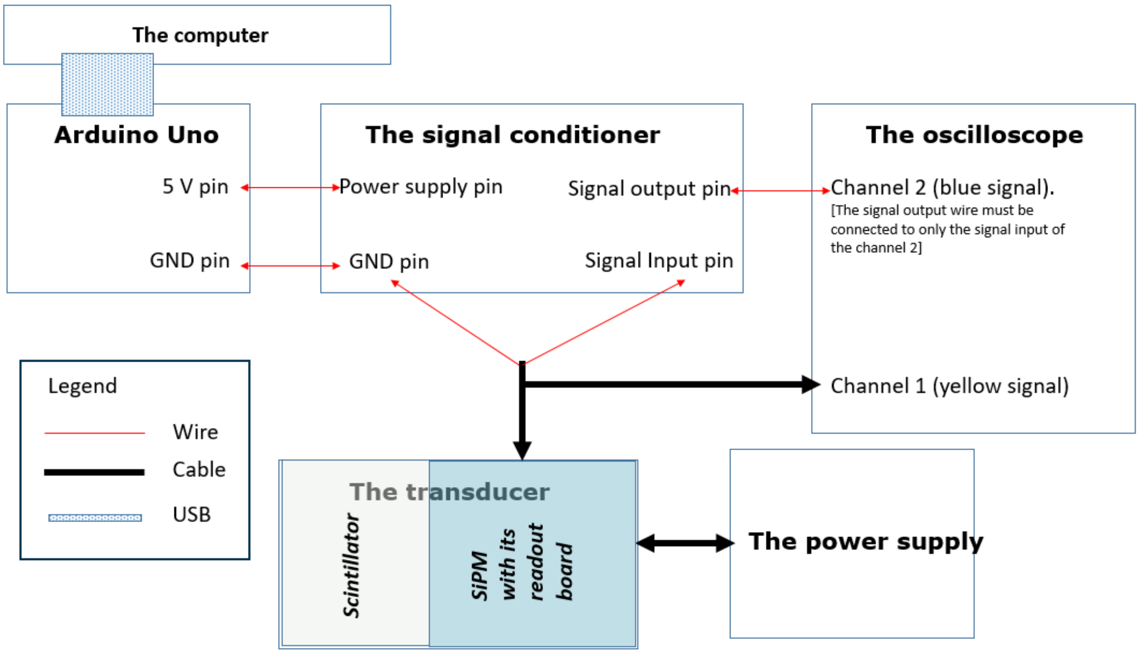

Fig. 3.5 Testing setup for the transducer part and the signal processing. [The pin positions of all the components are only illustrative]

4. Coding with Arduino

Step 1: It is recommended testing Arduino with the LCD code first. Getting used to the LCD - Arduino configuration and coding LCD in Arduino application on the computer is necessary.

Step 2: The complete code for the Arduino (when it interfaces the signal conditioner and the LCD) is the following:

```
/*
  ReadAnalogVoltage

  Reads an analog input on pin 0, converts it to voltage, and prints the
result to the Serial Monitor.
  Graphical representation is available using Serial Plotter (Tools >
Serial Plotter menu).
  Attach the center pin of a potentiometer to pin A0, and the outside
pins to +5V and ground.

  This example code is in the public domain.

  https://www.arduino.cc/en/Tutorial/BuiltInExamples/ReadAnalogVoltage
*/
```

```
/*
 * LiquidCrystal Library - counting printed on LCD
 *
 * The circuit:
 *--------FOR LCD-----------
 * LCD GND pin 1 to Arduino Uno pin GND
 * LCD VDD pin 2 to Arduino Uno pin 5V
 * LCD V0(contranst) pin 3 to Arduino Uno pin GND,
    * V0 to GND provides the strongest contrast, recommended for
beginners
 * LCD RS pin 4 to Arduino Uno digital pin 12
 * LCD R/W pin 5 to Arduino Uno pin GND
 * LCD Enable pin 6 to  Arduino Uno digital pin 11
 * LCD D4 pin 11  to Arduino Uno digital pin 5
 * LCD D5 pin 12 to Arduino Uno digital pin 4
 * LCD D6 pin 13 to Arduino Uno digital pin 3
 * LCD D7 pin 14 to Arduino Uno digital pin 2
 * LCD LED+ pin 15 to Arduino Uno pin 5V
 * LCD LED+ pin 16 to Arduino Uno pin GND
 */

#include <LiquidCrystal.h> // includes necessary library

// Set the variable for counting
int numint=0;

const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);


// Analog input pin:
int sensorPin = A0;

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);

  // Set LCD:
  lcd.begin(16,2);
  lcd.clear();
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
```

```
  int sensorValue = analogRead(sensorPin);

  // Convert the analog reading (which goes from 0 - 1023) to a voltage
(0 - 5V):
  float voltage = sensorValue * (5.0 / 1023.0);

  // print out the value you read:
  if (voltage > 0.3) // the detection threshold
  {
    numint= numint +1;

    //Print the result: on LCD
    lcd.setCursor(0, 0);
    lcd.print(voltage); lcd.print("V");  lcd.print("      ");
    lcd.setCursor(0, 1);
    lcd.print(numint);

    //Print the result in the Arduino Serial Monitor
    Serial.println(voltage);
  }

}
```

