Low-cost meteor radiometer

Denis Vida[1], Renato Turčinov[2], Damir Šegon[3] and Emil Silađi[1]

[1] **Astronomical Society "Anonymus", B. Radića 34, 31550 Valpovo, Croatia**

Faculty of Electrical Engineering, University of Osijek, Kneza Trpimira 2B, 31000 Osijek, Croatia
`denis.vida@gmail.com, emil.siladi@gmail.com`

[2] **Uljanik TESU elektronika d.o.o., Flaciusova 1, 52100 Pula, Croatia**
`renato.turcinov@ute.hr`

[3] **Astronomical Society Istra Pula, Park Monte Zaro 2, 52100 Pula, Croatia**
`damir.segon@pu.htnet.hr`

In this paper we discuss possibilities of building a low-cost system for radiometric observations of meteors. A meteor radiometer is a high time-resolution photometer for measuring sky brightness. As the radiometers have proven to be an invaluable source of data during the fireball fragmentation modelling, and yet there are so few radiometers operational, we propose using inexpensive photodiodes, operational amplifiers and microcontroller boards. We present the prototype's electronics design, give the source code and discuss the testing results.

1 Introduction

A radiometer is a high time-resolution photometer which measures the sky brightness. It is used for recording meteors as they contribute to the brightness of the sky during a short period of time (under a few seconds), thus they are distinguishable among other longer (the Moon, satellites) or periodic (aero plane lights) light sources.

In 2001, the first results of radiometric observations were presented and compared to the photographic data (Spurný et al., 2001). This was, as it is known to the authors, the first mention of radiometers being used for meteor observation. Recently, an unpublished book chapter (Borovička et al., 2015a) mentioned radiometric observations as one of the observational methods. Radiometric observations are often used in fragmentation modelling, one example being the Križevci meteorite fall (Borovička et al., 2015b) where the data used had a sampling rate of 500 Hz.

Although being presented as a well-established observational method among a small group of scientists, and used for over 15 years, the authors failed to find any design details of radiometric systems that are currently operational. Thus it was decided to design a low-cost system that would enable amateur astronomers and electronics hobbyists to perform radiometric observations of meteors.

2 System design

Requirements

To serve as a useful observational tool, a meteor radiometer needs to have a high enough sampling frequency and high enough sensitivity to be able to record the most interesting events – meteorite producing fireballs. Sampling frequency needs to be at least an order of magnitude larger than with conventional methods, but not higher than the sensor is able to properly respond to the changes in the radiant flux produced by the fireball. The radiometer needs to be sensitive enough to register at least -4 magnitude events, as they would fall into the fireball category. The system's dynamic range should be at least 16 bits, as any lower precision would mean a loss of detail during the less luminous events.

Also the goal price for building such system should not exceed 100 USD, as we consider that to be the threshold below which every meteor observation system would be considered "cheap".

Data acquisition

The first goal of the project was to prove that it is possible to have a high-frequency high-precision sampling at minimum cost. In the recent years, microcontroller boards such as Arduino UNO gained enormous popularity and communities started to develop around them. This had an effect on the available data acquisition possibilities – today it is possible to buy an Arduino board and a compatible analog-digital converter for less than 10 USD.

The center of the used Arduino UNO system is a programmable ATmega328P microcontroller which can communicate with a PC via USB interface and it is programmed in a language similar to C. The board operates at 5V – 12V voltage. These features make the system very easy to communicate with, program and supply with power.

For analog-digital conversion, an AD7705 based board was chosen which enables data collection at 16-bit precision and 500 Hz sampling rate. A library[1] for easily controlling the board is available on the Internet. The library requires several modifications of the AD770x.cpp file: setting the sampling frequency to 500 Hz (using the UPDATE_RATE_500 constant) and setting the gain to a preferable level (e.g. using the GAIN_8 constant for 8X gain).

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[1] AD7705 library: https://github.com/kerrydwong/AD770X

The 16-bit number is broken into 2 separate bytes and sent via serial connection to a PC which is running a Python script and capturing the incoming stream of data. PySerial[2] library was used for establishing a serial connection with Arduino in Python. Each data point is timestamped and saved to memory, until a predefined buffer is filled when the data is saved to disk as a CSV file. All source code that is needed to run the radiometer is given freely on a GitHub repository[3].

