Analysis of RC circuits with the help of LabVIEW and data acquisition card for physics laboratory course

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Abstract

In this study, it is aimed to create a circuit and software that can be used in teaching RC circuits at the university level for physics laboratory courses. In this context, the change of the voltage on the capacitor and the current of the circuit during the charge/discharge of an RC circuit connected to DC voltage was taken into the computer environment with a data acquisition card (NI USB 6021) and LabVIEW program. The experimental procedure to be applied in the use of the teaching material (circuit and software) developed within the scope of the study was explained in detail. Furthermore, in order to test the accuracy of the circuit and software, experiments were performed using different resistors and capacitors and presented in the scope of the study. As a result, the importance of the developed experimental setup in terms of teaching was emphasized.

Keywords: Physics education, laboratory course, RC circuit, time constant, capacitor, LabVIEW.

Fizik laboratuvarı dersi için RC devrelerinin LabVIEW ve veri toplama kartı yardımı ile analizi

Öz

Bu çalışmada, fizik laboratuvarı dersi için üniversite düzeyinde RC devrelerinin öğretiminde kullanılabilecek bir devre ve yazılım oluşturulması amaçlanmıştır. Bu kapsamda DC gerilime bağlı bir RC devresinin şarjı/deşarjı sırasında kondansatör üzerindeki gerilimin ve devre akımının değişimi bir veri toplama kartı (NI USB 6021) ve LabVIEW programı ile bilgisayar ortamına alınmıştır. Çalışma kapsamında geliştirilen öğretim materyalinin (devre ve yazılım) kullanımında uygulanacak deneysel prosedür

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detaylı olarak anlatılmıştır. Ayrıca devrenin ve yazılımın doğruluğunu test etmek amacıyla farklı dirençler ve kondansatörler kullanılarak deneyler yapılmış ve elde edilen sonuçlar çalışma kapsamında sunulmuştur. Sonuç olarak, geliştirilen deney düzeneğinin öğretim açısından önemi vurgulanmıştır.

Anahtar kelimeler: Fizik eğitimi, laboratuvar dersi, RC devresi, zaman sabiti, kondansatör, LabVIEW.

1. Introduction

Capacitors are used in different industries due to their different application areas and they have become an essential part of daily life. The most common use of capacitors is energy storage. Additional uses include power conditioning, remote sensing, timing, and tuning. Camera flashes, televisions, radios, speakers, defibrillator (electroshock) devices and electromagnetic launchers can be given as examples of devices where the capacitor is used in daily life. One of the best examples to be given for this use is the "Capacitor Tree" used in the particle accelerator in Fermilab (Chicago) [1]. Its function is to reduce the voltage drop of the power supplies at high currents, by acting in series resonance with the leakage inductances of the system. In addition to this common use in daily life, capacitors are frequently used in undergraduate physics and electronics laboratory courses.

A circuit containing a series combination of a resistor and a capacitor is called an RC circuit. Basic experiments are carried out in the physics labs about RC circuits. With the help of these experiments, the changes that occur in the circuit during the capacitor charge/discharge can be observed. Also, variables such as time constant and capacitive reactance can be calculated. However, due to the very small values of the time constant, it is very difficult to make this observation in such experiments. For example, the time constant (τ) for an RC circuit with a 10 µF capacitor and a 5 kΩ resistor is 0.05 s. Under these conditions, it is not possible to read the voltage value with a voltmeter and record it depending on time during the experiment. To eliminate this difficulty, the change of the voltage value on the voltmeter depending on the time can be recorded using a smartphone camera [2]. In this case, the phone used for recording should be able to record video at high fps values. Only in this way, accurate data can be obtained during the charging and discharging of the capacitor. In general, oscilloscopes are used for measuring the time constants in an RC, LR, or LRC circuit [3]. However, oscilloscopes are sometimes not easily accessible for students. Apart from real oscilloscopes, virtual oscilloscopes are also used for this purpose [3]. In addition, Arduino is used to obtain data from experiments related to capacitors [4,5]. In this case, it is necessary to have coding knowledge to receive data with the help of Arduino.

