CIRCUIT THEORY

ΠΑΝΕΠΙΣΤΗΜΙΟ ΔΥΤΙΚΗΣ ΑΤΤΙΚΗΣ

UNIVERSITY OF WEST ATTICA

DEPARTMENT OF INFORMATION AND COMPUTER ENGINEERING

PROJECT 2
RLC COMPONENTS, TRANSIENT RESPONSE

CIRCUIT THEORY

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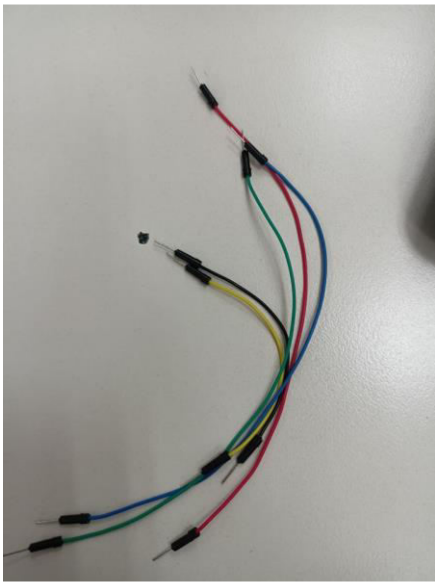
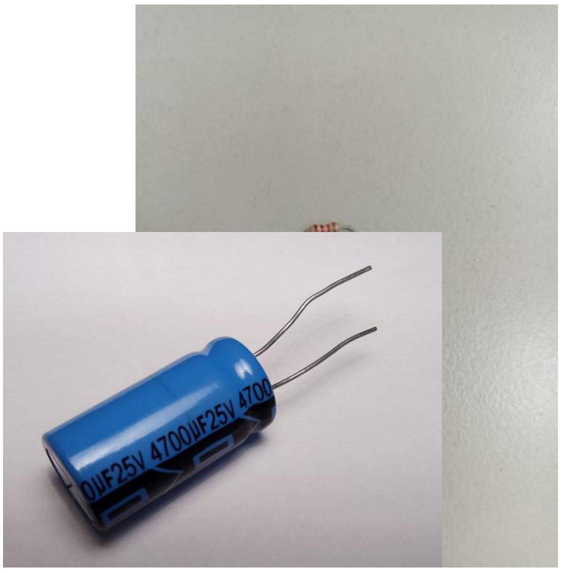
CIRCUIT THEORY

PHOTOGRAPHS OF EQUIPMENT USED IN THE LABORATORY



Breadboard

Cables



Digital Multimeter
Capacitor

Resistor

CIRCUIT THEORY

CONTENTS

1.2.1 : RC component

General

In the chapters "Simulated Solution" and "Experimental Solution" the components used and the observations made during the experiment are presented in detail with snapshots from the " Multisim " software and photos of the experiment from the laboratory environment respectively, while in the chapter " Theoretical Solution" the behavior of the circuit is analyzed in general.

Theoretical Solving

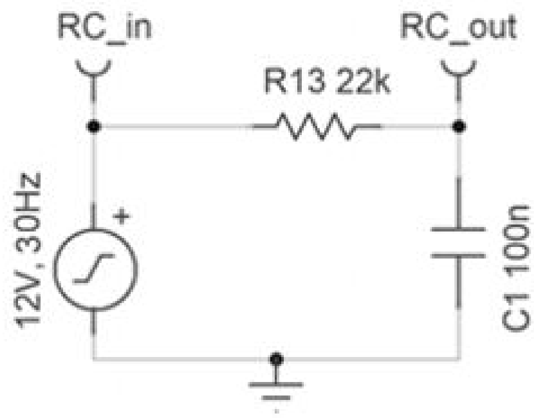


Figure 1

The circuit in Figure 1 achieves the transient response of an RC circuit. Initially, in order to charge capacitor C1 to its maximum capacitance, the 12 V square pulse voltage source supplies it with voltage (forced response). Once fully charged, the capacitor has stored energy that makes it independent of the open-circuit behavior, ie no current flows through it. This is demonstrated by the combination of Kirchhoff 's voltage law (1) and the voltage drop at the ends of the resistor R_{13} (2) and the capacitor C_1 (3).

(1) $V_S - V_{R13} - V_{C1} = 0$
(2) $V_{R13} = R_{13} * I(t)$
(3) $V_{C1}(t) = (1/C) * \int I(t)\,dt$

(1), (2), (3) => $V_S = R * I(t) + (1/C) * \int I(t)\,dt$ (4)
Differentiating both legs in terms of time we get : (4) => $(dI(t)/dt) + (1/R*C) * I(t) = 0$ (5)
Solving the differential equation assuming the capacitor charges through the source (5) => $I(t) = (V_S - V_C / R) * e^{-(1/R*C)*t}$ (6)

From Figure 2, it can be observed that the capacitor will be fully charged, but will never reach the source voltage until infinite time, as the voltage at its ends increases exponentially. Therefore, from relation (6) since $V_C \sim= V_S$ it follows that $I(t) \sim= 0$, which justifies that the capacitor when fully charged behaves as an open circuit.
Similarly, if the circuit is short-circuited, ie, the source is removed, the capacitor will discharge, but will never reach its original value (Figure 3). The capacitor's voltage decreases exponentially with time and therefore, it consumes power since it is connected to ground. This phenomenon is called the transient response of the RC circuit.