Photodiode and amplifier

The main component of the system is a Vishay BPW34 PIN photodiode with a fast response time and 7.5 mm^2 radiant sensitive area. It has an angle of half sensitivity of ± 65° and its spectral response is slightly shifted towards the near-infrared. The relative spectral sensitivity is shown on *Figure 1*.

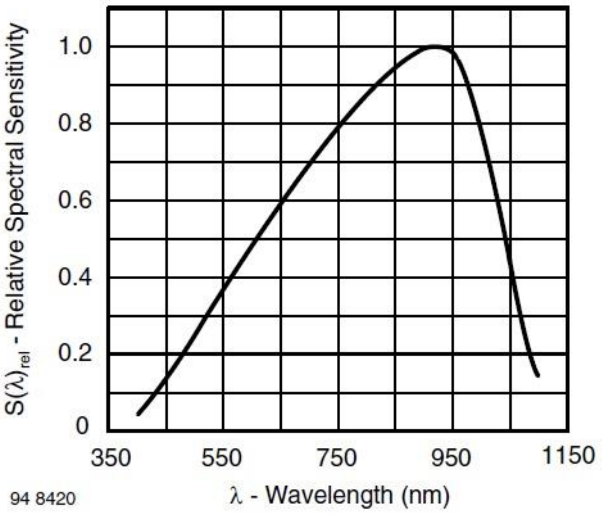

Figure 1 – BPW34 photodiode relative spectral sensitivity[4]

For amplifying the photodiode signal, LMC6462 was used. It is a rail-to-rail input and output CMOS operational amplifier.

Schematics and Components list

The components needed to build the proposed radiometer system are given in *Table 1*.

The schematics of the sensor are shown on *Figure 6*. All schematics are made with Fritzing software (Knörig et al., 2009). For the purpose of simplifying the schematics, several resistors which are actually connected in series are represented as one (e.g. two 100Ω resistors as one 200Ω resistor). R2 is a trimmer resistor which is used for adjusting the gain of the system. During the actual use it was always adjusted for maximum gain. The amplified output signal line is taken from the pin 7 of the LMC6462 operational amplifier, while the ground line is taken directly from the battery and connected to the analog-digital converter (ADC). The schematics of the signal acquisition setup is given on *Figure 7*. The output lines from the sensor setup are connected to the ADC board. The ADC board communicates with Arduino via SPI communication and the Arduino communicates with a PC via the serial communication protocol.

Table 1 – Meteor radiometer components list.

Component	Quantity
Arduino UNO R3	1
Arduino ProtoShield	1
AD7705 Module Board	1
BPW34 photodiode	1
LMC6462 OP	1
1 MΩ resistor	1
200 Ω resistor	1
20 KΩ trimmer resistor	1
0.1 µF ceramic capacitor	2
47 µF 6.3V electrolytic capacitor	1
TSC 78L05 voltage regulator	1
Double sided header pin strip (100 pins)	1
9V battery	1

3 Testing

The testing had several goals: to validate the frequency characteristics, the sensitivity of the system and the influence of noise.

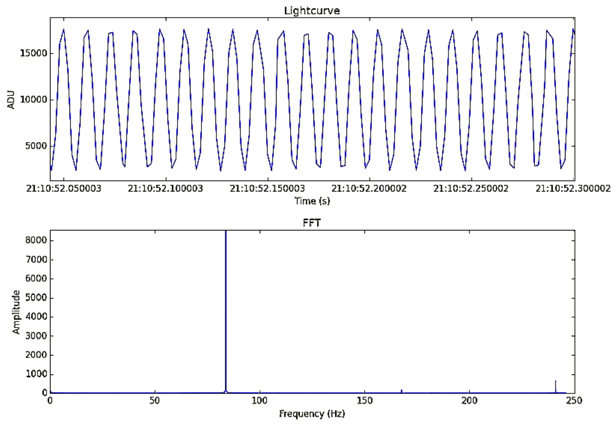

Figure 2 – 83 Hz square wave light signal sampled with the radiometer system (top) and its frequency spectrum (bottom).

