Use of the 555 integrated circuit for the construction of a PWM module

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Abstract

The use of technology has become increasingly viable in classrooms, especially in physics classes. Explaining phenomena related to circuits becomes simpler when we can provide practical examples to students. The present article aims to describe the construction of a low-cost PWM module, which was used in the classroom to demonstrate the basic principles of digital electronics. The module was built with the 555 integrated circuit and a few other components. The assembly was made on a breadboard. The results from the operation of the board were analyzed with a digital oscilloscope and corresponded to what was expected in theory, the compatibility of the pulse width could be successfully verified, as well as the effect of simulating the analog output signal. Alternatively, the prototype was also used with an electric motor to visualize the influence of pulse width on the motor's rotation.

Keywords: PWM generator, 555 timer integrated circuit, oscillator.

Uso do circuito integrado 555 para construção de um módulo PWM

Resumo

O uso da tecnologia tem se tornado cada vez mais viável nas salas de aula, em especial nas aulas de física. Explicar os fenômenos relacionados à circuitos se torna mais simples quando podemos fornecer aos alunos exemplos práticos. O presente artigo tem como objetivo descrever a construção de um módulo PWM de baixo custo, que foi utilizado em sala de aula para demonstrar os princípios básicos da eletrônica digital. O módulo foi construído com o circuito integrado 555 e mais alguns componentes. A montagem foi feita em uma protoboard. Os resultados provenientes do funcionamento da placa foram analisados com um osciloscópio digital e corresponderam com o esperado na teoria, a compatibilidade da largura dos pulsos pôde ser verificada com êxito, bem como o efeito da simulação do sinal de saída analógico. Alternativamente o protótipo também foi utilizado com um motor elétrico para visualização da influência da largura do pulso na rotação do motor.

Palavras-chave: gerador PWM, circuito integrado 555, oscilador.

1. Introduction

Access to technological resources and information on how to use them is becoming increasingly available. As a result, it has become easy to better understand the inherent aspects of electronic circuits as well as to reproduce circuits for our everyday use.

This paper describes the construction of a didactic PWM module based on the 555 integrated circuit, using only a few electronic components. The module was developed for didactic purposes, to help develop basic electronic skills in students of the Physics course.

Incorporating experimental activities in physics education often provides greater motivation to students. According to Zúbia and Alves (2011) in their collection of remote experiments for physics and engineering, experimental activities are essential to improve the learning of key concepts in science.

The PWM (Pulse Width Modulation) circuit is a device capable of generating digital signals that simulate an analog output. It basically has the function of generating high-frequency digital pulses, varying its width (pulse duration) to produce an average voltage value. This average voltage value can be changed according to the pulse duration, hence the name given to the circuit.

We can find various types of circuits to simulate the PWM signal, in some cases, such as in the work of (Silapam and Siripruchyanun, 2009), where the authors built a current-mode PWM simulator circuit with only a single active element. In the authors' work, the frequency relationship of the circuit was shown to be given by Equation 1

$$f = \frac{I_{B1}}{CV_T ln(\frac{V_T + 4I_{B1}R}{V_T})} \qquad \text{(Equation 1)}$$

In the circuit described by the authors, the frequency can be electronically controlled, and estimated by Equation 1 along with the other circuit parameters. Additionally, in the work of (Silapam and Siripruchyanun, 2009), we also find a graph illustrating the PWM output signal, shown in Figure 1.

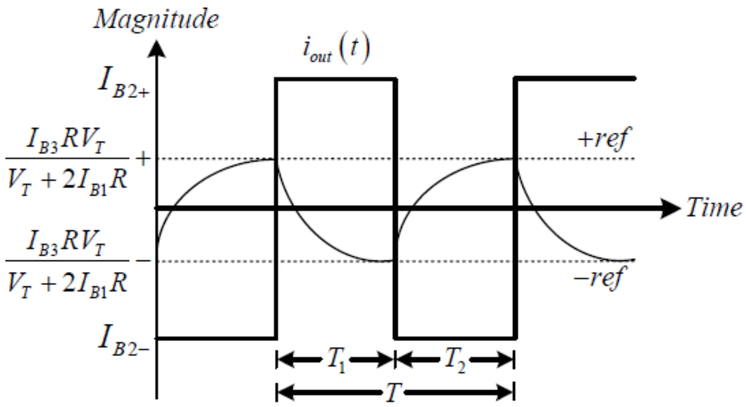

Figure 1. PWM signal graph. Source: (Silapam and Siripruchyanun, 2009, p.146).

