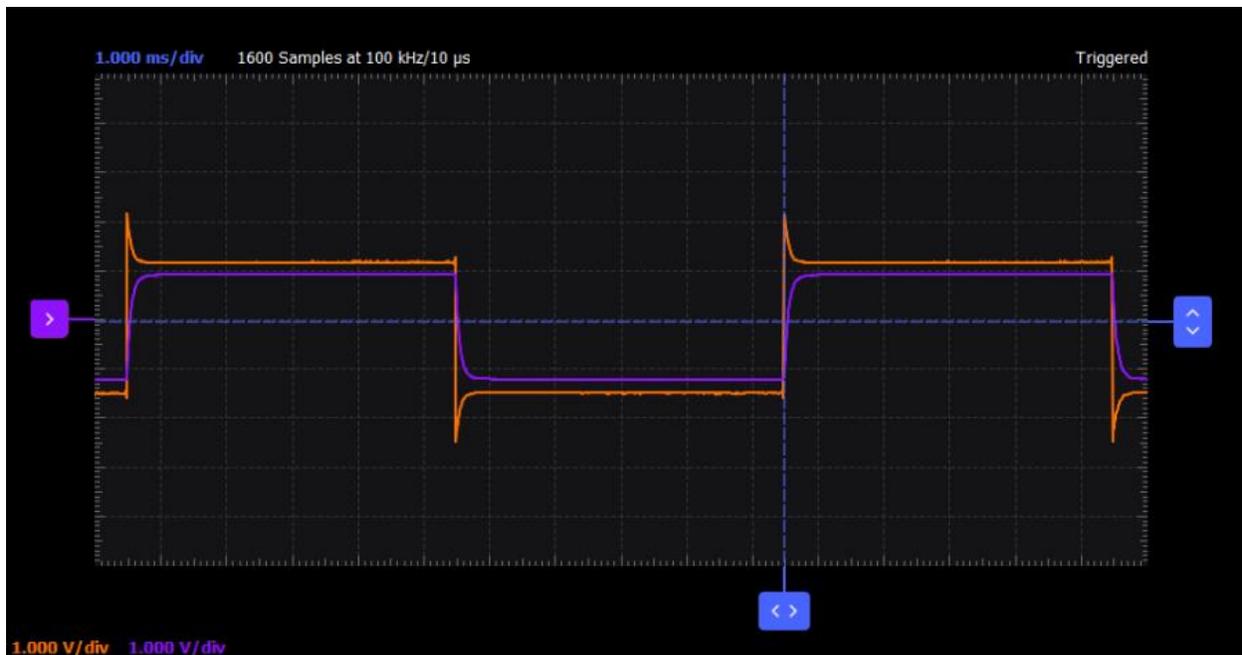
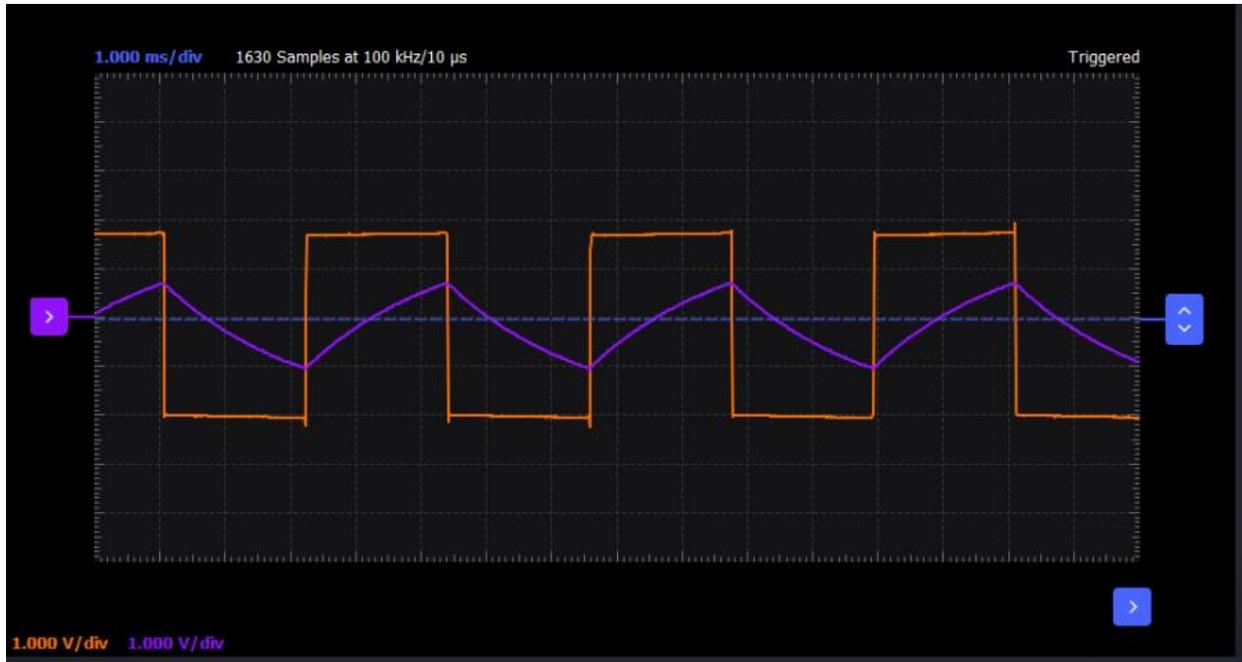