With a 500 Hz sampling rate, a 250 Hz sine signal is theoretically the highest frequency signal that can be properly sampled with the current setup, according to the Nyquist-Shannon theorem (Shannon, 1949). A light-emitting diode was connected to the Arduino PWM output at f = 83 Hz and pointed at the sensor in a dark environment. As the Arduino PWM output produces a square wave signal which has an infinite number of sine harmonics, a lower signal frequency had to be chosen to properly sample the second harmonic which resides at 3 times the base frequency (249 Hz). The result of the test is shown on *Figure 2*. The top graph shows the magnified signal at the oscillation’s timescale and the bottom graph shows the frequency spectrum. A large peak on the frequency spectrum is visible at 83 Hz which corresponds to the main oscillation frequency. A minor peak is visible

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[2] Pyserial library: http://pyserial.sourceforge.net/

[3] Meteor Radiometer GitHub page: https://github.com/CroatianMeteorNetwork/MeteorRadiometer

[4] BPW34: http://www.farnell.com/datasheets/1911355.pdf

close to 250 Hz, which corresponds to the second harmonic of an 83 Hz square wave signal. This confirms the needed frequency characteristics.

As very sensitive lux meters (below 1 lux) were not on our disposal, it proved to be a very challenging task to simulate any faint light source and know its exact brightness. Live testing on a daily basis is impossible as the frequency of events that are supposed to be recorded is only a few per year. Thus it was decided to use a natural light source of a known magnitude – the Moon. Tests were performed during a period after the Full Moon, at the 3rd of August 2015, when the radiometer gain was adjusted to ½ of the maximum value (at about 32 000 ADU) and the Moon was of -12 apparent magnitude. The graph is shown on *Figure 3*.

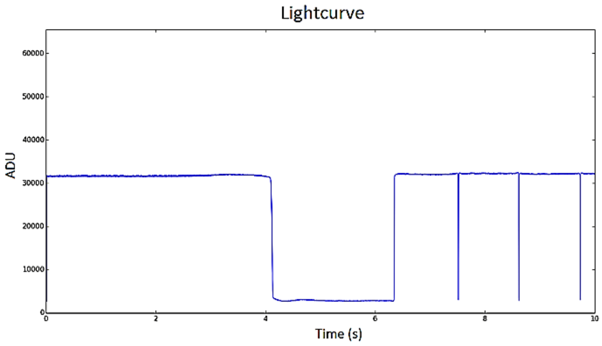

Figure 3 – Moonlight test.

Periods of high values represent the moonlight at about 45° angle off the photodiode plane, while the period of low values is caused by a hand being placed in front of the sensor. Sharp peaks to the bottom are caused by rapid movement of a hand in front of the sensor. Each peak is only one sample long. From this graph it is readily visible that there are no significant positive overshoots, positive undershoots, negative overshoots nor negative undershoots. There are also no visible oscillations after the rise of light level, meaning that the step response is very satisfactory.

Although the photodiode has a large angle of half sensitivity, experiments were performed with cheap wide-angle lenses. Mobile phone "fisheye" lenses, advertised as having a 180° field of view, were tested and results were conclusive – the sensitivity of the system was always better without any additional lenses mounted in front of the photodiode. The sensitivity was impaired even at very high angles of incidence.

One of the main sources of light noise during the testing were street lights which produced huge oscillations at 50 Hz, which correspond to power lines frequency. The problem is not prominent only when a direct light from the street lamp reaches the detector, but it also appears in the areas with high levels of light pollution, where the whole sky oscillates at 50 Hz. Such observations are quite heavy to interpret visually, thus we propose using a frequency spectrum filtering to obtain real changes in sky brightness.

On August 20, 2015 at about 22h local time, a high gain test with moonlight was performed. The Moon was 6 days after the New Moon and only 6° above horizon. It was slightly covered with clouds and the approximate apparent magnitude was -8, according to Stellarium software. The radiometer system was programmed for 64X gain and pointed towards the Moon. During the recording procedure, a hand was placed for a couple of seconds in front the sensor to cover it from incoming light. The result is shown on *Figure 4*. Just before placing the hand, several barely noticeable flashes of distant lightning could be seen. These were recorded and visible as 4 peaks around the 28th second on the graph. The oscillations on the graph were produced by the distant light pollution reflected by low clouds, while the Moon contributed with raising the average light value. This test shows that the limiting factor for radiometric observations is not the radiometer sensitivity but the conditions of observation.

