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A CURSOR-BASED METHOD FOR MEASURING CAPACITANCE AND RESISTANCE

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Purpose. *The purpose of this work is to develop and experimentally validate a cursor-based method for measuring capacitance and resistance in an RC circuit using a digital oscilloscope. The study focuses on determining circuit parameters through the time constant extracted from transient response waveforms.*

Methodology. *The research is based on analytical modeling of an RC circuit using step-response theory and Heaviside unit step functions. The transient response to a rectangular input pulse is mathematically described, and the time constant ($\tau = RC$) is determined from the characteristic waveform levels (63.2% during charging and 36.8% during discharging). Experimental validation is carried out using a pulse generator, a digital oscilloscope, and a test RC circuit. The cursor measurement technique is applied directly to oscilloscope waveforms to extract time-domain parameters without additional computational processing.*

Findings. *The study demonstrates that the proposed method enables the accurate determination of the circuit parameters. For the test circuit with $R = 1$ kΩ and $C = 1$ μF, the measured time constant $\tau = 1$ ms coincides with the theoretical value. The method provides reliable results when the input pulse duration is selected appropriately (3–5 times the rise time). Experimental waveforms show strong agreement with theoretical predictions, confirming the correctness and stability of the approach.*

Originality. *The originality of the work lies in the development of a simple and practical cursor-based technique for parameter extraction directly from oscilloscope displays without complex data processing. Unlike traditional measurement methods, the proposed approach emphasizes real-time visual determination of electrical parameters using transient response characteristics.*

Practical value. *The method is easy to implement using standard laboratory equipment and does not require specialized measurement instruments such as LCR meters. It is particularly useful for educational laboratories, engineering practice, and rapid diagnostics of electronic circuits, offering high accuracy due to precise time measurements of modern oscilloscopes.*

Keywords: *RC circuit; time constant; capacitance measurement; resistance measurement; transient response; digital oscilloscope; cursor method; step response; electrical measurements.*

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I. INTRODUTION

Methods used for measuring resistance include: the bridge method (e.g., Wheatstone bridge), which compares an unknown resistance with known reference values; the direct current method, which calculates resistance using voltage and current measurements according to Ohm's law; digital multimeters, which commonly include resistance measurement functionality; the alternating current method, which relies on the phase relationship between current and voltage; the four-terminal (Kelvin) method, which eliminates the influence of lead resistance; and the voltage divider method, which determines resistance based on voltage distribution [1] - [4].

The selection of a specific method for measuring capacitance or resistance depends on the required accuracy, measurement range, and the availability of instrumentation.

Modern digital oscilloscopes provide extremely high

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accuracy in measuring time-related parameters, reaching up to 0.0001%. This capability can be utilized to develop a more precise approach, namely the cursor-based method for measuring capacitance and resistance.

Any electrical circuit responds to an input signal not instantaneously but with a certain delay. This behavior is described by the step response g(*t*) of the circuit. The primary parameter of the step response is the time constant τ. The time constant is defined as the time interval from the moment a unit step input is applied to the circuit until the output reaches a level of $(1 - 1/e) \cdot 100 = 63{,}2\%$ of its steady-state value.

Unlike traditional transient-based approaches, the proposed method emphasizes direct parameter extraction using oscilloscope cursor positioning without additional computational processing. The method is optimized for practical implementation, including recommendations for pulse duration selection and measurement conditions to improve accuracy and repeatability.

The object of study is the transient charging and discharging process of an RC circuit excited by a rectangular pulse and recorded by a digital oscilloscope.

The subject of study is a cursor-based method for determining the time constant of an RC circuit and indirectly measuring capacitance or resistance from the transient response waveform.

The purpose of the work is to develop and experimentally verify a cursor-based method for measuring capacitance and resistance in an RC circuit by determining the time constant from the transient response displayed on a digital oscilloscope

II. ANALYSIS OF LAST RESEARCHES

The measurement of resistance and capacitance is a fundamental task in electrical engineering, instrumentation, and laboratory diagnostics. Conventional resistance measurement techniques include bridge-based methods, direct current methods based on Ohm’s law, digital multimeters, four-terminal measurement techniques, and voltage-divider-based approaches. These methods are well established and provide reliable results under standard measurement conditions, especially when the un-known resistance is measured directly using dedicated instruments [1], [3], [4].