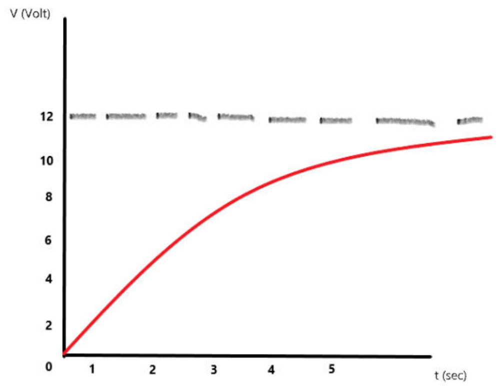
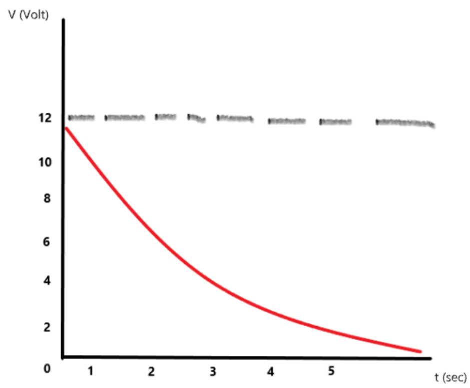


Figure 2



Picture 3

Simulative Resolution

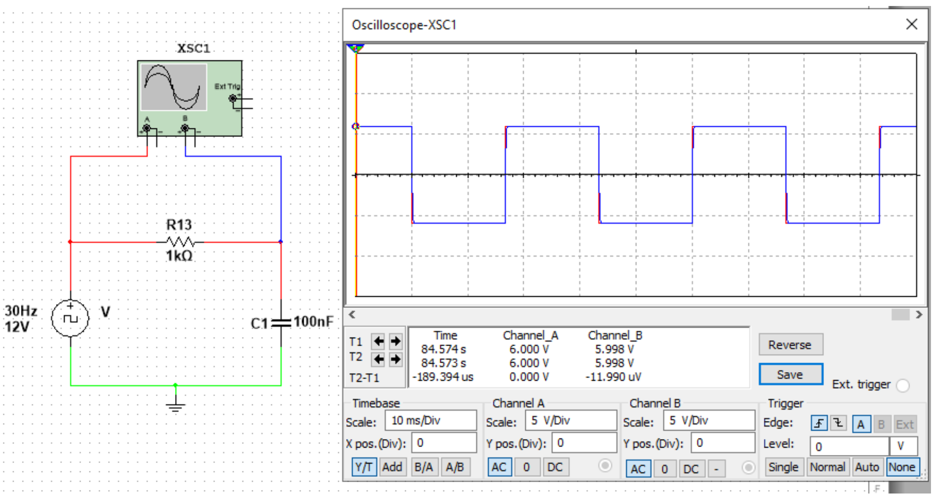


Figure 4

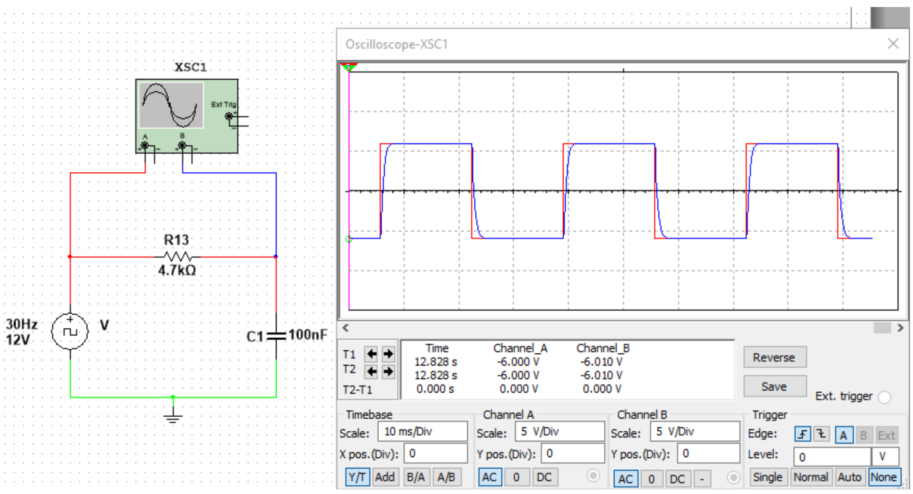


Figure 5

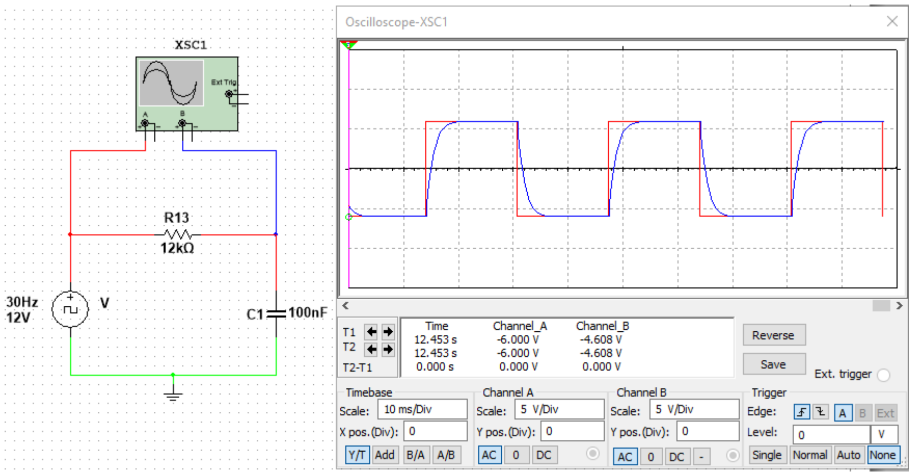


Figure 6

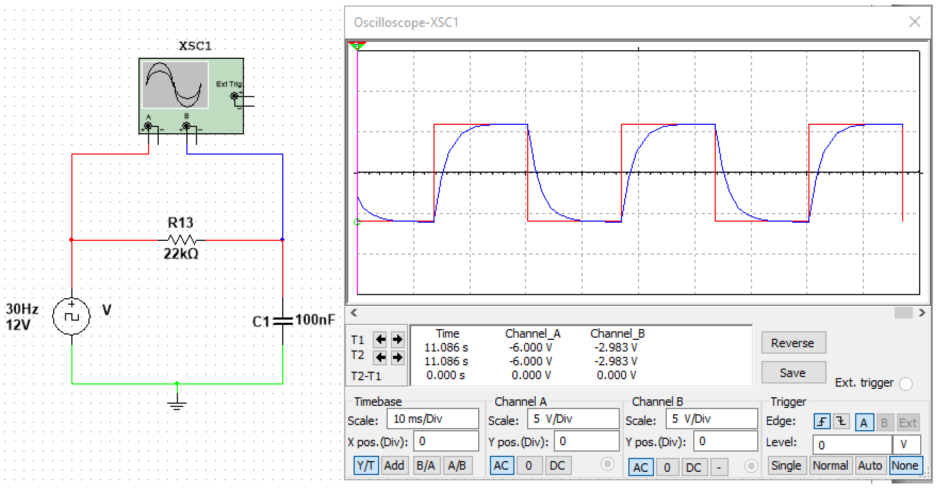
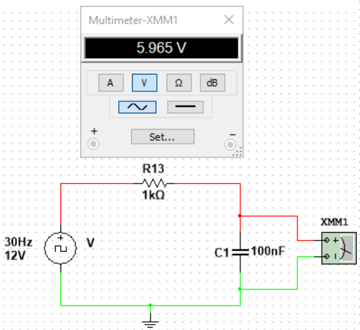
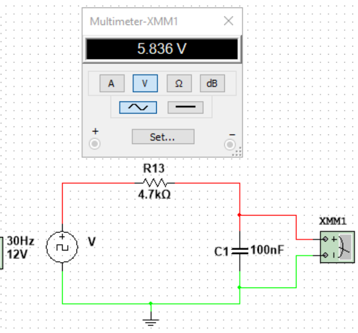
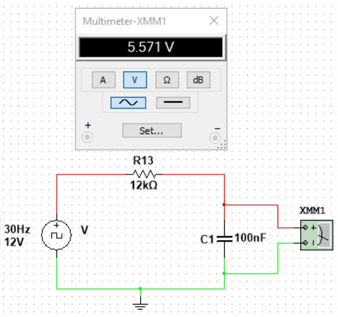


Figure 7







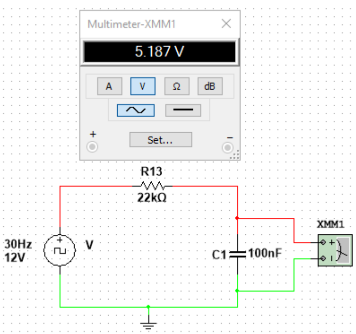


Figure 8 *Figure 9* *Figure 10* *Figure 11*

From the simulated solution of the circuit in the " Multisim " software (Figures 4, 5, 6, 7), the voltage drop at the ends of the capacitor for various values of resistances (1 kΩ , 4.7 kΩ , 12 kΩ , 22 kΩ) is clearly illustrated. The charging time of the capacitor for various time constants "τ = kRC ", where k belongs to the positive integers, is summarized in "Table 1" in the chapter "Experimental Solution", where the experiment was carried out in the laboratory environment and the corresponding times were noted.
With the help of the oscilloscope, the observation is recorded that the voltage drop at the ends of the capacitor (blue trace) does not coincide with the voltage at the ends of the square pulse source, which