Experiment 2: Transient Response of RC and RL Circuits

This experiment is adapted from material provided on the Analog Devices Wiki at <https://wiki.analog.com/university/courses/electronics/labs>.



I. Transient Response of an RC Circuit

Objective:

The objective of this exercise is to study the transient response of a series RC circuit and understand the time constant concept using pulse waveforms.

Background:

In this exercise you will apply a pulse waveform to the RC circuit to analyze the transient response of the circuit. The pulse-width relative to a circuit's time constant determines how it is affected by an RC circuit.

Time Constant (τ): Denoted by the Greek letter tau, τ , it represents a measure of time required for certain changes in voltages and currents in RC and RL circuits. Generally, when the elapsed time exceeds five time constants (5τ) after switching has occurred, the currents and voltages have reached their final value, which is also called steady-state response.

The time constant of an RC circuit is the product of equivalent capacitance and the Thévenin resistance as viewed from the terminals of the equivalent capacitor.

$$\tau = RC \quad (1)$$

A Pulse is a voltage or current that changes from one level to another and back again. If a waveform's high time equals its low time it is called a square wave. The length of each cycle of a pulse is its period (T).

The pulse width (t_p) of an ideal square wave is equal to half the time period.

The relation between pulse width and frequency is then given by

$$f = \frac{1}{2t_p} \quad (2)$$

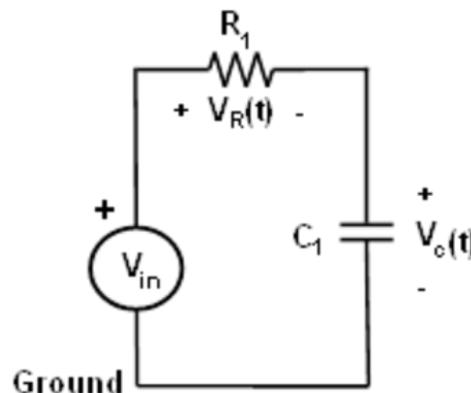


Figure 1: Series RC Circuit.

From Kirchhoff's laws, it can be shown that the charging voltage $v_C(t)$ across the capacitor is given by:

$$v_C(t) = V \left(1 - e^{-\frac{t}{RC}} \right) \quad \text{for } t \geq 0 \quad (3)$$

where V is the applied source voltage to the circuit at time $t = 0$. The product RC is the time constant. The response curve is increasing and is shown in Figure 2.

