

Laboratory 1: RC Circuits

Lab Section AA

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EE233 Circuit Theory

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Abstract — In this lab, the characteristics of RC circuits were explored with two types of input voltages: step-function and sinusoidal. Familiarization of lab equipment for testing/analyzing circuits was conducted. This lab effectively demonstrated the effects of changing input magnitude and frequency on output voltage.

I. INTRODUCTION

In this lab, students will explore methods for characterizing circuit systems, focusing specifically on an RC circuit system. This serves to acquaint them with the equipment and techniques used for analyzing fundamental response trends of step and sinusoidal input functions in RC circuits.

Understanding the behavior of an RC circuit is crucial as it forms the foundation for more complex circuit designs. By studying the input-output relationship of the RC circuit, students gain insights into how changes in input parameters like magnitude and frequency influence the output signal. This knowledge is essential for designing and troubleshooting circuits in various applications.

Moreover, this lab is a part of a broader curriculum aiming to build towards the final audio mixer circuit. By understanding the characteristics of individual components like the RC circuit, students can better comprehend their role within the larger system and optimize their design choices accordingly.

II. LAB PROCEDURE

The equipment to construct the different circuits for this lab included a breadboard, 10k Ω resistors, 0.01 μ F capacitors, and jumper wires to connect the components.

The multimeter was used to measure the capacitance values of different capacitors to find the correct one needed.

The function generator was used to produce different waves required such as a square or sine wave. For the square wave, the function generator was set to a square wave with a frequency of 333.33 Hz, amplitude of 5.0Vpp, offset of +2.50V. For the sine wave, the function generator was set to a sine wave with a frequency of 1 kHz, and amplitude of 2Vpp.

The oscilloscope was used to measure output voltage over the capacitor. The cursor function was used to measure time intervals between two points. The measure function was used to precisely calculate rise, fall, and delay times. Two main channels were used from the oscilloscope: Channel 1 and 2. Those channels were connected to the input signal voltages that were supplied by the waveform generator and the various output signal voltages measured across the different circuit components respectively.

III. EXPERIMENTAL PROCEDURE AND ANALYSIS

Firstly, the circuit in Figure 1 was constructed, and the function generator was set up to run the square wave from the lab procedure.

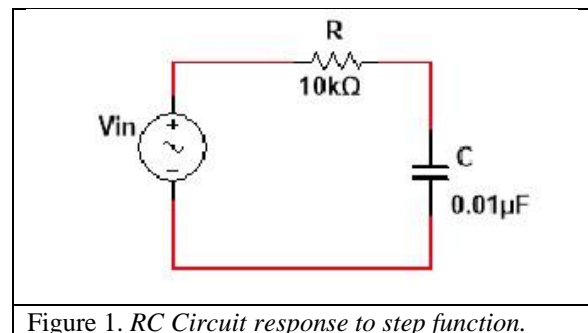


Figure 1. RC Circuit response to step function.

The oscilloscope was then used to display the input signal, along with displaying the output voltage over the capacitor from the circuit constructed. The oscilloscope display can be seen in Figure 2.

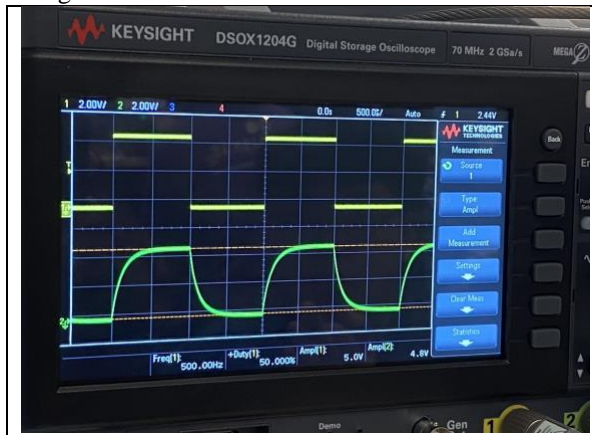


Figure 2. Input voltage (yellow) and output voltage over capacitor (green) displayed on oscilloscope display.

1. The oscilloscope displays the same waveform that was plotted in section 3.1 item 7 shown in Figure 3. In both cases, the output voltage exponentially increases when the input voltage is at 5V (step response) and exponentially decreases when the input voltage is 0V (natural response).

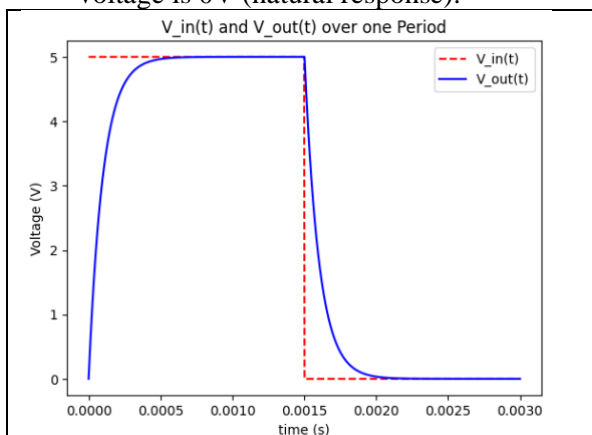


Figure 3. Section 3.1 item 7, output voltage of capacitor in response to square wave input.