verifies the diagrams and the behavior of the circuit analyzed in the chapter "Theoretical Solution" (Figures 2, 3). In other words, a phase difference between the source and capacitor signal is observed. It is worth noting that the larger the value of the resistor resistance R_{13}, the greater the deviation of the voltage drop at the ends of the capacitor with the voltage at the ends of the source. This fact is justified by Ohm's law, namely, that the current intensity is proportional to the potential difference ($I = V / R$), therefore, the greater the resistance, the greater the potential difference will be.

Experimental Solution

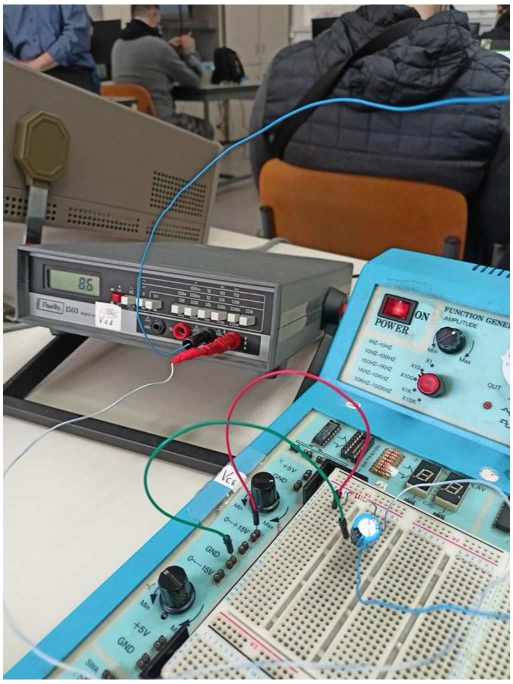


Figure 12

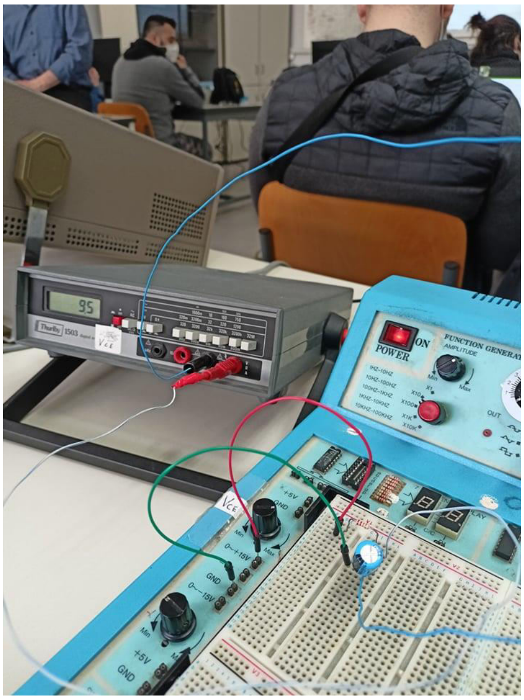


Figure 13

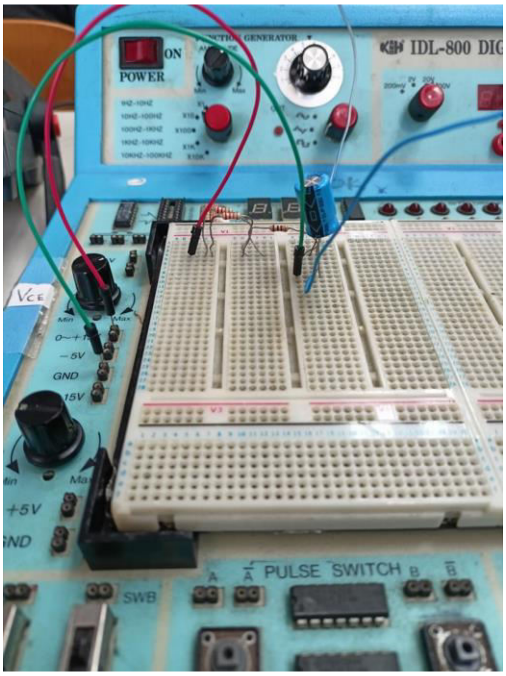


Figure 14

Spring = 12V			Source frequency 30Hz			
RC			time constant = ?			
R (Ω)	τ=RC Sec	V_C (1t) Volts	V_C (2t) Volts	V_C (3t) Volts	V_C (4t) Volts	V_C (5t) Volts
1k	7.10	3.75	5.18	5.66	5.84	5.92
4k7	30.00	3.68	5.08	5.55	5.72	5.80
12k	60.00	3.51	4.85	5.29	5.46	5.53
22k	120.0	3.27	4.51	4.93	5.09	5.15