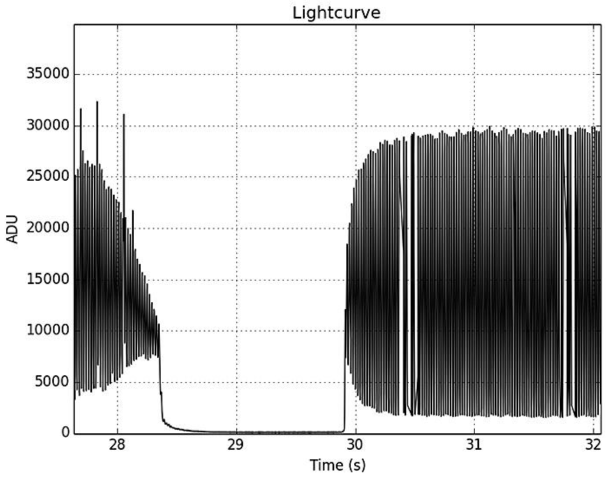

Figure 4 – 64X gain test.

The last remark is about the power supply noise. It was found that some notebooks have very bad USB power supply noise filtering, which produced huge oscillations on the captured signal. It is highly recommended to use better USB power sources or test the Raspberry Pi device as a device which runs the capture software – a possibility that we still did not explore. In such configuration, the whole radiometer system could be easily powered by a 12V battery during the course of one night and recharged during the day.

4 Observations

Only several nights of observations with fine-tuned parameters were performed as the system was finished shortly before the Perseid meteor shower of 2015.

First night of observations was done on August 3 in Višnjan, Croatia. After going through the video meteor data, no major fireballs were present, thus nothing was expected to be found on the radiometric data. Several peaks were noticed that do not correspond to any visually recorded meteors which are probably caused by birds in low flight.

The second night of observations was performed on August 8 in Pula, Croatia. The major issue with Pula observations is the light pollution which produces great frequency oscillations. No fireballs were recorded during the night, only a few long period changes in sky brightness.

It was decided to travel to a less light polluted area, to the mountain Platak near Rijeka, Croatia on the night of the Perseid shower maximum, August 12. The observations had to be done on battery as there was no electric power available, thus only one hour of observations was made. The recording was done from 23:00 to 00:08 local time. Groups of visual observers reported no major fireballs during that time, only meteors fainter than -1 apparent magnitude. These meteors were not present in the radiometric observations. The observing site was visited by numerous amateur visual observers, mostly the curious citizens of Rijeka. The radiometric data often shows great jumps in brightness – a sole witness of a bad observing etiquette by the visitors. Periods of radiometer saturation were followed by a negative audial response by the observers, mostly concerning the passing driver and his/her choice of headlights. *Figure 5* shows a distant car turn signal. Notice the lack of large amplitude oscillations which are usually present in light polluted areas.

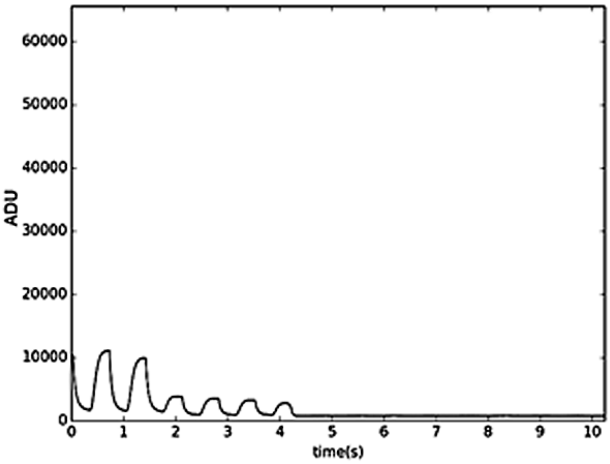

Figure 5 – Car turn signal light recorded at Platak.

Continuous observations are planned throughout the year and hopefully a fireball will soon be recorded by the radiometer system.

5 Conclusion

A new meteor radiometer system was successfully designed and tested. Details of the system were given, as well as the source code needed to run the system.