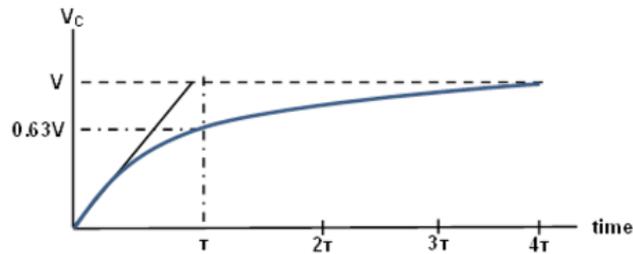


Figure 2: Capacitor Charging for Series RC Circuit with a Step Input.
(Time Axis Normalized by τ .)

The discharge voltage for the capacitor is given by:

$$v_C(t) = V_0 e^{-\frac{t}{RC}} \quad \text{for } t \geq 0 \quad (4)$$

where V_0 is the initial voltage stored in the capacitor at $t = 0$. The product RC is often referred to as the so-called time constant, τ . The response curve is a decaying exponential as shown in Figure 3.

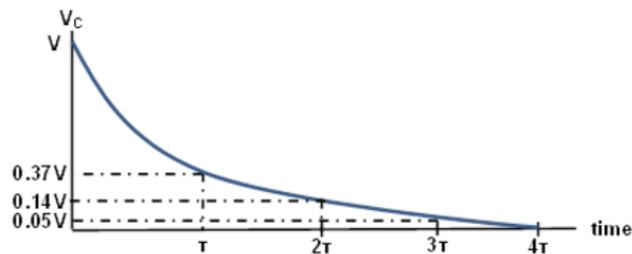


Figure 3: Capacitor Discharging for Series RC Circuit.

Equipment Needed:

- ADALM2000 Active Learning Module with Scopy Software
- Breadboard and Jumper Wire Kit
- 1 2.2k Ω Resistor

- 1 $1\ \mu\text{F}$ Capacitor
- 1 $10\ \text{k}\Omega$ Resistor
- 1 $0.01\ \mu\text{F}$ Capacitor

Hardware Setup:

Set up the circuit shown in Figure 4 on your breadboard with the component values $R_1 = 2.2\ \text{k}\Omega$ and $C_1 = 1\ \mu\text{F}$.

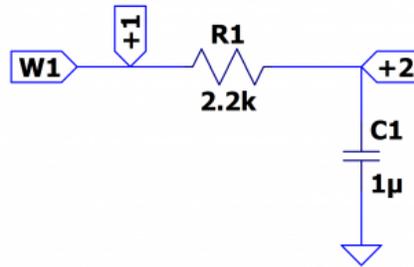


Figure 4. Series RC Circuit with $R_1 = 2.2\ \text{k}\Omega$ and $C_1 = 1\ \mu\text{F}$.

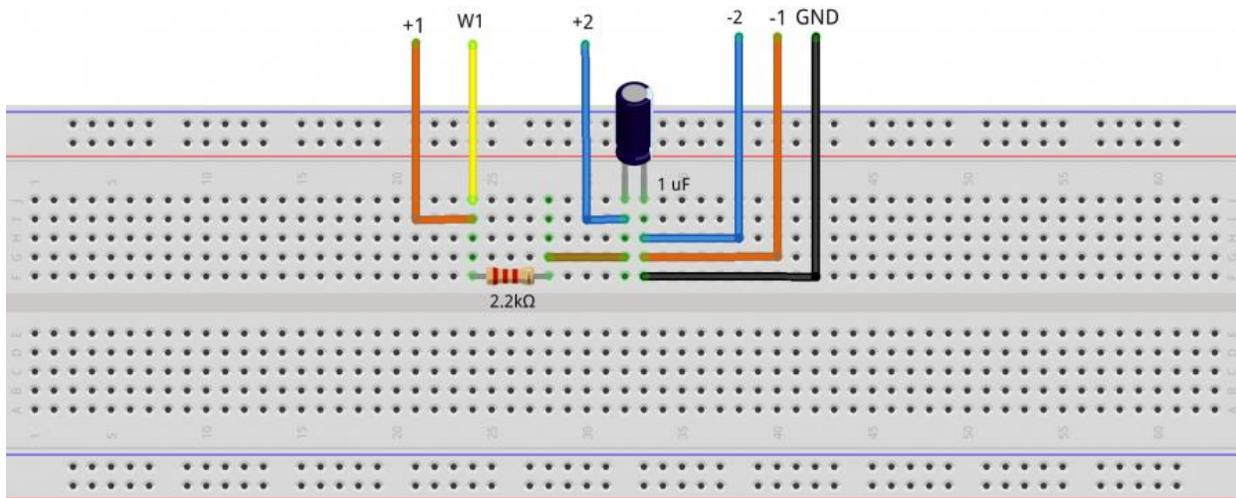


Figure 5. Breadboard Connections of Series RC Circuit.