Programming languages can be grouped under two main headings as graphical (visual) programming and text-based languages. In a text-based programming language, coding is done by typing various characters from a list of codes (e.g., C++, Java, JavaScript, Python). In addition to the use of text-based languages in the design of teaching materials, the use of graphical programming languages (e.g., LabVIEW) is increasing day by day. Unlike text-based programming languages, programming in graphical languages is usually accomplished by linking symbols and blocks. The biggest advantages of graphical programming languages over text-based programming languages are that they are more visually understandable and easier to learn. Shorter learning time and visual programming

processes allow people who are not very familiar with programming or new to programming to use the program easily. With this feature, the use of LabVIEW as a programming language has increased considerably, especially in the field of physics [6,7] and chemistry [8,9] education.

In addition to the choice of programming language, one of the important factors in transferring the experimental data to the computer environment is the choice of the data acquisition card. Different alternatives are used as data acquisition cards in experimental setups with LabVIEW. In addition to experimental setups using data acquisition cards (DAQ) developed by National Instruments [10,11], there are also studies using Arduino boards [12-15]. However, there are also studies in which teaching material (simulation) is developed using only LabVIEW software [16]. One of the most important issues in choosing the type of data acquisition board is the resolution at which we want the data to be acquired. For higher-resolution data acquisition and more precise measurements, specially produced DAQ cards are generally used instead of Arduino boards.

In this study, it is aimed to create a circuit and software that can be used in teaching RC circuits at the university level for physics laboratory courses. In this context, the change of the voltage on the capacitor and the current of the circuit during the charge/discharge of an RC circuit connected to DC voltage was taken into the computer environment with a data acquisition card (NI USB 6021) and LabVIEW program. LabVIEW software is preferred because it is more visual than text-based programming languages and can be easily learned/applied by both students and teachers in a short time. In addition, the data acquisition card produced by NI is preferred instead of different cards such as Arduino because the data is wanted to be taken into the computer environment with higher resolution. The Arduino Mega 2560 and Uno can read analog data at 10-bit resolution, while the NI USB-6210 data acquisition board can read at 16-bit. The experimental procedure to be applied in the use of the teaching material (circuit and software) developed within the scope of the study was explained in detail. Furthermore, in order to test the accuracy of the circuit and software, experiments were performed using different resistors and capacitors. The time constant and capacitance of the capacitors were also calculated.

2. Method

In this section, the theoretical background and experimental setup of teaching material are described in detail including the experimental procedure.

2.1. Theoretical background

A simple circuit used for analyzing RC circuits in the physics/electronics laboratory is given in Figure 1. An RC circuit is a type of electrical circuit that consists of a resistor (R) and a capacitor (C) connected in series with a voltage source. The current of the circuit is measured with an ammeter (A) connected in series with the circuit, while the potential difference between the terminals of the capacitor is measured with a voltmeter (V).
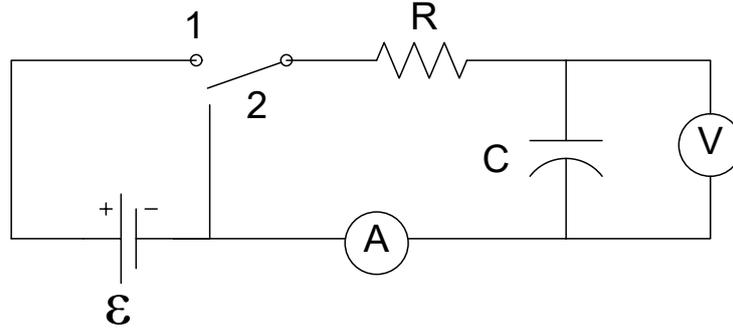
Figure 1. Experimental setup for RC circuit

Let the capacitor in the circuit (Figure 1) be empty initially. If the switch is thrown to the position 1 at t = 0, the current begins to flow through the circuit. As the current continues to flow through the circuit, the potential difference between the plates of the capacitor increases. The current flow through the circuit ends when the potential difference between the plates of the capacitor is equal to the power supply voltage. In other words, when the capacitor is fully charged, current no longer flows through the circuit. In this case, the maximum charge is stored on the capacitor. Charge as a function of time for a capacitor being charged is as follows;

$$q(t) = C\varepsilon\left(1 - e^{-t/RC}\right) = Q(1 - e^{-t/RC}) \tag{1}$$

Q is the maximum charge on the capacitor and is equal to the value of Q=Cε. Current as a function of time for a capacitor being charged is as follows;

$$I(t) = \frac{\varepsilon}{R}\left(e^{-t/RC}\right) = I_0(e^{-t/RC}) \tag{2}$$

According to Eq. 2, the current takes the maximum value of $I_0=\varepsilon/R$ at t = 0.