Table 1

For the experimental solution carried out in the laboratory environment, the " breadboard " interface board , a DC voltage source set at 12 V , a grounding, three 22 kΩ resistors, two 1 kΩ resistors , one 4 kΩ resistor, were used. 7 kΩ, a 100 nF capacitor, a digital bench top multimeter set to calculate DC voltage (voltmeter) and a timer (see photos of equipment used in the lab, page 3).
Initially, the digital bench multimeter (voltmeter) was used with the positive end connected to the DC voltage source and the negative end
connected to ground in order to set the source to 12 volts . The multimeter is then disconnected and the circuit assembly is started.
First of all, a 1 kΩ
resistor is connected in series with the capacitor and with two wires one to the left of the resistor is connected to the source and the other to the left of the capacitor is connected to ground (Figures 12, 13) . Then, with a timer, the charging time of the capacitor with a resistor of resistance 1 kΩ starts to be recorded. The same procedure is repeated for the 4.7 kΩ and 22 kΩ resistors. Due to the absence of a 12 kΩ resistor, two 22 kΩ resistors connected in parallel and a 1 kΩ resistor connected in series with the two parallel resistors were used (Figure 14).
The results are recorded in "Table 1" from the timings noted during the execution of the experiment in the laboratory environment and from the snapshots in the "Simulation Solution" section (Figures 8, 9, 10, 11). The calculations of the capacitor potential differences for each time constant were calculated from the formula $V_C = V * (1 - e^{-t * RC}$
). It is worth noting that the larger the resistance, the longer the time interval needed to charge the capacitor, and this is verified by the formulas discussed in the "Theoretical Solution" chapter for the RC circuit constant (τ = RC). The potential difference at the ends of the capacitor reaches the value of the source voltage in time more than "5t" for higher resistances, where "τ = RC " is the time constant of the circuit.

1.2.2 : Component RL

General

In the chapters "Simulation Solution" and "Experimental Solution" the observations made during the experiment are presented in detail with snapshots from the " Multisim " software, while in the chapter "Theoretical Solution" the behavior of the circuit is analyzed in general.

Theoretical Solving

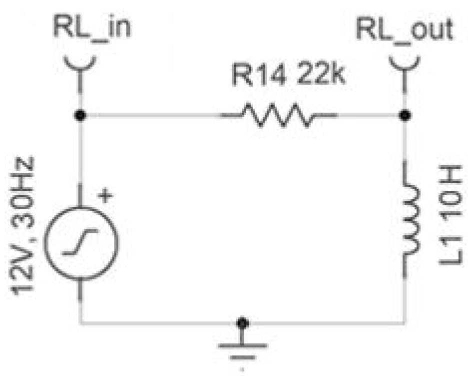


Figure 15

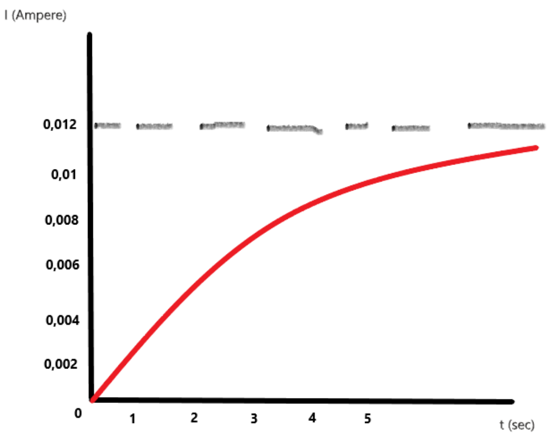
The circuit of Figure 15 achieves the transient response of circuit RL . Initially, in order to supply current to coil L_1 , the 12 V square pulse voltage source supplies it with

DC voltage (forced response). After the current is passed, the coil has stored energy that makes it independent of the need to behave like a short circuit, ie, to pass a high current. This is demonstrated by the combination of Kirchhoff 's voltage law (1) and the voltage drop at the ends of the resistor R_{14} (2) and the coil L_1 (3).

(1) $V_S - V_{R14} - V_{L1} = 0$
(2) $V_{R14} = R_{14} * I(t)$
(3) $V_{L1}(t) = L * (I(t) / dt)$

(1), (2), (3) => $V_S = R * I(t) + L * (I(t) / dt)$ (4)
Differentiating both legs in terms of time we get : (4) => $(dI(t) / dt) + (R / L) * I(t) = V / L$ (5)
Solving the differential equation assuming the capacitor charges through the source (5) => $I(t) = (V / R) * (1 - e)^{-(R/L)*t}$ (6)

From Figure 16, it can be observed that the current in the coil increases exponentially and will reach its maximum value. Therefore, from relation (6) since the switch is switched to the source it follows that I (t) >> 0, which justifies that the coil behaves like a short circuit.
Similarly, when the switch is switched to the source, the current flowing through it decreases exponentially without reaching its initial value (Figure 17). This phenomenon is called the transient response of the RL circuit.