Further improvements in sampling rate, sensitivity and dynamic range are planned. A sampling rate of several kilohertz would bring the system up to modern standards, as well as using 24-bit precision. With a larger dynamic range, more sensitivity could be achieved to capture less luminous events. We propose testing the ADS1252 analog-digital converter to achieve the proposed functionality. Improvements should also be made in the frequency characteristics to properly sample a higher frequency signal. Using the Arduino digital outputs it is possible to implement hardware gain scheduling, where the radiometer gain could be adjusted by redirecting the connections through different resistors, thus adjusting the gain of the system.

We have also noticed that there are no means of visually simulating a fireball, thus making the testing of this system a challenging task.

The system still awaits a more luminous event to be properly tested.

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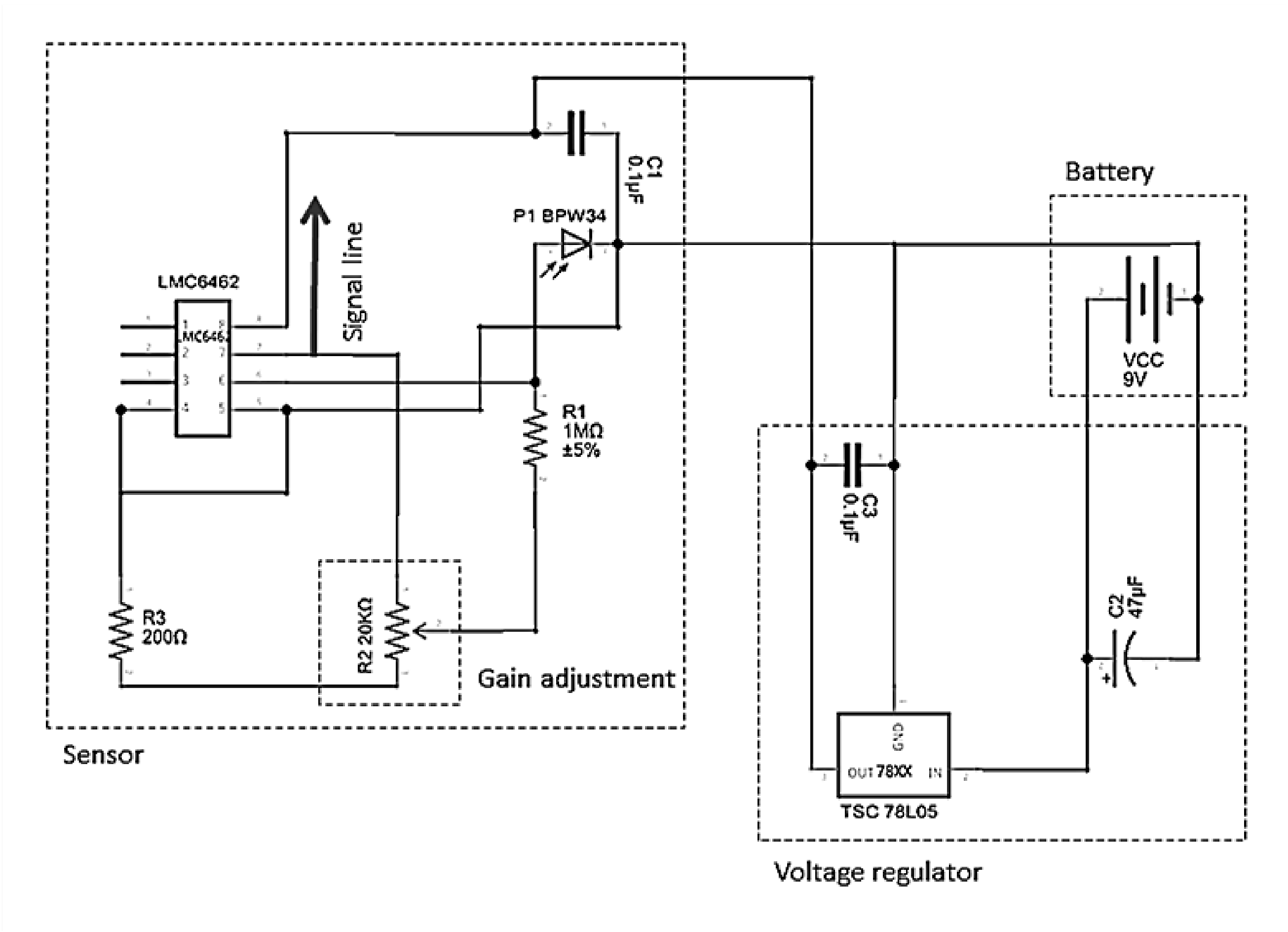

Figure 6 – Radiometer schematics.