5. The final setup- connecting every part together

The final setup/configuration is in the Fig. 5.1

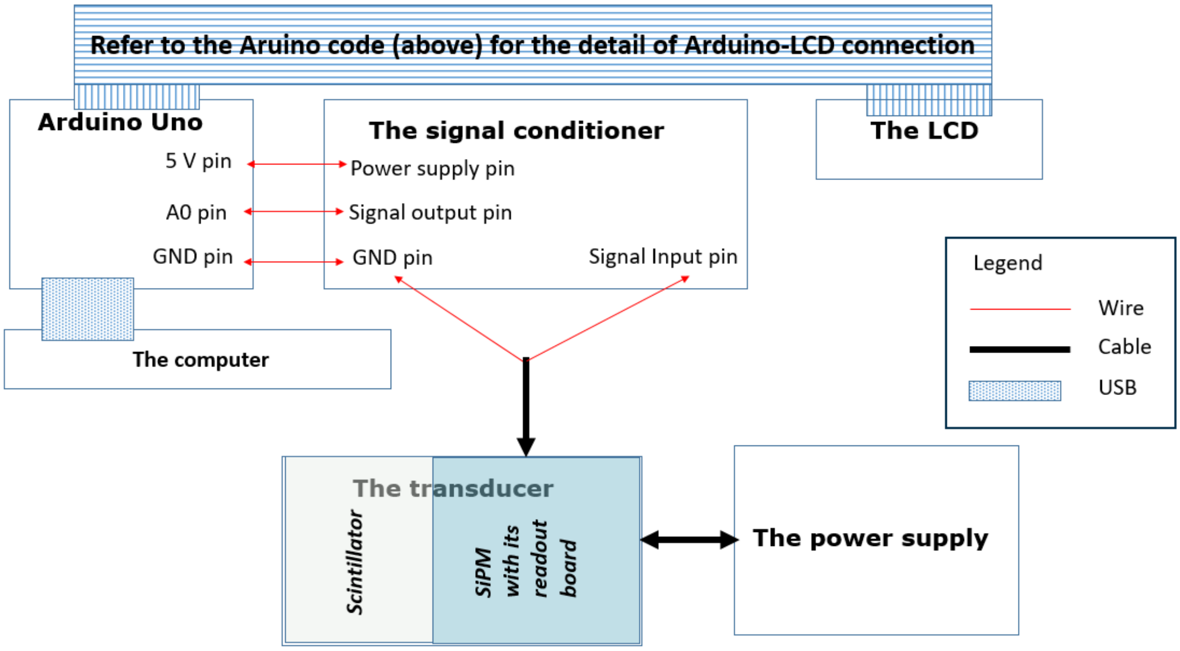

Fig. 5.1 Final setup (The transducer, the signal conditioning, the Aruino Uno, the LCD)

6. Common mistakes

1. **When testing the transducer part:**

When testing the transducer part: it's crucially important to shield the SiPM from the ambient light, since it's very sensitive and the response for comparatively bright ambient light much greater, than for actual signal from the scintillator. That's why for testing period one should keep the transducer system in a dark place (a box, for example), but for actual use it's more convenient to wrap the scintillator coupled with SiPM in an opaque material to prevent external light getting inside.

Furthermore, in order to see the very small signal (e.g Dark current) of the SiPM on the Oscilloscope, it is important to set the Channel impedance to 50 [Ohm]. Otherwise, no signal could be seen on the Oscilloscope.

2. **When doing the signal processing/ conditioning part:**

The supply voltage of the op-amp must be taken care of carefully.

