

# ECE 0101 – Linear Circuits and Systems

## Laboratory # 7 – Transient response of RC circuits

Objectives:

- Understand the behavior of RC circuits.
- Measure and understand the importance of RC time constants and the effect of the time constant on the behavior of RC circuits.

## Introduction

This laboratory assignment will reinforce the concepts learned in class about the behavior of RC and RL circuits. The circuit diagram shown in Figure 1 shows a series RC circuit. In the laboratory experiment the waveform generator will be used in place of the voltage source  $v_s(t)$ .

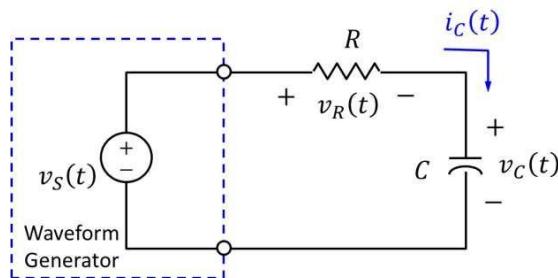


Figure 1 - RC circuit

Assume  $v_s(t)$  is a square wave with period  $T$  that varies over the range  $[V_H, V_L]$  of high to low voltages. The peak-to-peak voltage  $V_{pp} = V_H - V_L$ .

The RC circuit responds to the applied square wave voltage by charging and discharging the capacitor. This is shown in Fig. 2 with the source voltage  $v_s(t)$  shown in blue and the corresponding steady-state capacitor voltage  $v_C(t)$  shown in red. “Steady-state” is defined as the conditions reached after the natural response of the circuit has died out such that the response of the circuit to the square wave is a sustained oscillation.

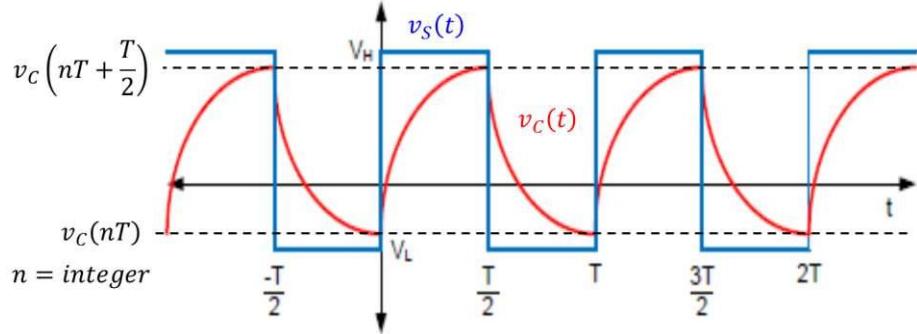


Figure 2 - RC circuit response to a square wave.

Note that in Fig. 2 the capacitor is never able to either fully charge or discharge. This drawing is based on the assumption that  $T_C > T$  (the time constant of the RC circuit is greater than the period of the square waveform). If  $T_C \ll T$ , the capacitor would fully charge and discharge during each period of the waveform. Conversely, if  $T_C \gg T$ , the capacitor voltage would remain nearly constant.

In the pre-lab homework you will derive the formal equation for the steady-state response of an RC circuit to a square wave voltage source. The formal equation can be derived using the initial and final value method for step response

We use circuit equations to derive the equation

$$v_c(t) = v_c(\infty) + (v_c(0) - v_c(\infty))e^{-\frac{t}{T_C}} V$$

Where  $v_c(0)$  is the initial capacitor voltage and  $v_c(\infty)$  is the final capacitor voltage. We utilize the step response because a square wave is modeled as a series of step functions.

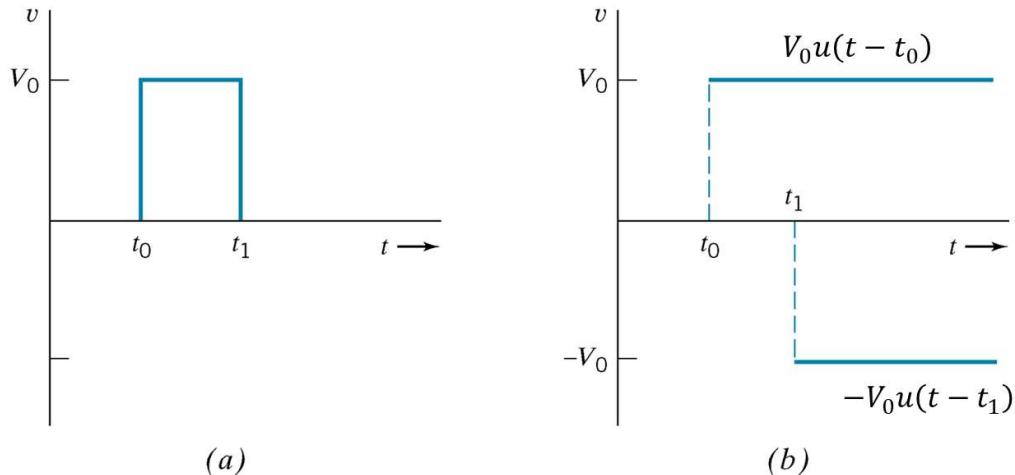


Figure 3 - (a) Pulse signal (b) Pulse signal constructed using step functions

# Homework

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The equations describing  $V_C(nT + \frac{T}{2})$  and  $V_C(nT)$  from Fig. 2, in terms of  $V_L$ ,  $V_H$ ,  $T$ ,  $R$ , and  $C$  are