Similarly, capacitance measurement is commonly performed using LCR meters, RC bridge methods, or indirect transient-based approaches. In practical educational and laboratory environments, however, the availability of specialized instruments may be limited. For this reason, indirect methods based on circuit response analysis remain relevant, particularly when modern digital oscilloscopes with high temporal resolution are available [2], [3].

The theoretical basis for transient-based measurement methods is rooted in the classical analysis of linear time-invariant circuits. The time-domain response of first-order RC circuits to step and pulse excitations has been extensively described in the literature. In particular, the capacitor voltage in a first-order RC circuit under unit-step excitation follows an exponential law characterized by the time constant τ = RC, which determines the speed of charging and discharging processes [3], [4]. This relation-ship makes it possible to estimate either resistance or capacitance when one of the parameters is known and the time constant is measured experimentally.

Mathematical representations of step and pulse signals using the Heaviside unit step function are also widely used in electrical engineering and applied mathematics. Such representations simplify the derivation of analytical expressions for the input and output signals of linear circuits under piecewise-defined excitation [5]–[7]. In particular, the decomposition of a rectangular pulse into two shifted unit-step functions of opposite polarity provides a convenient analytical framework for modeling the transient response of RC circuits, which directly supports the method proposed in this study [5], [6].

Previous research has also demonstrated that transient analysis can be used not only for classical parameter estimation, but also for more advanced circuit diagnostics. For example, probabilistic and analytical approaches to the investigation of RC transient behavior with un-known capacitance have been reported, confirming that the transient waveform contains sufficient information for parameter identification [2]. Other studies have considered the behavior of RC circuits under more complex or disturbed operating conditions, including stability analysis and data-driven evaluation methods, further confirming the diagnostic significance of transient responses [12].

The significance of the RC time constant as a measurable physical quantity has been emphasized in both theoretical and applied studies. Oldham analyzed the physical interpretation and practical implications of the RC time constant in electrochemical systems, showing that the concept of the time constant remains central across different domains of circuit and system analysis [10]. In addition, studies devoted to transient and steady-state analysis of electrical circuits, including first- and second-order systems, support the broader applicability of time-domain parameter extraction techniques in engineering measurements [11].

A key practical consideration in transient-based measurement is the correct selection of the excitation pulse duration relative to the dynamic properties of the circuit. The rise time of the response waveform is directly related to the time constant and can be used as a practical criterion for selecting the duration of the rectangular pulse applied to the circuit. Related measurement studies have shown that the relationship between transient duration and system response is essential for improving accuracy and avoiding waveform distortion during observation and parameter extraction [9], [10].

Despite the availability of substantial theoretical literature on RC transient analysis, most published sources focus either on general circuit theory or on the use of dedicated measurement instruments. Comparatively less attention has been given to simple oscilloscope-based cursor methods that can be directly implemented in laboratory practice without complex postprocessing. Therefore, the present study addresses this gap by proposing a practical method in which the time constant is determined directly from the oscilloscope screen using cursor positioning at characteristic levels of the transient waveform, namely 63.2% during charging and 36.8% during discharging. This approach combines classical circuit theory with the precision timing capabilities of modern digital oscilloscopes and offers a straightforward solution for indirect measurement of capacitance and resistance in RC circuits [2]–[4], [9], [10].