Procedure:

On Channel 1 of the oscilloscope you will visualize the input voltage, and on channel 2 the voltage on the capacitor. Generate a square wave on channel 1 of the signal generator with 4 V amplitude peak-to-peak. The frequency will be set according to τ for the following three cases:

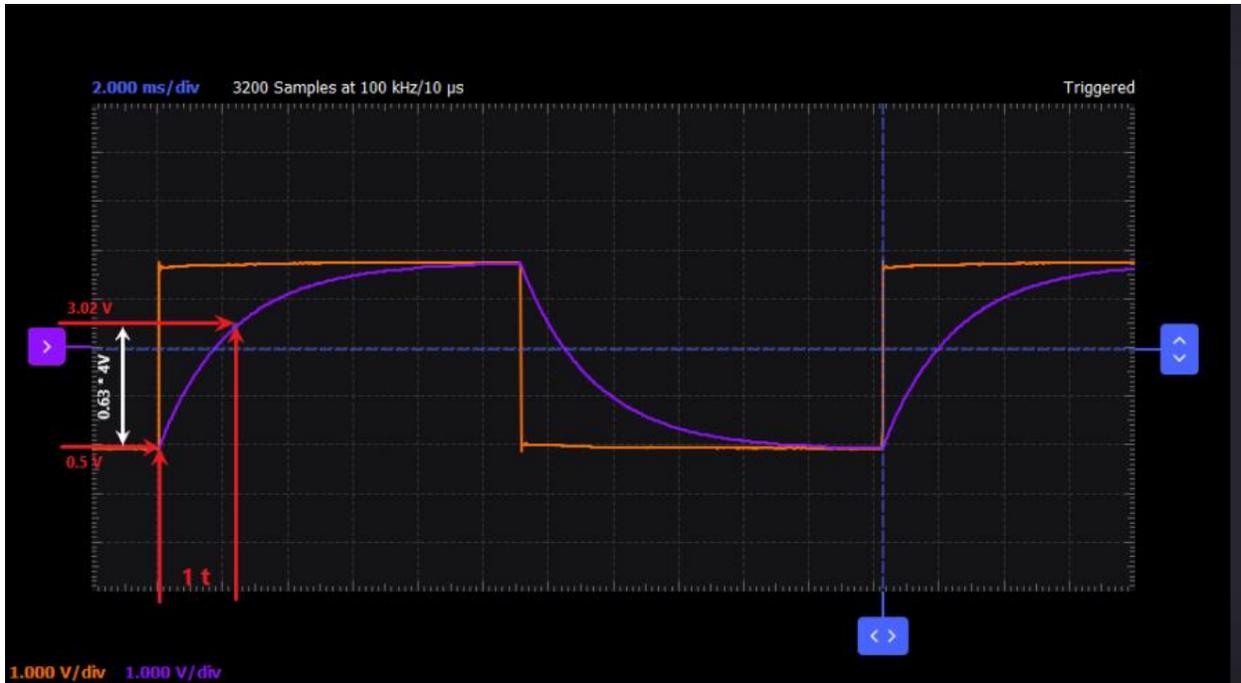
- Pulse width $\gg 5\tau$: Set the frequency of the W1 output such that the capacitor has enough time to fully charge and discharge during each cycle of the square wave. So, let the pulse width be 15τ and set the frequency according to equation (2). The value you have found

should be approximately 15 Hz. Determine the time constant from the waveforms obtained on the screen if you can. If you cannot obtain the time constant easily, explain possible reasons.