The circuit that was built in this work resembles that of the authors in the sense that we obtained, as the output result, the PWM signal that could be controlled to obtain different pulse widths. The circuit was used in the classroom to simulate a voltage source, gradually increasing the rotation of a DC motor. The main goal of the work was to develop in the students the skills for assembling electrical circuits and improve the learning of physics concepts related to circuits.

2. Materials and Methods

The work was developed in a class of undergraduate physics students, composed of 5 students, at a Federal institution in the state of Rio de Janeiro. The context of the work was in laboratory classes, and the students had access to the experimental apparatus that will be described in this section.

2.1 The IC555 - Examples

The 555 integrated circuit has three basic modes of operation: bistable, monostable, and astable. These operating modes refer to the stability of the signal at the output of the 555. In the work of Admiral (2021a), for instance, we find the construction of a vibration sensor based on the 555 operating in bistable mode. In this mode of operation, the output of the integrated circuit remains at a low level until the contact with the trigger pin is triggered, only then does the gate go to a high level and will remain so until someone resets the circuit. The circuit is shown in Figure 2.

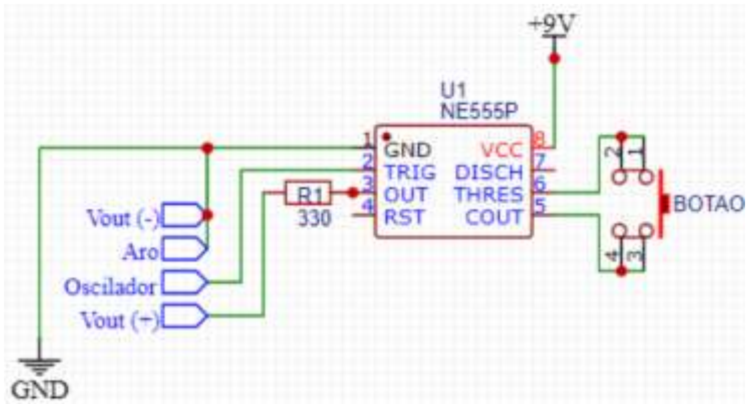

Figure 2. Example of circuit in bistable mode. (Admiral, 2021a, p. 89271).

Another way to use the 555 is in monostable mode, in which the 555 has one of the logical levels of the output signal as default, and the other mode is activated for a predefined time. In the work of Admiral (2021b), we have an example of a circuit with the 555 in monostable mode. In this example, the circuit remains with its output at a low logic level until an automatic float triggers the trigger pin, then the circuit changes the logic level of the output to high, allowing the water pump to be activated, and remains in this state for approximately 1 minute, then returns automatically to the low logic level. Figure 3 illustrates the circuit used by the author:

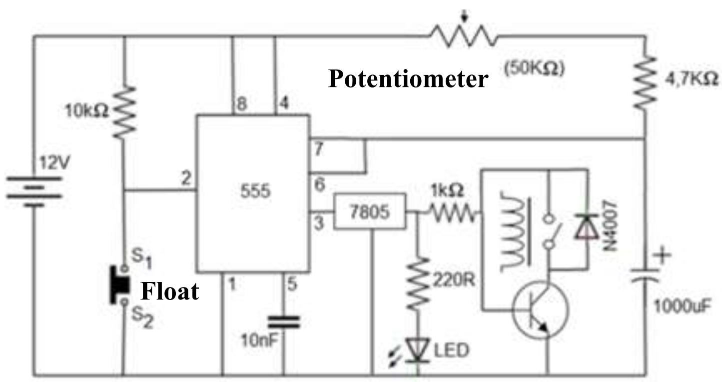

Figure 3. Circuit using a IC555 in monostable mode. (Admiral, 2021b, p. 103818).

In the circuit shown in figure 3, in addition to the 555, there are several other components intended for the operation of the board, which was designed to control an external load (electric motor) upon activation. Among the traditional passive components (resistors and capacitors), we have the indication of the electronic float, which was the sensor responsible for determining the activation. We also have a relay, intended for the electromechanical activation of the motor, and a voltage regulator (7805) to adjust the output voltage of the 555 (currently 12V) to the 5.0V compatible with the activation relay.

2.2 The astable mode

The astable mode of operation causes the 555 to function as an oscillator, with the output signal turning on and off alternately. Figure 4 shows the basis for the astable mode of operation. In the figure, we can see that the oscillation frequency of the circuit depends on the set of resistors and capacitors associated with the 555 gates. In the same figure, taken from the 555 datasheet, we can also see that the pulse width can be obtained using the expression 1.1RC.

