Aim

To observe the time response of RC and RL series circuits for a square input signal

Introduction

The complete response in a driven RC or RL circuit can be written as a sum of forced (steady-state) response and natural (transient) response. The transient response is triggered when the circuit is subjected to some perturbation (such as flipping of a switch or jump in voltage) after being in a steady state for a long time.

The complete response f(t) (voltage or current) for the transient can be written as:

$$f(t) = f(\infty) + [f(0^+) - f(\infty)]e^{-t/\tau} \tag{1}$$

where τ is the time constant of the transient state, $f(\infty)$ (steady-state response) is final value that would have been reached as $t \to \infty$, and $f(0^+)$ is the initial value from where the transient started.

In this experiment, you are required to observe and record the output time-domain waveforms for both RC and RL series circuits (for outputs across both R and C or L). From the observed waveforms, re-calculate and verify the value of time constant τ, and find the frequencies for which the circuit behaves as an integrator or differentiator.

Time response of RC Series Circuits

Experiment (i)

Wire the circuit of Figure 1. Connect the FG to the RC circuit, and also to the CH1 of the DSO. Choose square wave signal and adjust the amplitude control to obtain a waveform going from -5 V to +5 V. Connect the output across the capacitor of the RC circuit to CH2 input of the DSO. Be sure to choose the DC mode for both CH1 and CH2 inputs so as to observe the dc levels of the signals. Use DSO to set the frequency of FG as stated in Table 1.

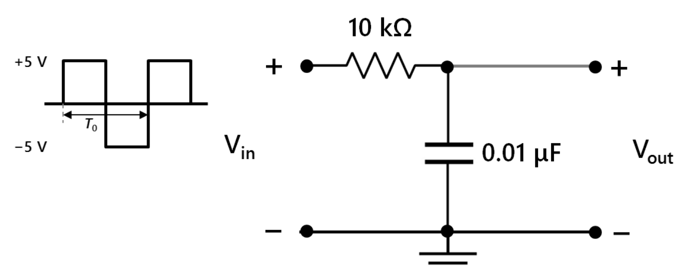


Figure 1: Circuit diagram for RC Circuit (output measured across C)

<u>Calculation of Time Constant (τ)</u>

Turn on the Cursors and Select '**Track**' mode for CH2. Using the cursors in Track mode, you will be able to simultaneously measure time and voltage for a given point on the waveform.

<u>Step 1</u>: In the observed output, select any one (charging or discharging) cycle for finding the time constant. For example, if you have chosen a charging cycle (refer to Figure 2a), find the initial voltage of this cycle at a temporary initial time instant t′ = 0 (i.e. V(0)). The steady-state voltage for the charging cycle V(∞) is +5 V. (Note that if you had chosen a discharge cycle, the steady-state voltage V(∞) would be −5 V.

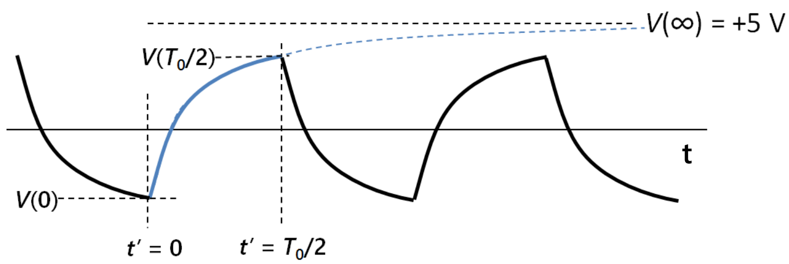
Step 2: Now measure the voltage at some other time instant in the charging cycle (e.g at $t' = T_0/2$), and record this voltage as V(t'). Note that in cases where τ is much smaller than time period, the charging occurs rapidly and waveform quickly reaches the steady-state. In such cases, you must make sure that the selected time instant t' lies in the transient region of the waveform (as shown in Figure 2b).

Step 3: In Eq. (1), plug in the values of V(0), V(∞), V(t') and t'. That is, rewrite the expression as follows:

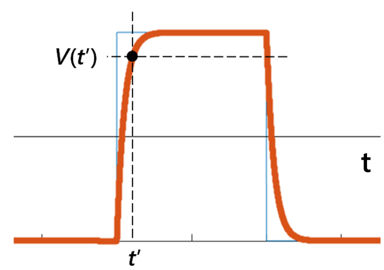
$V(t') = V(\infty) + [V(0^+) - V(\infty)]e^{-(t')/\tau}$. Calculate the value of τ from this equation.

Step 4: Repeat Steps 1 to 3 for all given frequencies and compare the calculated value of time constant with the actual value (RC) in Table 1.

Step 5: At which of the three cases of frequencies does this circuit behave as an integrator? Why?