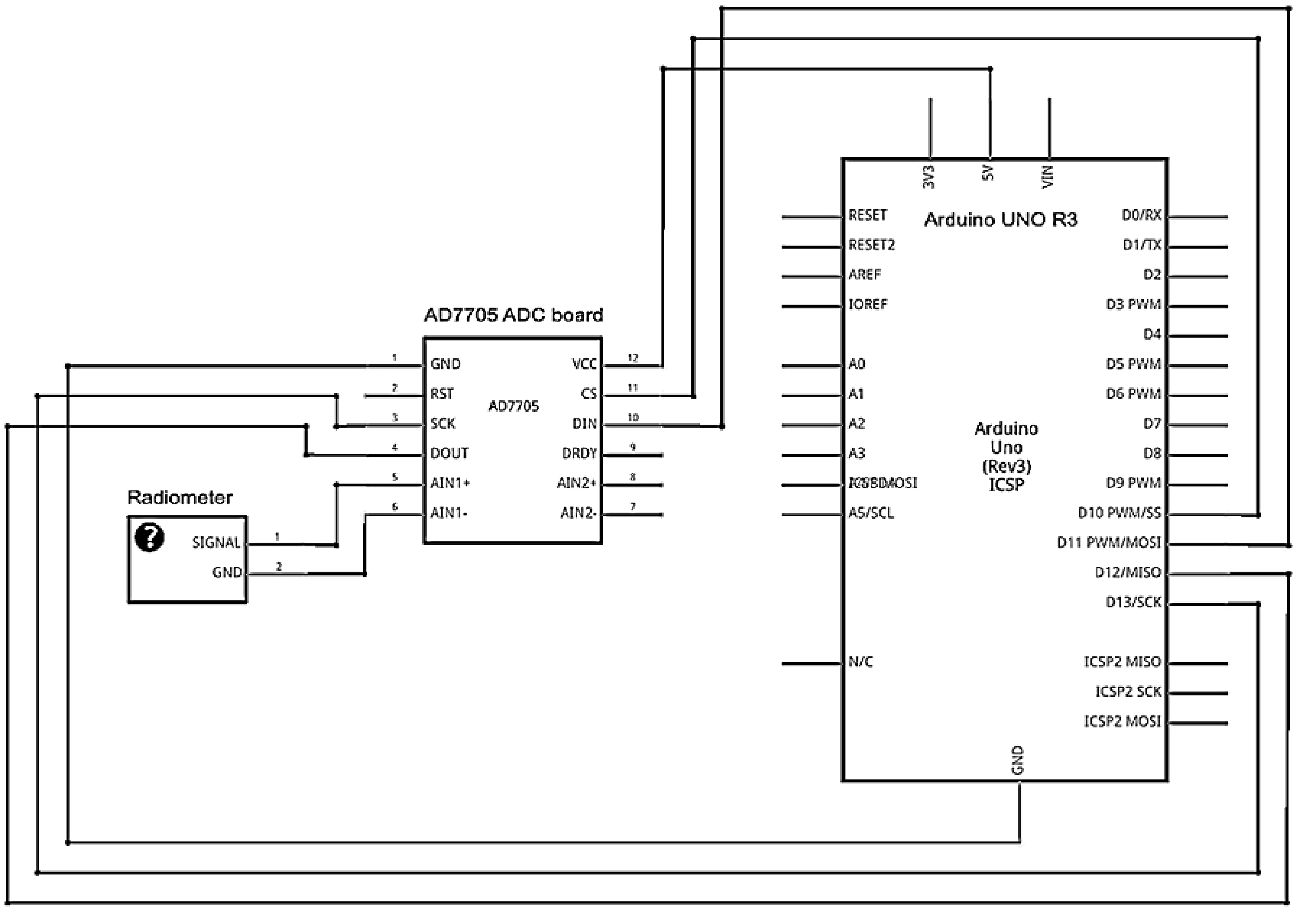

Figure 7 – Radiometer signal acquisition setup.