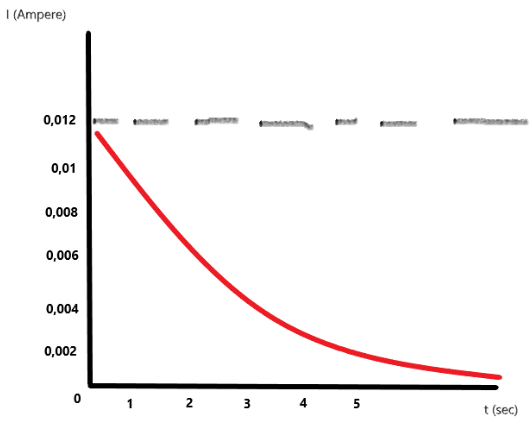


Figure 16 Figure 17

Simulative Resolution

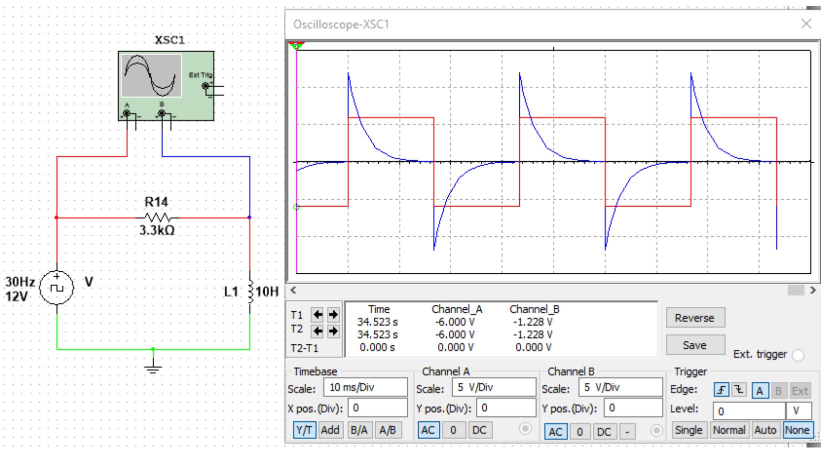


Figure 18

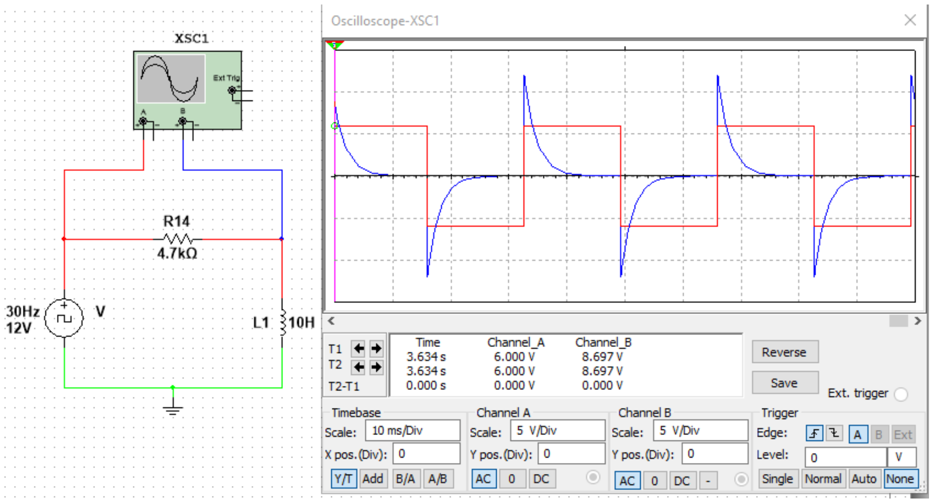


Figure 19

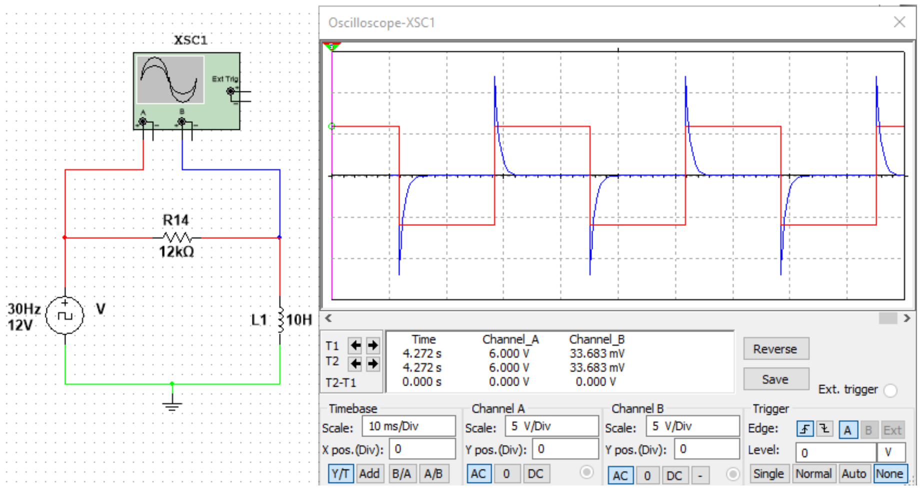


Figure 20

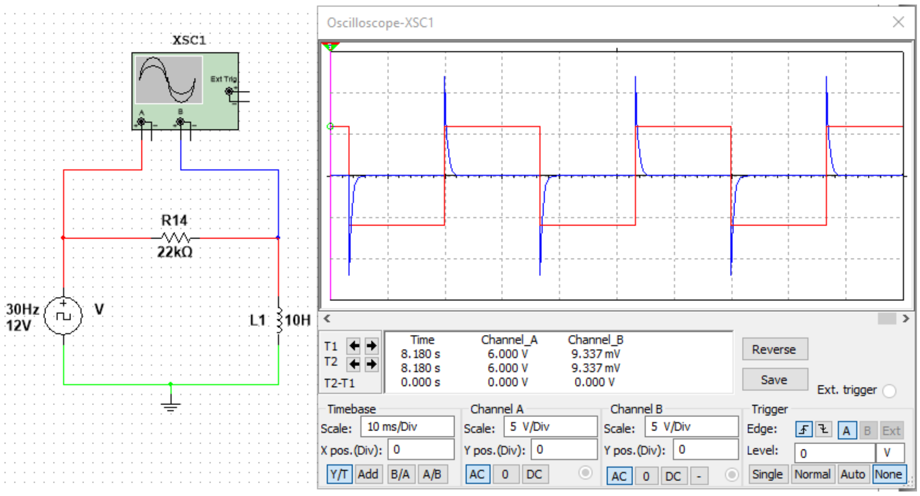


Figure 21

From the simulated solution of the circuit in the " Multisim " software (Figures 18, 19, 20, 21), the variation of the current in the coil for various values of resistance (3.3 kΩ , 4.7 kΩ , 12 kΩ , 22 kΩ) is clearly illustrated.
With the help of the oscilloscope, the observation is recorded that the variation of the current in the coil (blue trace) shows a phase difference with the current flowing in the source, which verifies the diagrams and the behavior of the circuit analyzed in the chapter "Theoretical Solution" (Figures 16, 17). It is worth noting that the larger the value of the resistor resistance R_{14} , the smaller the change in current in the coil. This fact is justified by Ohm's law, ie, that the intensity of the current is inversely proportional to the resistance (I = V / R).

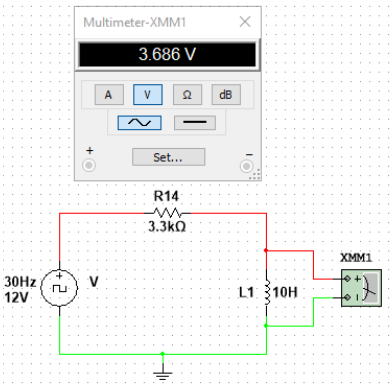


Figure 22

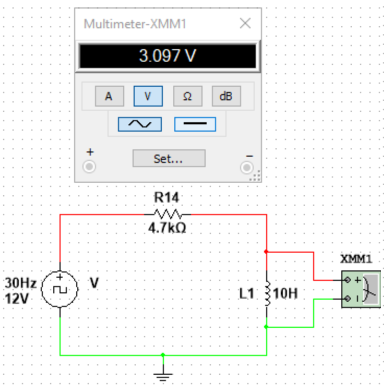


Figure 23

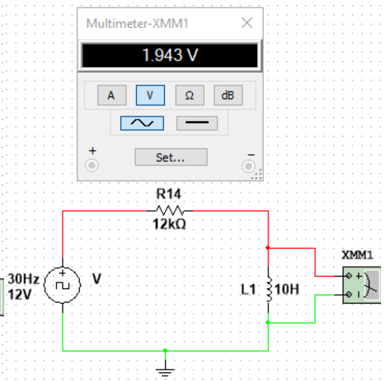


Figure 24

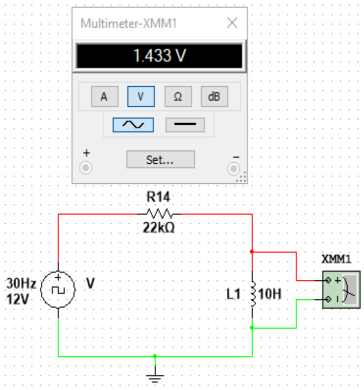


Figure 25

Table 2

Spring = 12V			**Source frequency 30Hz**			
RL			**time constant = ?**			
R (Ω)	**τ=L/R**	**V_L(1t)**	**V_L(2t)**	**V_L(3t)**	**V_L(4t)**	**V_L(5t)**
3k3	-	1.36	0.48	0.18	0.07	0.03
4k7	-	1.11	0.39	0.15	0.06	0.02
12k	-	0.72	0.25	0.10	0.04	0.01
22k	-	0.53	0.19	0.07	0.03	0.01