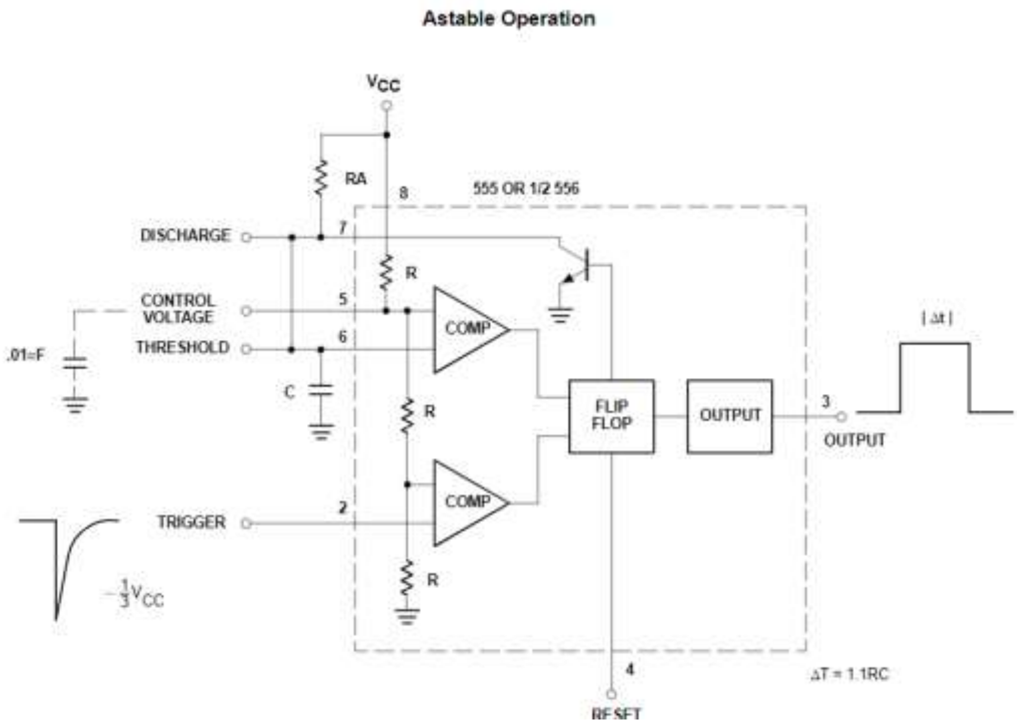

Figure 4. Basic circuit in astable mode, main frame os function. Source: https://pdf1.alldatasheet.com/datasheet-pdf/view/17972/PHILIPS/NE555.html

In our prototype, the following components were used:

- Timer Ne555;
- 10k Resistor;
- 10k Adjustable resistor;
- 1,0 uF Eletrolitic capacitor;
- 10 nF Capacitor;
- 5,0V Source;
- Breadboard;
- Osciloscope.

The assembly of the equipment, as well as the results obtained from the measurements, will be presented in the next section.

3. Results and Discussion

3.1 Prototype measurements

Next, we will address the results measured with the help of the prototype developed. The prototype was assembled using a protoboard, also a voltage source providing 5.00V. The components were connected according to the simplified circuit shown in figure 5:

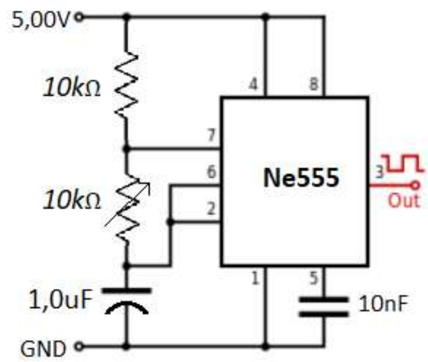

Figure 5. Circuit used in class. Source: Author, 2023.

The assembled circuit can be seen in Figure 6.

Figure 6. On the right, the circuit assembled on the breadboard, on the left we can see the oscilloscope reading the output signal. Source: Author, 2023.

The two resistors that make up the circuit, along with the electrolytic capacitor, define the frequency of the signal, as well as the duration of the high signal pulse. The percentage of time that the signal stays at the high logic level is called Duty Cycle, in Figure 6 we can see the value of this parameter as approximately 68.7%.

By directly measuring the resistance values with the students, we determined that the expected Duty Cycle value would be 68.5%, very close to what was observed on the oscilloscope. The total frequency result was compared with what we expected theoretically, given by equation 2.

$$f = \frac{1,44}{C(R_s + 2R_v)}$$ (Equation 2)

Later, during class, it was demonstrated to the students that by turning the potentiometer, we can change the value of one of the electrical resistances and, consequently, we can also change the duration of the high pulse. The phenomenon was viewed in real-time on the portable oscilloscope.

Another experiment that was performed consisted of connecting an electric motor directly to the output of the 555 and GND. As the electric motor has a nominal operating voltage of 6.0V, it worked perfectly with the small electric current provided by the 555. Figure 7 illustrates the circuit now already connected to the electric motor. At the end of the electric motor, a small piece of red tape was attached to help visualize the rotation of the motor shaft.