III. FORMULATION OF THE WORK PURPOSE

Measuring the capacitance of a capacitor and the resistance of a resistor is one of the most common operations in applied electronics. A wide range of measuring instruments are used for this purpose. In some cases, highly accurate measurements are required. Specialized measuring instruments have been developed for this purpose. However, both of these instruments are unavailable to the average user. Therefore, the method for measuring capacitance and resistance using a cursor described in this article is of great practical importance. The measurement is based on the formula for the time constant of an RC circuit: $\tau = R_x C$ or $\tau = RC_x$, where R_x and C_x are the measured resistance and capacitance, respectively. These formulas relate three parameters: resistance, capacitance, and time constant. Clearly, given the known values of two parameters, the third parameter can be calculated as: $R_x = \tau / C$ or $C_x = \tau / R$. The accuracy of the measurement is directly determined by the accuracy of the time constant. High accuracy in time constant measurements is more than guaranteed by modern digital oscilloscopes. However, in most cases, even a hobbyist oscilloscope can provide the required accuracy.

IV. EXPOUNDING THE MAIN MATERIAL AND RESULTS ANALYSIS

For the purposes of this study, it is assumed that a rectangular pulse duration τ_i is applied to the input of the electrical circuit. As a result, a pulse of the same duration τ_i is formed at the output. The mathematical representations of the input and output signals, expressed using the Heaviside function $\sigma(t)$ are given as follows [5]-[8]:

$$u_{\text{in}}(t) = \sigma(t) - \sigma(t - \tau_i), \tag{1}$$

$$u_{\text{out}}(t) = g(t) \cdot \sigma(t) - g(t - \tau_i) \cdot \sigma(t - \tau_i). \tag{2}$$

In expressions (1) and (2), the amplitudes of the input and output signals are not considered, as they do not affect the nature of the problem under investigation. The circuit diagram of an RC network, in which the output signal is taken as the voltage across the capacitor is shown in Figure 1.

The step response of the RC circuit is given by [3]:

$$g(t) = [1 - \exp(-t/\tau)] \cdot \sigma(t), \tag{3}$$

where $\tau = RC$ is the time constant of the RC circuit.

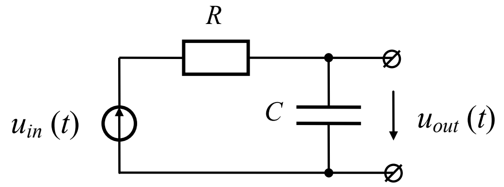

Figure 1. RC Circuit Diagram

Based on the above analysis, it can be inferred that a known step response of the RC circuit and a known resistor value (R) can be used to determine the capacitance (C_x). Conversely, a known step response and a known capacitance (C) can be used to determine the resistor value (R_x).

In accordance with the problem under consideration, it is necessary to establish a direct relationship between the step response, the time constant, and the shape of the output signal of the RC circuit. Using equation (3), the step response of an RC circuit with component values R=1 kΩ and C=1 μF was calculated and plotted (Fig. 2). It should be noted that the actual values of the RC circuit components can be arbitrary.

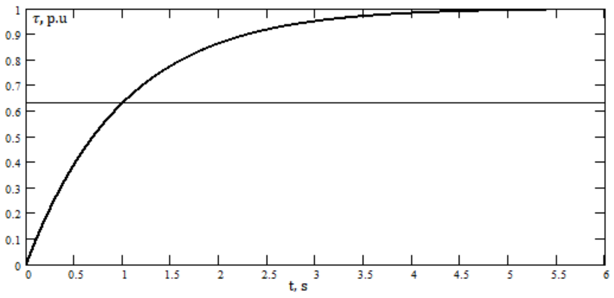

Figure 2. Step Response of the RC Circuit for R=1 kΩ and C=1 μF

From the graph in Figure 2, it can be observed that at the time t =1 ms, the step response reaches 63.2% of its final value, in this case, unity. In other words, the time constant of the considered RC circuit, determined indirectly from the graph, is 1 ms, which coincides with the calculated value RC = 1 ms.

From the standpoint of practical implementation, a unit step voltage is not typically used in measurements; instead, a rectangular pulse of duration τ_i is applied. This pulse is formed by two-unit step signals of opposite polaity, shifted relative to each other by the time interval τ_i.

Using equation (2), the output response of the RC circuit with parameters R=1 кΩ and C=1 μF to an input rectangular pulse of duration τi = 5 ms was calculated and plotted (Figure 3).