The time it takes the coil to reach the maximum current for various time constants "t = kRL ", where k belongs to the positive integers, is not summarized in "Table 2", ie, the experiment was not performed in the laboratory environment. The RL circuit behaves as a short circuit which this signals high current intensities and therefore, an increased risk of an electric shock accident.
For the simulation in " Multisim "
software , therefore, four resistors with resistance 3.3 kΩ , 4.7 kΩ , 12 kΩ and 22 kΩ, a 12 V square pulse source, grounding, oscilloscope and a coil with inductance 10 H. The results are recorded in "Table 2" from the snapshots (Figures 22, 23, 24, 25). The calculations of the coil potential differences for each time constant were calculated from the formula $V_L = V * (e)^{-t*(R/L)}$.

1. 3 : Questions

Question 1

When an engineer needs a circuit to provide time delays, he almost always chooses an RC circuit instead of an RL circuit. Explain why.

For the needs of the engineer to provide time delays, an RC circuit is almost always preferred over an RL circuit for the following reasons. First, the RC circuit provides high resistance when the capacitor is fully charged, causing it to behave like an open circuit, ie, as if no current is flowing through it. In contrast, in the RL circuit, the resistance decreases as energy is stored in the inductor, so that it behaves like a short circuit, ie, as if a high current is flowing. This reason makes RC a safer circuit than RL . Secondly, capacitors are lightweight and cheap components unlike inductors which are heavy and expensive. Third, in RC circuit, the resistance is 0 when the capacitor is not charged, whereas when it is charged and energy is stored in the form of electric field, the resistance reaches infinity. In contrast, in the RL circuit, the resistance is large and decreases as energy is stored in the coil in the form of a magnetic field. Therefore, in the RC circuit the voltage at the ends of the capacitor, due to zero resistance at the beginning, will increase smoothly unlike the RL circuit where the current will increase instantaneously due to the decrease in resistance.

Question 2

Describe the maximum value of the current, as well as what will be observed in the current upon closing the switch in the following circuit:

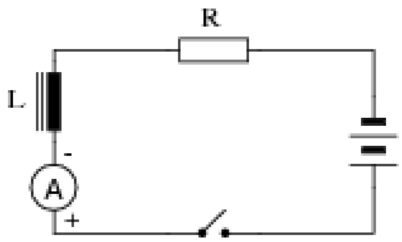


Figure 26

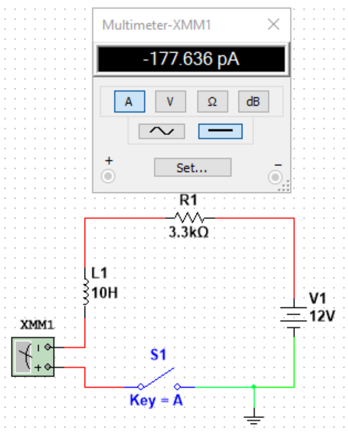


Figure 27

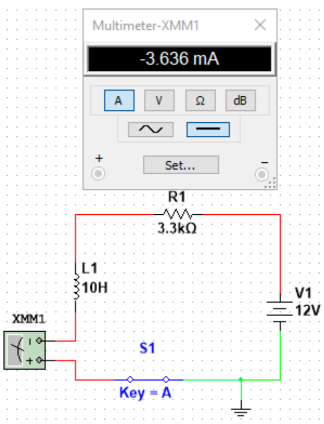


Figure 28

Figures 27 and 28 show the simulated solutions to meet the requirement of question 2. The first illustrates the circuit of Figure 26 with an open switch, while, the second illustrates the circuit of Figure 26 with a closed switch.

First, it is a circuit RL powered by a DC voltage source V_1 12 V , containing a resistor R_1 with a resistance of 3.3 kΩ and a coil L_1 with an inductance of 10 H . Between the coil and ground is a switch S_1 and an ammeter HMM $_1$ connected in series after the coil and before the switch. The switch for a start is open (Figure 27) and the ammeter reading for current intensity is -177.636 pA. When the switch is closed (Figure 28), the ammeter reading for current intensity is -3.636 mA . The negative values of the readings are justified by the fact that the positive end of the ammeter is connected to the side where the current enters the negative end of the

Source V_1 . The circuit RL operates as a short circuit at DC voltage, due to the decrease in resistance over time ($\tau = R/L$), so the maximum current value will be according to Ohm's law, $I = V/R$.

Question 3

What value of resistance is required in an RC circuit with a capacitor value of 50μF in order to have a time delay of one second?

The time constant of an RC circuit is $\tau = RC$. Therefore, the resistance value required with a capacitor value of 50 μF in order to have a time delay of one second is :

$\tau = RC \Rightarrow R = \tau / C \Rightarrow R = 1 \text{ sec} / 5 * 10^{-5} \text{ F} \Rightarrow R = 20 \text{ k}\Omega$