Let's assume that the capacitor in the circuit is fully charged. In this case, if the switch is thrown to the position 2, the capacitor begins to discharge through the resistor. If it is assumed that the charge of the capacitor is Q at time t = 0, the change of the charge on the capacitor depending on time is as given in Eq.3.

$$q(t) = Qe^{-t/RC} \tag{3}$$

The time derivative of this equation gives the change of current with time

$$I(t) = -\frac{Q}{RC}e^{-t/RC} = -I_0 e^{-t/RC} \tag{4}$$

The expression "RC" in these equations is called the "τ" time constant of the circuit and it is the time taken for the capacitor voltage to reach $1-e^{-1} = 0.632$ of the power supply voltage or current to reach $1/e = 0.368$ of the I_0. In addition, it is accepted that the capacitor is almost fully $(1-e^{-5} = 0.993)$ charged at the end of "5 τ" time [17,18].

2.2. Experimental setup of teaching material
2.2.1 LabVIEW and NI USB 6021

LabVIEW is an abbreviation for "Laboratory Virtual Instrument Engineering Workbench" and is used to describe a programming environment. It consists of two main parts "Block Diagram" and "Front Panel". Block Diagram is the section where the codes are written, and Front Panel is the user interface [19].

To provide the connection between the outside world and the computer, the LabVIEW program uses interfaces called Data Acquisition Cards (DAQ) produced by National Instruments. The connection of these cards with the computer can be made via USB or the main board. The fact that DAQ cards have many options regarding the number of terminals, terminal type and sensitivity and that LabVIEW is a graphical language highlights this software language and the use of data collection cards during experiments.

USB-6210 multifunction DAQ device has 16 analog inputs (16 bit, 250kS / s), 4 digital inputs and 4 digital outputs. In addition, the device has two 32-bit counters. The device can read analog input voltage with a maximum sensitivity of 91.6μV. The USB-6210 has a + 5V output channel and can give a current up to 50 mA [20].

2.2.2. Circuit design and software

In order to observe the voltage on the capacitor and the current passing through the circuit depending on time during the charge and discharge of the capacitor, the circuit given in Figure 2 was built. In addition, the block diagram of the program written for transferring the data to the computer is given in Figure 3.
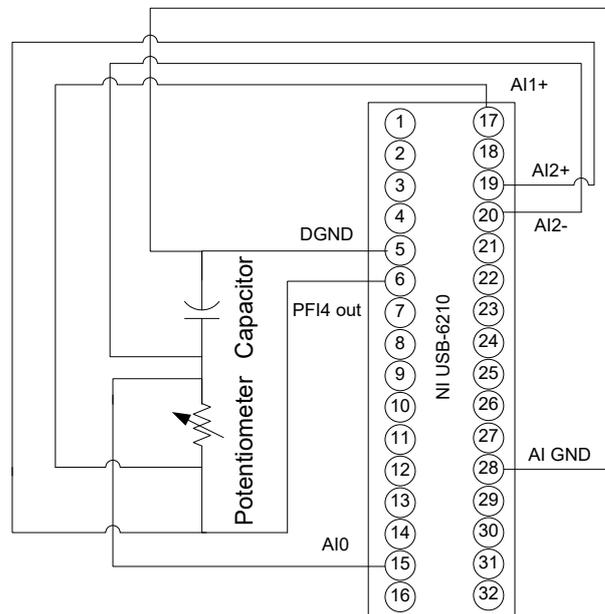
Figure 2. Circuit diagram of the experimental setup.
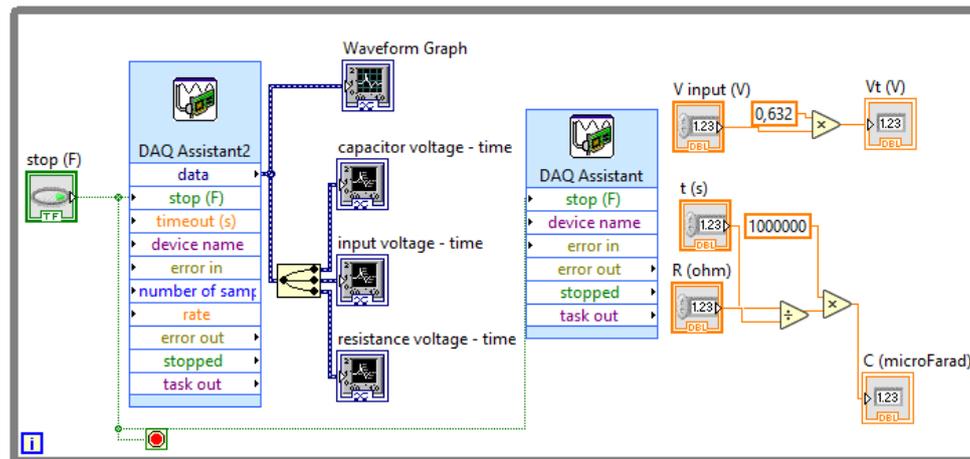
Figure 3. Block diagram of the LabVIEW program