Under these conditions, the time constant of the RC circuit can be determined from both the rising and the falling edges of the output response. When determining the time constant from the rising edge, the time at which the output response reaches 63.2% of its steady-state value is measured. When determining the time constant from the falling edge, the time at which the output response decreases to 36.8% of its steady-state value is measured. In the latter case, the measured time is equal to the sum of the pulse duration and the time constant of the RC circuit.

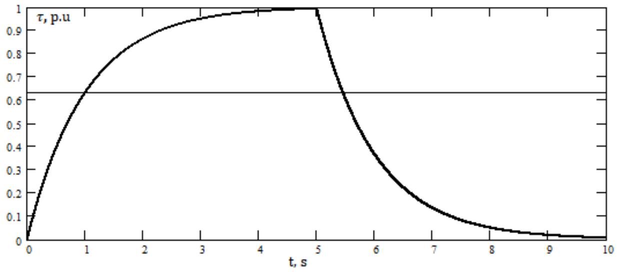

Figure 3. Output Response of the RC Circuit with for R=1 kΩ and C=1 µF to a Rectangular Input Pulse of Duration τi=5ms

During the measurement process, the selection of the input pulse duration τi is of significant importance. In this context, it is necessary to consider the rise time of the step response τ_r. This parameter is related to the time constant τ as follows [9-12]:

$$\tau_r = \ln(9)\cdot\tau. \qquad (4)$$

For improved accuracy, the duration of the input pulse τi should be selected to be 3–5 times greater than the rise time τr of the step response of the RC circuit.

The graphs in Figure 2 and Figure 3, as well as equations (1), (2), (3), and (4), clearly illustrate the relationship be-tween the step response, the time constant, and the shape of the output signal of the RC circuit. All of these provide a solid theoretical foundation for the cursor-based meth-od of measuring resistance and capacitance in an RC circuit.

This section describes the measurement procedure. It should be noted that the procedure is not strictly fixed and may be adapted depending on the specific conditions. The experimental setup is shown in Figure 4. A rectangular pulse with a duration of τ_i=5 ms, generated by the G5-54 pulse generator, is applied to the input of the RC circuit and is also used to trigger a RIGOL MSO 4052 oscilloscope.

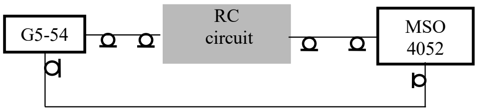

Figure 4. Experimental Setup Diagram

The rectangular pulse of duration τ_i=5 ms from the G5-54 pulse generator and the signal from the output of the RC circuit are applied to the first and second input channels of the MSO 4052 oscilloscope, respectively.

The oscilloscope waveform of the input signal in the form of a rectangular pulse with a duration of τ_i=5 ms and an amplitude of 2 V is shown in Fig. 5(2). The corresponding output response waveform of the RC circuit with parameters R=1 кΩ and C=1 µF is also presented in the same figure Figure 5.

The output response waveform of the RC circuit matches the shape of the calculated graph shown in Figure 3. Therefore, any parameter measured from the output response waveform of the RC circuit can be used to verify the theoretical assumptions for this electrical circuit. In other words, the time constant value obtained from the output waveform can be used to determine the resistance and the capacitance.

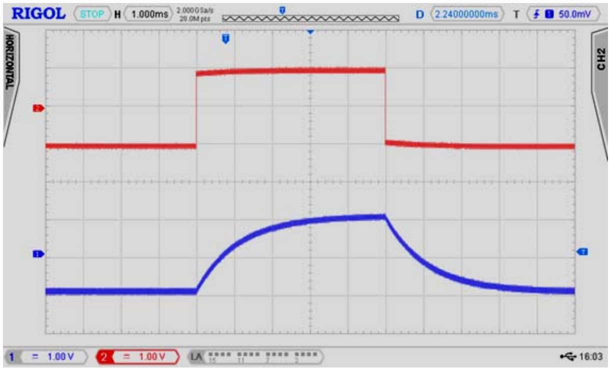

Figure 5. Oscilloscope Waveforms of the RC Circuit Response (1) with R=1 kΩ and C=1 µF to a Rectangular Input Pulse (2) with Duration τ_i=5ms

