EXPERIMENT 5: Transient Response of RC Circuit

Objective:

Study the transient response of a series RC circuit and understand the time constant concept using pulse waveforms.

Equipment:

- NI – ELVIS
- Resistors (2 KΩ, 100 KΩ)
- Capacitors (1 μF, 0.01 μF)

Theory:

In this experiment, we apply a pulse waveform to the RC circuit to analyse 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 ($\tau$): 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 ($5\tau$) 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.

$$\tau = RC$$  \hspace{1cm} (1)

A Pulse is a voltage or current that changes from one level to the other and back again. If a waveform’s high time equals its low time, as in figure, it is called a square wave. The length of each cycle of a pulse train is termed 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,

$$f = \frac{1}{2 t_p}$$  \hspace{1cm} (2)
From Kirchoff’s laws, it can be shown that the charging voltage $V_C(t)$ across the capacitor is given by:

$$V_C(t) = V(1 - e^{-t/RC}) \quad t \geq 0 \tag{3}$$

where, $V$ is the applied source voltage to the circuit for $t \geq 0$. $RC = \tau$ is the time constant. The response curve is increasing and is shown in Figure 2.

The discharge voltage for the capacitor is given by:

$$V_C(t) = V_o e^{-t/RC} \quad t \geq 0 \tag{4}$$

Where $V_o$ is the initial voltage stored in capacitor at $t = 0$, and $RC = \tau$ is time constant. The response curve is a decaying exponentials as shown in Figure 3.
Procedure:

1. Set up the circuit shown in Figure 1 with the component values \( R = 2 \, K\Omega \) and \( C = 1 \, \mu F \) and switch on the ELVIS board power supply.

2. Select the Function Generator from the NI - ELVIS Menu and apply a \( 4V_{p-p} \) square wave as input voltage to the circuit using the amplitude control on the FGEN.

3. Open the Function Generator and Oscilloscope from the NI - ELVIS Menu. Set the Source on Channel A, Source on Channel B, Trigger and Time base input boxes as shown in figure 4 below.

![Figure 4: Oscilloscope Configuration.](image)

This configuration allows the oscilloscope to look at the output of the function generator on channel A, the output of the circuit on channel B. Make sure you have clicked on the Run button of the FGEN panel and on the OSC panel. Any settings on the FGEN panel cause changes on the oscilloscope window.

4. Observe the response of the circuit for the following three cases and record the results.
   a. \( t_p >> 5\tau \): Set the frequency of the FGEN output such that the capacitor has enough time to fully charge and discharge during each cycle of the square wave. So Let \( t_p = 25\tau \) and accordingly set the FGEN frequency using equation (2). Determine the time constant from the waveforms obtained on the OSC panel.
   b. \( t_p = 5\tau \): Since the pulse width is exactly \( 5\tau \), the capacitor should just be able to fully charge and discharge during each pulse cycle.
c. $t_p \ll 5\tau$: In this case the capacitor does not have time to charge significantly before it is switched to discharge, and vice versa. Let $t_p = 0.5\tau$ in this case and set the frequency accordingly.

5. Repeat the procedure using $R = 100$ KΩ and $C = 0.01\mu F$ and record the measurements.

**Questions for Lab Report:**

1. Calculate the time constant using equation (1) and compare it to the measured value from 3a. Repeat this for other set of $R$ and $C$ values.

2. Comment upon the expected and observed results in case 3b.

3. Discuss the effects of changing component values.