(a) General case of measuring voltages in one charging cycle



(b) Observing voltage at any time instant in the transient part of the waveform

Figure 2: One charging cycle of the capacitor (for the circuit shown in Figure 1)

Table 1: Verification of time constant using time response of RC circuit shown in Figure 1

Frequency	T_0 (ms)	$T_0/2$ (ms)	Over one ___________(charging/discharging) cycle						
			V(∞) (V)	V(0) (V)	Selected t' (ms)	V('t) (V)	Calculated τ (ms)	Actual τ (ms)	Case (>> / << / =)
250 Hz	4.0	2.0							τ ____ ($T_0/2$)
5,000 Hz	0.2	0.1							τ ____ ($T_0/2$)
50,000 Hz	0.02	0.01							τ ____ ($T_0/2$)

Experiment (ii)

Wire the circuit shown in Figure 3, and connect input signal to CH1 and the output voltage across R to CH2. Observe and save the output waveforms for the three frequencies stated in Experiment (i). Time constant calculation is not required in this part of the experiment.

For which test frequency does this circuit behave as a differentiator and why?

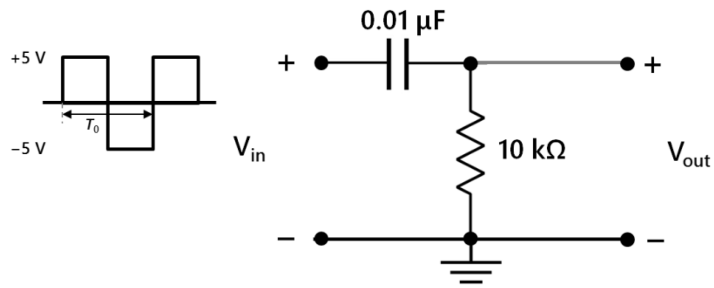


Figure 3: Circuit diagram for RC Circuit (output measured across R)

Time response of RL Series Circuits

Experiment (iii)

Wire the circuit shown in Figure 4. Connect the input signal to CH1 of the DSO and the output waveform across R to CH2. Repeat the steps described in Experiment (i) to calculate the time constant of this circuit over any one charging/discharging cycle for the frequencies stated in Table 2.

At which of the three cases of frequencies does this circuit behave as an integrator? Why?

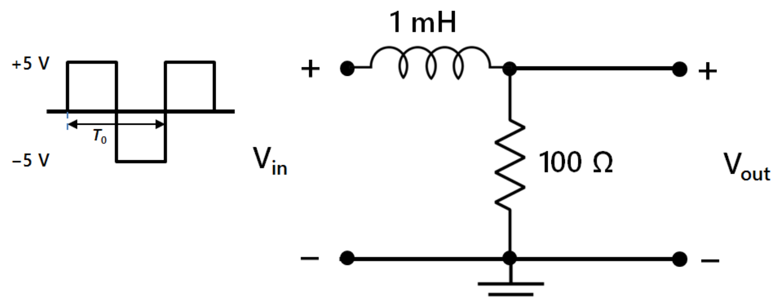


Figure 4: Circuit diagram for RL Circuit (output measured across R)

Table 2: Verification of time constant using time response of RL circuit shown in Figure 4

Frequency	T_0 (µs)	$T_0/2$ (µs)	Over one ___________(charging/discharging) cycle						
			V(∞) (V)	V(0) (V)	Selected t′ (ms)	V(′t) (V)	Calculated τ (µs)	Actual τ (µs)	Case (>> / << / =)
5 kHz	200	100							τ _____ ($T_0/2$)
50 kHz	20	10							τ _____ ($T_0/2$)
500 kHz	2	1							τ _____ ($T_0/2$)

Experiment (iv)

Wire the circuit shown in Figure 5, and connect input signal to CH1 and the output voltage across R to CH2. Observe and save the output waveforms for the three frequencies stated in Experiment (iii). Time constant calculation is not required in this part of the experiment.

For which test frequency does this circuit behave as a differentiator and why?

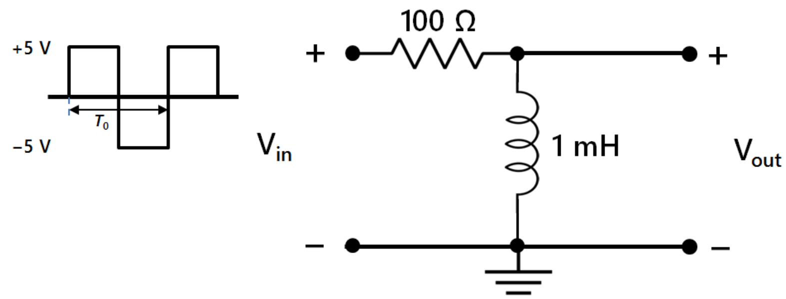


Figure 5: Circuit diagram for RL Circuit (output measured across L)