Unlike the basic circuit in Figure 1, square wave output (PFI4 out and DGND) is used instead of a DC source in the circuit given in Figure 2. In this way, the need to continuously open and close the switch in Figure 1 is eliminated. In the first stage of the two-stage experiment, a potentiometer was used instead of a fixed resistor. By using the USB 6210 data acquisition card, the potentiometer (resistor) (pin 19-20), the capacitor (pin 15-28) and the input voltage (pin 17-28) were read and transferred to the computer.

2.3. Experimental procedure

First of all, DAQ (USB-6210) is connected to the computer via USB. Then, a data acquisition and display program written with LabVIEW is opened. There are four different graphics on the user interface of the program (Figure 4). Three of these graphs on the left show the input signal, the voltage on the capacitor and the voltage on the resistor with time, respectively. The last graphic (right side), similar to an oscilloscope screen, is the section where all these three graphs are displayed simultaneously.

It was thought that planning the experiment in two stages would make teaching more effective. For this reason, it was planned to make observations and measurements in the first stage and to make measurements and calculations in the second stage of the experiment.

The first stage (analysis with potentiometer); Observation of the dependence of the charge and discharge curves on the value of the resistance and the determination of the time constant on the graph are the purposes of the first step. For these purposes, the value of the capacitor in the circuit must be kept constant and the resistance value must be changed by using the potentiometer. The charge stored on the capacitor and the potential difference on the capacitor are directly proportional to each other. The same is true for the current flowing through the circuit and the potential difference on the potentiometer. Therefore, the characteristics of the charge-time and current-time curves will be examined by examining the graphs obtained. Then the input voltage value should be read on the graph and entered into the relevant field in the program. The computer program displays the capacitor voltage value on the screen where the time constant (τ) should be obtained depending on the input voltage value. The time equivalent of this voltage value can be read on the graph. It can also be observed that the capacitor is fully (99.3%) full at 5τ time.

The second stage (analysis with constant resistance); In the second stage, the program is re-run by connecting a fixed resistor instead of the potentiometer in the circuit. The observations made at the first stage will guide the selection of the value of this resistance. At this stage, again with the help of the program, the capacitor voltage required to obtain the time constant (τ) is determined. After reading the τ value on the graph, the capacitance of the capacitor is calculated with the help of $\tau = RC$. The experiment is completed by comparing this calculated value with the real value. In addition, at this stage, the capacitance of the capacitor and the value of the resistance can be given to the student and the student may be asked to calculate the time constant. In this way, the calculated time constant can be compared with the time constant that is read on the graph (experimental).