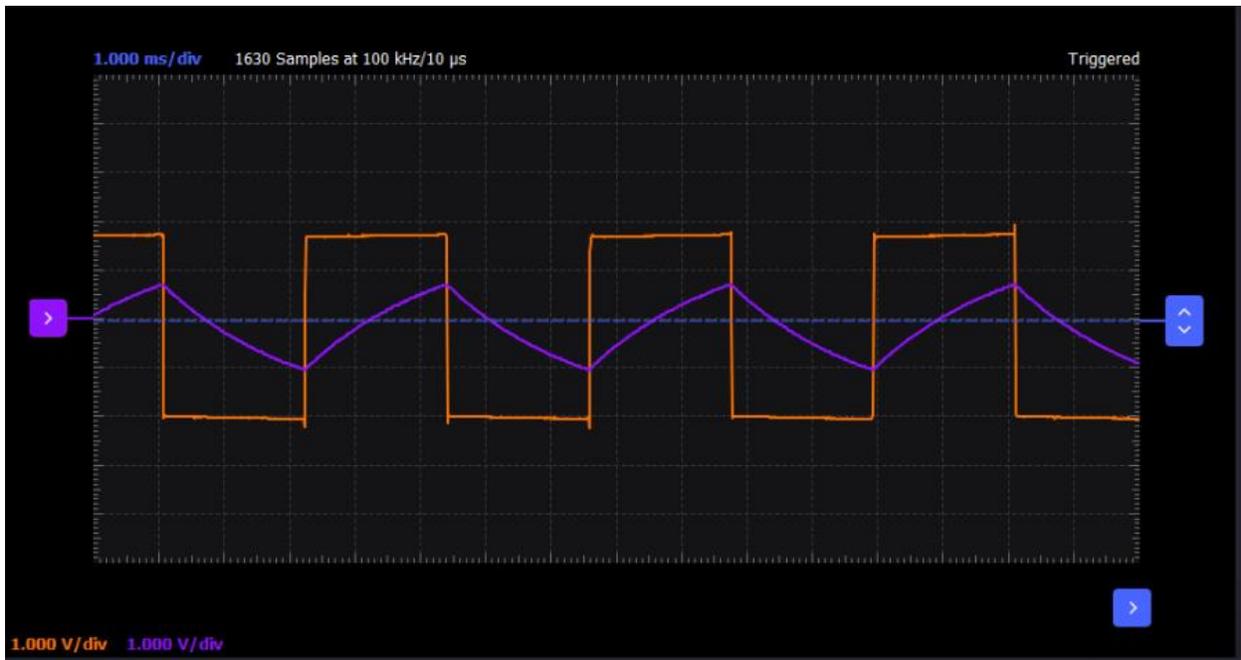


Figure 6. Waveforms for Pulse Width Equal to 15τ .

- b. Pulse width = 5τ : Set the frequency such that the pulse width = 5τ (this should be approximately 45 Hz). Since the pulse width is 5τ , the capacitor should just be able to fully charge and discharge during each pulse cycle. From the figure determine τ (see Figure 2 and Figure 7 below.)

Figure 7. Waveforms for Pulse Width Equal to 5τ .

- c. Pulse width $\ll 5\tau$: In this case the capacitor does not have time to charge significantly before it is switched to discharge, and vice versa. Let the pulse width be only τ in this case and set the frequency accordingly.

Figure 8. Waveforms for Pulse Width Equal to τ .

Repeat the procedure using $R_1 = 10\text{k}\Omega$ and $C_1 = 0.01\ \mu\text{F}$, and record the measurements.

Questions:

- Calculate the time constant using equation (1) and compare it to the measured value for each set of R and C values.
- Discuss the effects of changing component values.

Lab Resources:

- Fritzing files: [transient_response_RC_bb](#)
- LTspice files: [transient_response_RC_ltspice](#)

II. Transient Response of an RL Circuit

Objective:

The objective of this experiment is to study the transient response of inductor circuits using a series RL configuration and understand the time constant concept.

Background:

This exercise is similar to the “Transient Response of an RC Circuit” exercise, except that the capacitor is replaced by an inductor. In this experiment, you will apply a square waveform to the RL circuit to analyze the transient response of the circuit. The pulse width relative to the circuit's time constant determines how it is affected by the RL circuit.