Measurement. The principle is as follows. One of the components of the RC circuit (Figure 1) is to be measured, while the other component is known. The cursor is positioned at the level corresponding to 63.2% of the steady-state value of the output response. In this case, this level equals 1.264 V. The time constant is then determined; in this example, τ = 1 ms. Subsequently, using the relation τ = RC, the unknown parameter is calculated. In this case, a resistance of 1 kΩ corresponds to a capacitance of 1 µF.

The obtained results confirm that the proposed cursor-based method is theoretically justified and practically feasible for the indirect measurement of capacitance and resistance in first-order RC circuits. The method relies on the well-known exponential nature of the transient response and the physical meaning of the time constant τ = RC. Since the time constant can be identified from characteristic points of the waveform, namely 63.2% of the steady-state value during charging or 36.8% during discharging, the unknown circuit parameter can be calculated directly when the other parameter is known [3, 4, 10].

One of the principal advantages of the proposed method is its simplicity. Unlike bridge-based or dedicated LCR measurement techniques, the method does not require specialized capacitance or resistance meters. Instead, it uses a standard laboratory configuration consisting of a pulse generator, a digital oscilloscope, and a reference component. This makes the method especially useful in educational laboratories, engineering training, and situations where rapid approximate diagnostics are needed using already available instruments [1], [3].

The experimental results presented in this study demonstrate good agreement between theory and practice. For the tested circuit with R = 1 kΩ and C = 1 μF, the experimentally determined time constant was τ = 1 ms, which exactly matches the theoretical value RC = 1 ms. In addition, the observed oscilloscope waveform was consistent with the analytically calculated transient response. This agreement indicates that the proposed approach preserves the essential dynamic behavior predicted by classical circuit theory and that cursor-based extraction of the time constant is sufficiently accurate under controlled laboratory conditions [2], [3], [8].

An important practical issue is the selection of the input pulse duration. If the rectangular pulse is too short, the capacitor may not reach a sufficiently developed transient level before the falling edge begins, which can reduce the accuracy of time-constant estimation. For this reason, the recommendation to choose the pulse duration 3–5 times greater than the rise time of the step response is technically justified. This ensures that the charging transient becomes clearly observable and that the cursor can be placed at the required voltage level with minimal ambiguity [9], [10]. Thus, pulse-duration selection is not merely a procedural detail but a critical factor affecting measurement reliability.

From a metrological point of view, the accuracy of the method depends primarily on the time-measurement precision of the digital oscilloscope and the tolerance of the known reference component. Since modern digital oscilloscopes provide very high temporal resolution, the instrumental contribution of time measurement error can be considered small in comparison with the tolerance of practical resistors and capacitors. Therefore, when precision reference components are used, the method can yield sufficiently accurate results for laboratory and engineering applications [1], [3]. However, in practical implementations, parasitic capacitances, contact resistances, probe loading, and component tolerances may slightly affect the measured waveform and should be considered when very high accuracy is required.

Compared with classical direct measurement techniques, the proposed method has both strengths and limitations. Its main strength lies in the ability to determine the unknown parameter visually and rapidly without additional computational complexity. This makes it highly suitable for demonstration purposes and for intuitive understanding of transient processes in first-order circuits. At the same time, the method is inherently limited to systems whose response can be approximated by a single dominant time constant. In more complex networks, such as higher-order RLC circuits or circuits with significant non-idealities, the transient response may not follow a simple first-order exponential law, and direct cursor-based interpretation becomes less straightforward [4], [11].

Another important aspect is the educational value of the method. Because the measurement process is directly linked to the physical meaning of the RC time constant, the method not only provides a practical measurement tool but also serves as an effective didactic technique. Students can visually observe the charging and discharging process, identify characteristic waveform levels, and immediately connect theoretical formulas with real experimental data. This integration of theory and practice strengthens understanding of linear system response, step functions, and transient analysis [5]–[7].