3. Experimental data

The experimental setup created by sending a square wave with a frequency of 1Hz and an amplitude of 4.95 V to the circuit containing a potentiometer of R=10 kΩ and a capacitor of C=10 μF is given in Figure 4.
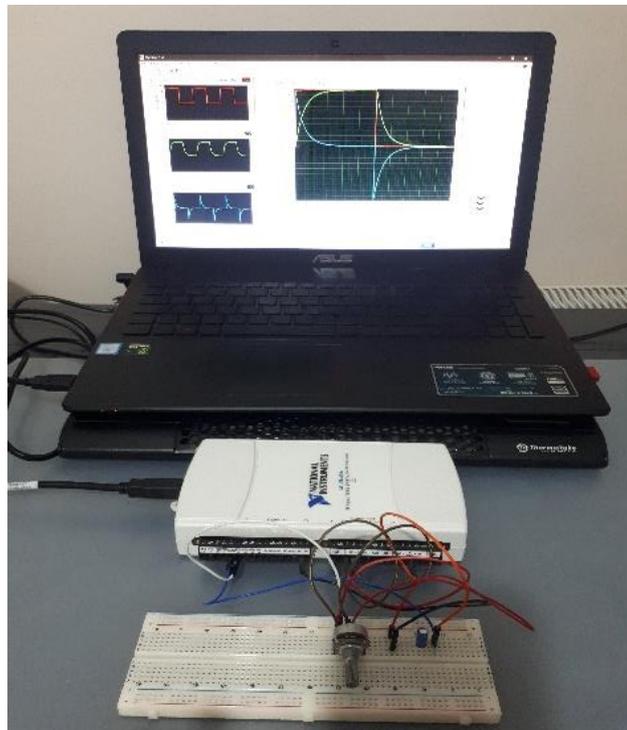
Figure 4. Experimental setup

In the first stage of the experiment, the graphs obtained for different values of the potentiometer in the experimental setup is given in Figure 5.
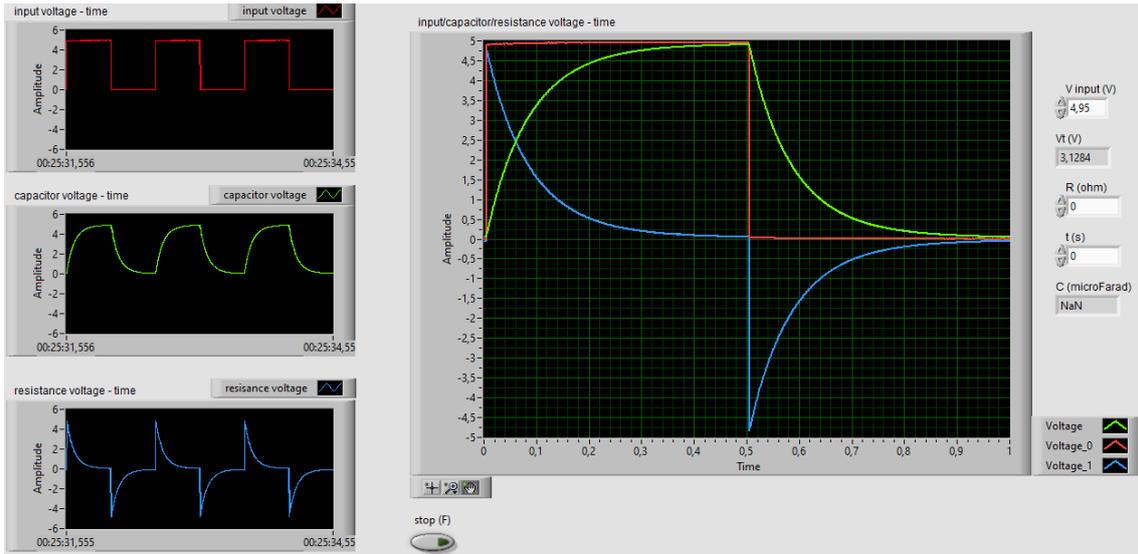
(a)
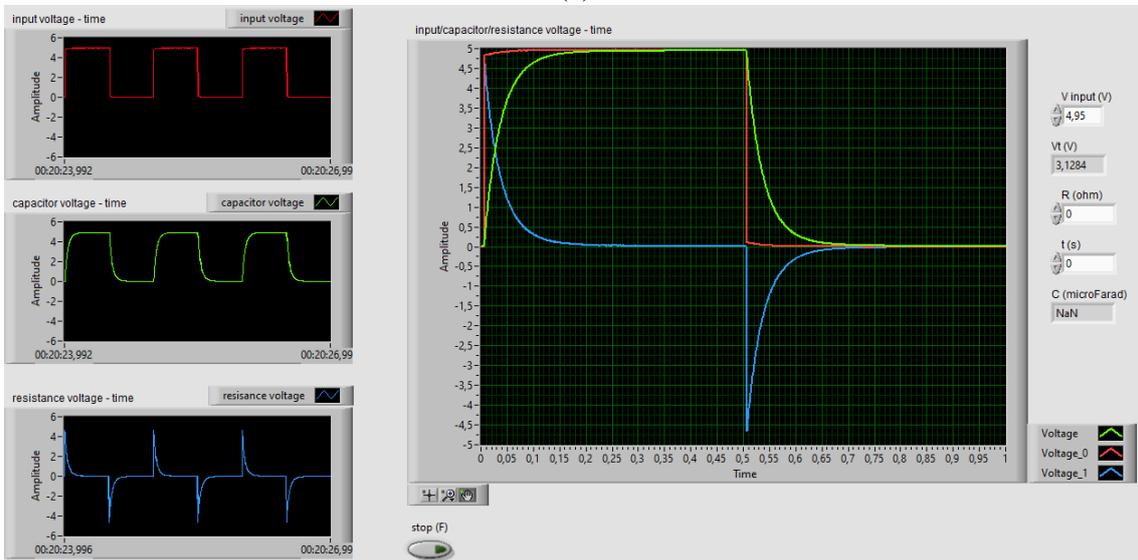
(b)