Time Constant (τ): It is a measure of time required for certain changes in voltages and currents in RC and RL circuits. Generally, when the elapsed time exceeds five time constants (5τ) after switching has occurred, the currents and voltages have reached their final value, which is also called steady-state response.

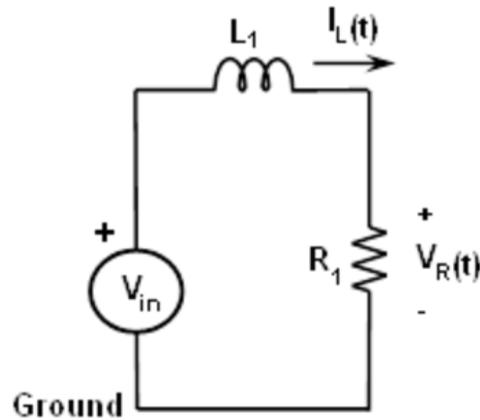
The time constant of an RL circuit is the equivalent inductance divided by the Thévenin resistance as viewed from the terminals of the equivalent inductor.

$$\tau = \frac{L}{R} \quad (1)$$

A pulse is a voltage or current that changes from one level to another and back again. If a waveform's high time equals its low time, it is called a square wave. The length of each cycle of a pulse train is its period (T). The pulse width (t_p) of an ideal square wave is equal to half the time period.

The relation between pulse width and frequency for the square wave is given by:

$$f = \frac{1}{2t_p} \quad (2)$$

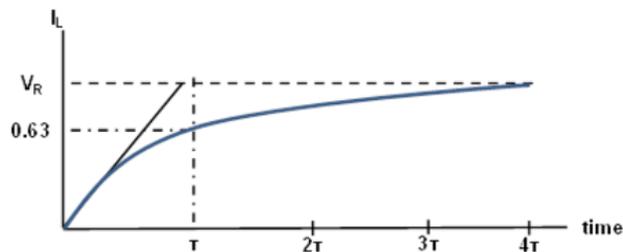
Figure 1: Series RL Circuit.

In an RL circuit, voltage across the inductor decreases with time while in the RC circuit the voltage across the capacitor increased with time. Thus, current in an RL circuit has the same form as voltage in an RC circuit: they both rise to their final value exponentially.

The expression for the current in the inductor is given by:

$$i_L(t) = \frac{V}{R} \left(1 - e^{-\frac{t}{\tau}} \right) \quad \text{for } t \geq 0 \quad (3)$$

where V is the applied source voltage to the circuit for $t = 0$. The response curve is increasing and is shown in Figure 2.

Figure 2: Current Increasing in an Inductor in a Series RL Circuit.
(Time Axis Normalized by τ)

The expression for the current decay in the inductor is given by:

$$i_L(t) = I_0 e^{-\frac{t}{\tau}} \quad \text{for } t \geq 0 \quad (4)$$

where I_0 is the initial current stored in the inductor at $t = 0$, and $\tau = \frac{L}{R}$ is the time constant.

The response curve is a decaying exponential and is shown in Figure 3.

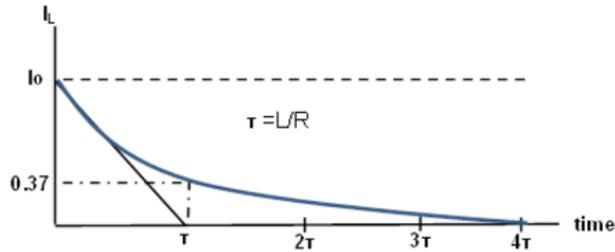


Figure 3: Current Decay Through the Inductor for a Series RL Circuit.

Since it is possible to directly measure the current through the inductor (current supplied by driving source) with the ADALM2000, we will measure and compare both the current and the output voltage across the resistor. The resistor waveform should be similar to the inductor current as $V_R = R \cdot I_L$. From the waveforms on the scope, we should be able to measure the time constant

τ which should be equal to $\tau = \frac{L}{R_{total}}$.

Here, R_{total} is the total resistance and can be calculated from $R_{total} = R_L + R$.