The proposed method may also be viewed as a foundation for further development. In future studies, the approach can be extended to automated digital processing of oscilloscope data, where software-based cursor placement or waveform fitting could reduce operator dependence and improve repeatability. In addition, similar principles may be adapted for parameter estimation in more complex circuits if appropriate analytical models are used. Therefore, while the present work focuses on a first-order RC circuit, the general concept of extracting circuit parameters from characteristic transient features has broader perspective for instrumentation and diagnostics [2], [8], [12].

Overall, the discussion of the theoretical background, experimental verification, and practical constraints indicates that the cursor-based method is a valid, accessible, and efficient approach for measuring capacitance and resistance in RC circuits. Its combination of analytical transparency, low implementation complexity, and compatibility with common laboratory equipment makes it a useful contribution to both engineering practice and educational methodology [3], [4], [9], [10].

Conflict of interest. The authors declare that they have no conflicts of interest.

V. CONCLUSION

There is a wide variety of rectangular pulse generation circuits. At the same time, the requirements for the pulse parameters are not strict. It is sufficient that the duration of the rectangular pulse be 3–5 times greater than the rise time of the RC circuit step response. Thus, the cursor-based method for measuring capacitance and resistance provides higher measurement accuracy compared to conventional methods when a modern digital oscilloscope and reference resistors and capacitors are available.

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МЕТОД ВИМІРЮВАННЯ ЄМНОСТІ ТА ОПОРУ НА ОСНОВІ КУРСОРА

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Мета роботи. *Метою цієї роботи є розробка та експериментальна перевірка курсорного методу вимірювання ємності та опору в RC-колі за допомогою цифрового осцилографа. Дослідження зосереджено на визначенні параметрів кола за допомогою постійної часу, отриманої з форм сигналів перехідної характеристики.*

Методи дослідження. *Дослідження базується на аналітичному моделюванні RC-схеми з використанням теорії ступінчастої характеристики та одиничних ступінчастих функцій Хевісайда. Математично описано перехідну характеристику на прямокутний вхідний імпульс, а постійну часу (τ = RC) визначено з характерних рівнів форми сигналу (63,2% під час заряджання та 36,8% під час розряджання). Експериментальна валідація проведена за допомогою генератора імпульсів, цифрового осцилографа та тестової RC-схеми. Метод курсорного вимірювання застосовується безпосередньо до форм сигналів осцилографа для вилучення параметрів часової області без додаткової обчислювальної обробки.*

Отримані результати. *Дослідження демонструє, що запропонований метод дозволяє точно визначати параметри кола. Для тестового кола з R = 1 кОм та C = 1 мкФ виміряна стала часу τ = 1 мс збігається з теоретичним значенням. Метод забезпечує надійні результати, коли тривалість вхідного імпульсу вибрана належним чином (у 3–5 разів більше часу наростання). Експериментальні форми сигналів демонструють сильну відповідність з теоретичними прогнозами, що підтверджує правильність та стабільність підходу.*

Наукова новизна. *Оригінальність роботи полягає в розробці простого та практичного методу на основі курсорів для вилучення параметрів безпосередньо з дисплеїв осцилографа без складної обробки даних. На відміну від традиційних методів вимірювання, запропонований підхід робить акцент на візуальному визначенні еле-*

ктричних параметрів у реальному часі за допомогою характеристик перехідного процесу.

Практична цінність. *Метод легко реалізувати за допомогою стандартного лабораторного обладнання та не вимагає спеціалізованих вимірювальних приладів, таких як LCR-метри. Він особливо корисний для навчальних лабораторій, інженерної практики та швидкої діагностики електронних схем, пропонуючи високу точність завдяки точним вимірюванням часу сучасними осцилографами.*

Ключові слова: *RC-коло, стала часу, вимірювання ємності, вимірювання опору, перехідна характеристика, цифровий осцилограф, курсорний метод, ступінчаста характеристика, електричні вимірювання.*