$$-\frac{1}{2fRL} V_C(nT) = \frac{-\zeta(1 - e^{-\frac{T}{2RC}})}{\left(1 - e^{-\frac{T}{RC}}\right)} + \frac{\zeta(e^{-\frac{T}{2RC}} - e^{-\frac{T}{RC}})}{\left(1 - e^{-\frac{T}{RC}}\right)} \underset{e^{-4}}{\cancel{\sim}} \frac{-1 + e^{-4} + e^{-4} - e^{-8}}{1 - e^{-8}}$$

$$-\frac{1}{0.02f} V_C\left(nT + \frac{T}{2}\right) = \frac{\frac{1}{2}\zeta(1 - e^{-\frac{T}{2RC}})}{\left(1 - e^{-\frac{T}{RC}}\right)} + \frac{\frac{1}{2}\zeta(e^{-\frac{T}{2RC}} - e^{-\frac{T}{RC}})}{\left(1 - e^{-\frac{T}{RC}}\right)} \underset{e^{-8}}{\cancel{\sim}} \frac{-1 + e^{-2} - e^{-4}}{1 - e^{-4}}$$

- (30 points) Calculate  $V_C(nT)$  and  $V_C\left(nT + \frac{T}{2}\right)$  for frequencies of 12.5, 16.67, 25, and 50 kHz, assuming that  $R = 1k\Omega$  and  $C = 0.01 \mu F$ . The period  $T$  is equal to the inverse of the frequency. With such complicated equations it may be easier to use Matlab or Excel rather than performing the calculations by hand or with a calculator.

	12.5 kHz	16.67 kHz	25 kHz	50 kHz
$V_C(nT)$	-4.8201 V	-4.5145 V	-3.7382 V	-1.9979 V
$V_C(nT + \frac{T}{2})$	4.8201 V	4.5145 V	3.7382 V	1.9979 V

# Laboratory Procedure

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1. On your breadboard, build the circuit shown in Fig. 1 using  $R = 1k\Omega$  and  $C = 0.01 \mu F$ .
2. Configure the function generator to output a Square waveform with the following characteristics:
  - Amplitude =  $10 V_{pp}$  with 0 DC offset.
  - Frequency = 10 kHz
  - Duty Cycle = 50%
  - Phase =  $0^\circ$

A simple method for setting the 0 DC offset:

- i. Press the 'Amplitude' menu button to switch to the 'High Level' parameter. Use the keypad to enter +5V.
- ii. Press the 'Offset' menu button to switch to the 'Low Level' parameter. Use the keypad to enter -5V.
3. Connect the waveform generator and the circuit to the oscilloscope. Simultaneously display 4 periods of the input square wave  $v_S(t)$  and the output voltage across the capacitor  $v_C(t)$  similar to the graph of Fig. 2.



To connect the output of the function generator to both the oscilloscope and your circuit you will need to use a "BNC splitter" as shown to the left. This allows you to connect two BNC cables to the same output, one of which will go to the circuit and the other of which will go to the oscilloscope. To connect the function generator to the oscilloscope you will use a double-sided BNC cable and to connect to the breadboard you will use a BNC cable that terminates in alligator clips.

4. Measure the maximum and minimum voltage across the capacitor using the oscilloscope. With the equations shown in the prelab assignment, calculate the maximum and minimum voltages across the capacitor. Record both measurements and calculations in table 1.
5. Repeat step 4 for frequencies of 12.5, 16.67, 25, and 50 kHz.

(3 points per entry = 60 points)

	Frequency				
	10 kHz	12.5 kHz	16.67 kHz	25 kHz	50 kHz
Min $V_C$ (measured)	-4.933 V	-4.82 V	-4.53 V	-3.81 V	-2.31 V
Max $V_C$ (measured)	4.933 V	4.82 V	4.53 V	3.81 V	2.31 V
Min $V_C$ (calculated)	-4.9330 V	-4.8201 V	-4.5145 V	-3.7382 V	-1.9979 V
Max $V_C$ (calculated)	4.9330 V	4.8201 V	4.5145 V	3.7382 V	1.9979 V

Table 1

6. Answer the following questions:

- (5 points) How do the measured and calculated values compare with one another? Explain any differences.
- (5 points) Explain the relationships between frequency (or period),  $R$ ,  $C$ ,  $V_s$  (i.e. the amplitude of  $v_s(t)$ ), and the effect on  $V_C$ . How does increasing or decreasing the frequency affect  $V_C$ ? How does increasing or decreasing  $R$  affect  $V_C$ ?

a. When the frequencies are lower, the difference between measured and calculated is relatively small. As frequencies increasing, the difference also increases, at 50 kHz, the max difference is 0.3121 V (13.5%)

Reason: Maybe the component parameter deviation, and at higher frequency, the function generator and the function receiver will be influenced obviously

- $V_C$  will be closer to  $V_s$  when  $R, C$  is smaller.  
 $V_s$  determine the wave change of  $V_C$  ( $V_C < V_s$ )  
frequency will influence the difference between  $V_C$  and  $V_{\text{measured}}$   
frequency increase, the difference also increase.