A. If the inverting signal from negative to positive (i.e in the case of this project), it is recommended that only positive supply of the opamp is connected to 5V (or more depending on the op-amp datasheet), while the negative is connected to GND.
B. If the inverting signal from positive to negative (i.e in the case of this project), it is recommended that only negative supply of the opamp is connected to -5V

(or more depending on the op-amp datasheet), while the positive supply is connected to GND

3. **When testing the final product:**

There is an essential relation between **the bias voltage of the SiPM, the detection threshold (see the Arduino code)** and **the sensitivity of the product to the radiation source.** In order to reflect the sensibility of the product radiation-sensitivity, it is recommended to set the bias voltage (using the adjustable Laboratory Power Supply) around 27 [V], together with the detection threshold of 0.3. If the bias voltage is set above 27 [V], the product will become too sensitive to Dark current (i.e which we do not want to count). If the bias is set below 27 [V], the product will become insensitive to the radiation source.

7. Further improvements

a. Redesign of discriminator circuit

The first design choice that we could do is redesign the discriminator circuit, as this will allow us to adjust the triggering of the SiPM more precisely and will reduce noisy readings from dark counts. The block diagram from Hamatsu Photonics [4], suggests an amplifier and discriminator circuit before the counting stage. This can also provide valuable information on the correct radiation rates, and from this we can derive flux (Hamatsu, 2018)[4].

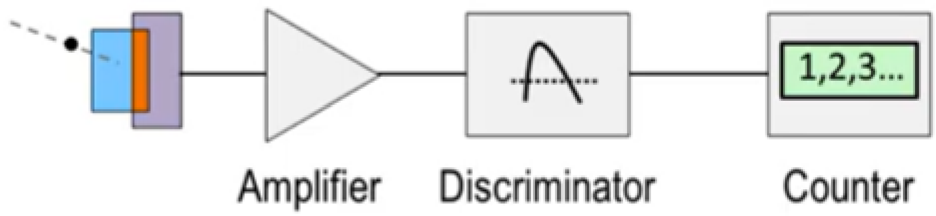

Figure 7.1. Suggested readout circuit from Hamatsu Photonics. Source [4]

Reverse configurations are also possible, as suggested by Physics Open Lab, 2016 [11], where the SiPM output is connected to a pulse extraction circuit, this section is used to properly shape the pulse and the two low-pass filters are used to lengthen the pulse to around 100 to 100 microseconds and reduce the peak values. The pulse shaper can be seen in the following figure.

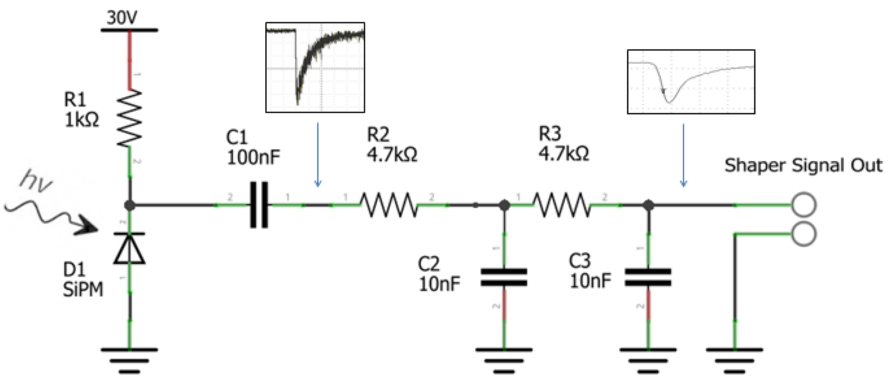

Figure 7.2. Shape pulser with low-pass filters. Source [11]

The signal incoming from the previous figure will have a very low amplitude, so then the amplification stage will be needed. The example provided by Physics Open Lab uses a sound card as an ADC, but this could easily be replaced by the Arduino ADC.

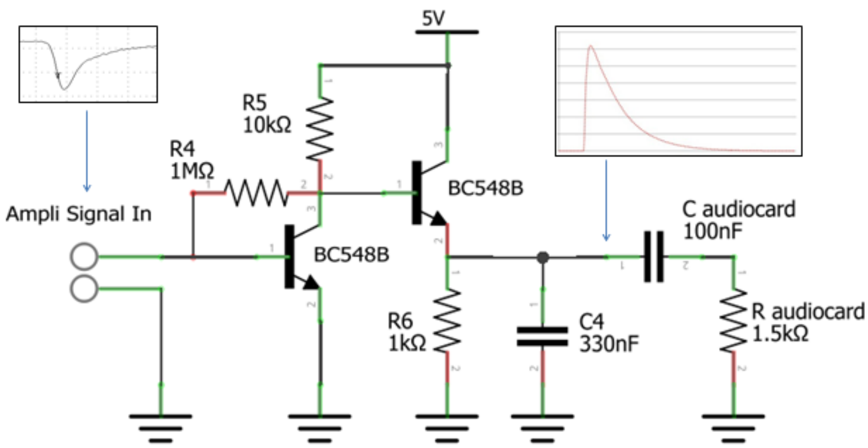

Figure 7.3. Pulse amplifier and output circuit. Source [11]