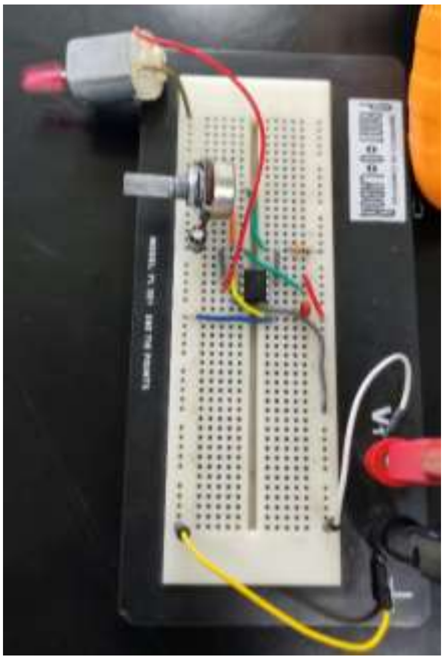

Figure 7. We can see the motor spinning, connected to the PWM circuit. Source: Author, 2023.

At this point, the students were able to turn the potentiometer to observe how the pulse width influenced the rotation of the motor. The larger the width, the higher the simulated average output voltage, on the other hand, the smaller the pulse width, the lower the rotation of the electric motor.

3.2 Results in learning

By monitoring the performance of the students throughout the classes, it was possible to identify some indications that point towards an improvement in learning regarding the main concepts. Initially, all the students were willing and attentive to the instructions for assembling the circuit. Three students even began to handle the components and tried to insert them on the board before the command. This happened because they had received a printed copy of the circuit diagram, so these students already had some knowledge and felt comfortable enough to take some risks.

However, they didn't get very far. The first difficulty appeared when they got confused about how the contacts between the pins on the protoboard work. From that moment on, the teacher started a more practical explanation about the components, such as identifying the value of resistors by the color code, identifying the contacts on the protoboard, and, mainly, how to identify the pins of the 555. It was identified that the students did not know this information at the beginning of the class, and by the end of the class, they already understood how everything worked.

It is interesting to observe that throughout the class time, the students, even being few in number, interacted collaboratively in the sense of helping each other to understand. According to Van der Veer, R. & Zavershneva (2011), who explains about Vygotsky's learning theory, interaction and communication are essential pieces for development and learning. At various moments, the teacher was not the one who answered the students' questions, but their own classmates. The teacher's interference occurred mainly during theoretical doubts.

Once the circuit assembly stage was completed, the students began to analyze the PWM pulse using the oscilloscope, and doubts arose again. The oscilloscope used in the experiment is portable and much simpler compared to the traditional one, but the students demonstrated difficulty in adjusting the ideal time scale to visualize the PWM patterns. The teacher explained that first, we can estimate the expected frequency by doing the calculations with equation 2, and then we adjust the oscilloscope to the ideal frequency range.

At various moments, the students asked practical questions and arrived at conclusions that showed they were understanding the concepts involved. At one point in the class, a student asked a question about how the inside of the 555 works and how it functions the way we see it. At this moment, the other students also showed interest in the topic, so the teacher spent a good amount of time in the class explaining about the internal voltage comparators of the 555 and how they act to decide on the output pin state. The students found the ingenuity of the device quite interesting.

4. Conclusions

Regarding the potential of the resource for learning, we can highlight some important points. Firstly, the students had the opportunity to observe the components they study in theoretical classes up close; capacitors and resistors were nothing more than symbols in books until then, but after the class they acquired the ability to recognize and manipulate these components in the circuit.

Another skill developed during the class involves reading and interpreting electrical signals from the oscilloscope. The oscilloscope was initially the device that presented the most difficulty in manipulation by the students. Replacing the bench oscilloscope with a portable one made the experiment more compact and simpler, both in assembly and execution.

The increase in interest and participation in classes observed during the use of the prototype agrees with other works in the literature that make similar analyses, such as the example of Amusa's work (2021). In his work, the author analyzes the importance of conducting experiments in the area of electricity to motivate and enhance the learning of physics and engineering students.

Finally, the experiment with the prototype proved to be a low-cost and easily accessible tool, very useful for introducing basic concepts of electronics also for reinforcing concepts learned in previous disciplines. The students' interest in experimental classes, although difficult to be measured numerically, is noticeably higher than in traditional theoretical classes. This point alone justifies bringing experiments to the classroom.

5. Acknowledgments

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7. Conflicts of Interest

No conflicts of interest.

8. Ethics Approval

Not applicable.

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