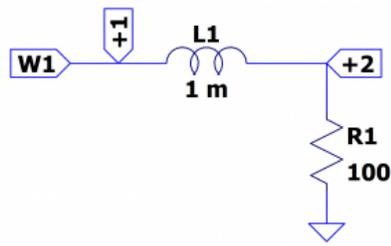
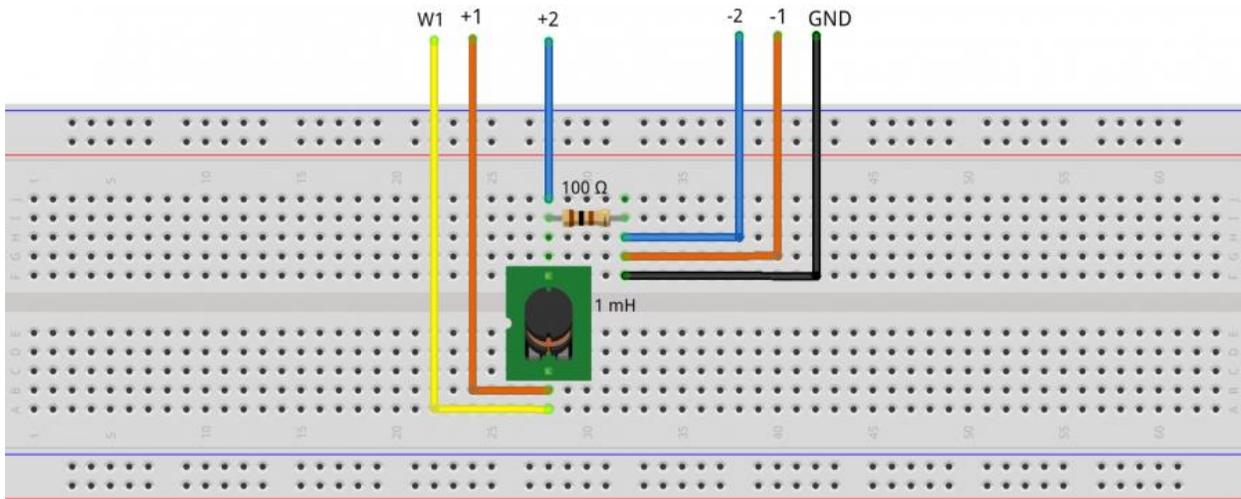
R_L is the measured value of inductor resistance and can be measured by connecting inductance to an ohmmeter prior to running the experiment.

Equipment Needed:

- ADALM2000 Active Learning Module with Scopy software
- Breadboard and Jumper Wire Kit
- 1 100Ω Resistor
- 1 1mH Inductor

Hardware Setup:

Set up the circuit shown in Figure 4 on your breadboard with the component values $R_1 = 100\Omega$ and $L_1 = 1\text{mH}$.

Figure 4. Series RL Circuit Schematic.Figure 5. Breadboard Connections of RL Circuit.**Procedure:**

On Channel 1 of the oscilloscope you will visualize the input voltage, and on channel 2 the voltage on the resistor (It has the same shape as the current through the inductor). Generate a square wave on channel 1 of the signal generator with 4 V amplitude peak-to-peak. The frequency will be set according to τ . Calculate the applied frequency using equation (2) for $t_p = 5\tau$.



Figure 6. Waveforms for Pulse Width equal to 5τ .

The waveform on channel 2 (voltage on the resistor) has the same shape as the $i_L(t)$ waveform. Measure the time constant τ and compare with the one that you calculated from $\tau = \frac{L}{R_{total}}$. (Hint: Find the time that corresponds to $0.63V_R$ value). Observe the response of the circuit and record the results again for $t_p = 25\tau$, and $t_p = 0.5\tau$.

Questions:

- Include plots of I_L and V_R for each of the t_p values given above.
- A Capacitor stores charge. What do you think an inductor stores? Answer briefly.
- How can you attenuate the spikes present on the input voltage?

Lab Resources:

- Fritzing files: [transient_response_RL_bb](#)
- LTspice files: [transient_response_RL_Itspice](#)