In the previous example circuit we can see that the output of this amplification stage is connected to an audio card to be used as an ADC. Other important factors are the bias voltage, for which the best resolution is achieved close to 30 V. The gain of this amplification stage is controlled by Resistor number 5 (R5), which could be easily tuned if needed.

a. DC-DC step up converter

The currently used setup requires a bench power supply, which is bulky and not portable, this would be a priority if the device is going to be used in more serious applications, as radiation monitoring devices are usually portable. One of the main problems during our setup was the design of the $\pm\ 5\ V$ used by the rail to rail operational amplifiers, as this also has to be coupled with a virtual ground to the bias circuitry. This setup needs to be redesigned, one of the options is to use a perforated board to mount the components and create the top of the board as a virtual ground. An idea for this setup is shown in the following figure, where two fixed voltage regulators are used to maintain the dual rail configuration and to create a virtual ground in the middle of both circuits.

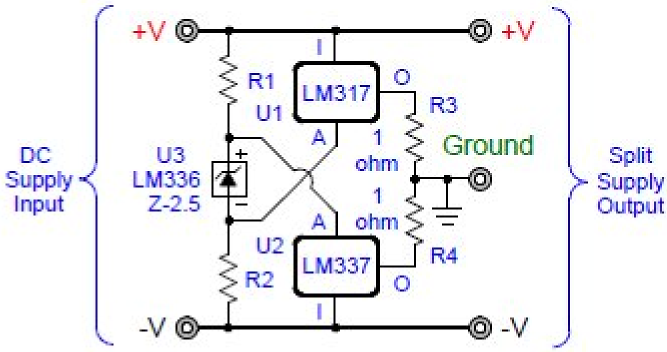

Figure 7.4. Split supply output from DC power supply. Source [5]

This setup also makes it possible to draw enough current from the circuit, as with the Arduino setup and tests we made with the DC-DC converter the current sink from the Arduino was insufficient to correctly drive the whole setup, as Arduino pins are limited to 150 mA recommended draw in absolute terms, and 40 mA per pin (Arduino, 2022)[8].

b. PCB Design

Once the biasing and readout improvements have been made, the next improvement would be to design a compact and replicable PCB. Multiple open source detectors exist on the web, with professional finish. One example of this is CERN's Open Source DIY Particle Detector, in which a small PCB is used. The cost of fabrication for 5-10 units of a 2 layer PCB in FR-4 substrate material is around €15-40 according to PCBWay [7].

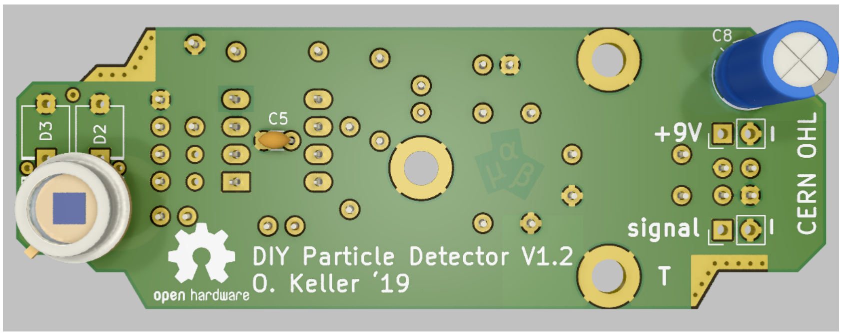

Figure 7.5. Open Source CERN's DIY Particle Detector. Source [6]

This improvement would also allow for replicability and standardization of components, which would be critical if entities or students would like to constantly replicate this design or improve on it. Such design can be prototyped in free and open-source EDA automation software such as KiCad [9].

One could also look at other open-source projects for further references about the different circuits and sensor types that could be used, and to get a sense of the finished product quality that can be achieved. For reference we briefly present the Safecast project, which is an open-source design and open-data radiation monitoring device [10].

Figure 7.6. Safecast radiation monitoring device. Source [10]

The important point about the Safecast device is the use of daughter boards to add functionality and modularity to the device, also the use of other open-source designs for the data login, i/o processing and high voltage loop, all of which can be found in the corresponding project page (Safecast, 2016)

8. References

- [0] Ozzblizzard. Scintillino - An Arduino-based Quick & dirty Scintillation Counter. 2014. Retrieved from the web on December 10, 2022 from: Scintillino - an Arduino-based Quick&dirty Scintillation Counter : 6 Steps (with Pictures) - Instructables
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