Figure 5. The graphs obtained for a) 7.46 kΩ b) 2.80 kΩ values of the potentiometer in the first stage of the experiment

In the graphs, the red line shows the change of input voltage, the green line shows the change of the voltage on the capacitor and the blue line shows the change of the voltage on the potentiometer with time. When these graphs are examined, it is seen that Eq.1, Eq. 2, Eq.3 and Eq.4 are consistent with the graphs obtained in the experiment. In addition, as a result of increasing the resistance with the help of the potentiometer, it was observed that the capacitor filled later, in other words, the time constant increased.

It was determined on the graph (Fig. 5a) that the input voltage value is 4.95 V. When this value was entered into the program, it was seen that the voltage equivalent of the time constant on the capacitor is 3.1284 V. The time taken (τ) for the voltage on the capacitor to become 3.1284 V was read from the graph. The time constant was experimentally determined as 0.082 s. The capacitor voltage value at the time of 5τ was also read on the graph as 4.88V. In this case, it can be said that the capacitor is approximately (98.59%) full charge at the end of 5τ time. This is consistent with theoretical knowledge.

In the second stage, the experimental setups were rebuilt by using a fixed resistor and a capacitor. In this case, the input voltage values read from the graphs were 4.95 V. The experimental data for different resistance and capacitor values are given in Table 1.

Table 1. Results obtained from the experiments

V_{input} (V)	R (kΩ)	C (μF) Real	τ (s)	C (μF) Experiment	Error (%)
4.95	56.40	1.50	0.089	1.58	5.33
4.95	19.56	3.30	0.071	3.63	10.00
4.95	14.60	10.0	0.160	10.96	9.60

Table 1 shows that the experimental data are compatible with the theoretical values with an error of less than ten percent.

4. Results and discussion

In this study, characteristic graphs and time constant (τ) of an RC circuit are determined during the charge and discharge of the capacitor without an ammeter, voltmeter, power supply and oscilloscope. In addition, depending on the change of resistance in an RC circuit, the changes in the voltage-time graph of the capacitor and the voltage (current)-time graph of the circuit were observed on the screen instantly with the help of the program. It was also determined by this experimental setup that the increase of the resistance value in the circuit causes the capacitor to charge later and increases the time constant. It was also determined that the capacitor was approximately fully charged at 5τ time. In addition, the capacitance of a capacitor with an unknown capacity was determined by the determination of the time constant with the help of the program.

Since data acquisition cards can be used repeatedly in different experiments for different purposes and the LabVIEW program includes a visual interface, it is thought that it will be beneficial to use this and similar experimental setups by both students and teachers. In addition, unlike control cards such as Arduino, this DAQ card, which has a very high resolution, can be easily used in experiments involving precise measurements using different sensors (temperature, humidity, current, magnetic). In this way, even those who do not have advanced programming knowledge can perform the experiments as they want sensitively by using this DAQ card in the physics and electronics labs.

In addition to all these, it can be thought that using the developed experimental setup in the laboratory will help students to focus on the subject conceptually. In particular, the experimental setups containing different measurement tools sometimes cause students to focus on different points other than the purpose of the experiment. These focal points are usually the use of oscilloscope or multimeter. However, although using these tools and the construction of the circuit are part of the teaching, the main purpose is to analyze RC circuits. From this point of view, it is thought that carrying out the experiment with less equipment and observing all variables from a single screen will contribute to the teaching of RC circuits.

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