From the nominal values of the resistor and capacitor, the theoretical rise time was calculated. By taking the 10% and 90% of the input voltage, then plugging them into the step response below, taking the difference in time yielded the rise time.

The theoretical fall time was calculated using a similar approach. By taking the 90% and 10% of the input voltage, then plugging them into the natural response, taking the time difference yielded the fall. The theoretical times are shown in Table 1.

Theoretical Equation for RC step/natural response

$$\text{Step: } V_{out}(t) = V_0 - V_0 * e^{(-t/R * C)}$$

$$\text{Natural: } V_{out}(t) = V_0 * e^{(-t/R * C)}$$

The delay time was calculated using the time difference between 50% of the input signal and 50% of the output voltage. The resulting calculations are shown in Table 1.

Table 1. 10%-, 50%-, and 90%-time values.

Time (10%)	Time (50%)	Time (90%)
10.5μs	69.3μs	230.25μs

From the display, measurements for the rise, fall, and delay time were taken using the cursor tool. The X and Y cursors were placed at different output voltages (10%, 50%, 90%) and the time difference was recorded. The resulting calculations are shown in Table 2.

2. When compared to the theoretical values of rise, fall, and delay times there is a margin of error which can be attributed to how the time values were estimated by trying to position the X cursor to intersect perfectly with the Y cursor before taking note of the time.

The oscilloscope auto generated measurements for rise, fall, and delay time were found using the Measure function. The resulting measurements are shown in Table 2.

3. The oscilloscope's measurement capability was used to measure rise, fall, and delay times. When compared to the measurements taken using the cursor, the error is marginally less and closer to the theoretical times. The error here is less because the measurement capability can precisely locate the times for the 10%, 50%, and 90% output voltage values to calculate rise, fall, and delay times. Like question 2, there is a slight precision error from the oscilloscope that contributes to this margin of error.

Table 2. Theoretical, Cursor tool, and Measure function rise fall and delay times.

	Rise	Fall	Delay
Theoretical	219.75μs	219.75μs	69.3μs

Cursor tool	312.4μs	330μs	84.4μs
Measure function	240μs	230μs	80.5μs

After the rise, fall, and delay times were found, 10 voltage measurements were taken along the fall-time of the output signal to find the time constant τ of the circuit. τ was calculated using the equation below. The results are shown in Table 3.

$$\tau = -t/(\ln |V_{out}(t) - V_{in}|/|V_0|)$$

Table 3. Time constant τ (Fall time) – One stage RC circuit (4.9V peak)

Time (us)	Voltage (V)	τ (s) Calculations
7.6	4.5	7.21×10^{-5}
14.0	4.25	8.61×10^{-5}
26.8	3.75	9.32×10^{-5}
42.0	3.25	9.75×10^{-5}
61.4	2.75	1.03×10^{-4}
86.6	2.25	1.08×10^{-4}
117.6	1.75	1.12×10^{-4}
159.2	1.25	1.15×10^{-4}
225.8	.75	1.19×10^{-4}
425.0	0.1	1.09×10^{-4}

- The theoretical equation for the single-stage circuit $\tau = RC$ yielded 0.0001s. The time was slightly off. This can be contributed to how time values were estimated by moving the X cursor until it intersected with the Y which was placed at the voltage.

The last step of this part involved constructing a two-stage and three-stage RC circuit which can be found in Figure 4 and Figure 5. The same 10k Ω resistor and 0.01 uF capacitors were used to create the circuits.

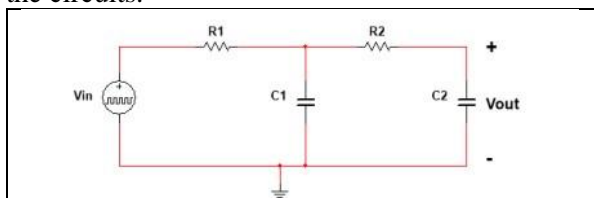


Figure 4. Two-stage RC circuit

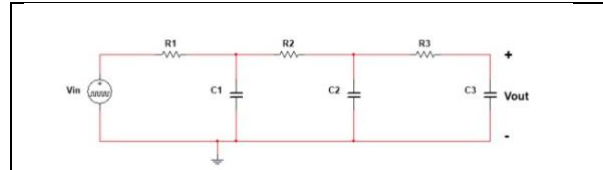


Figure 5. Three-stage RC circuit

The same steps were taken in measuring 10 voltage outputs from the circuits and calculating the time constant. Results for the two-stage are shown in **Error! Reference source not found..** R results for the three-stage are shown in **Error! Reference source not found..**

Time (us)	Voltage (V)	τ (s) Calculations
38.0	4.5	7.03×10^{-4}
64.0	4.25	5.75×10^{-4}
116	3.75	4.91×10^{-4}
168	3.25	4.43×10^{-4}
232	2.75	4.24×10^{-4}
306	2.25	4.10×10^{-4}
408	1.75	4.09×10^{-4}
534	1.25	4.00×10^{-4}
732	.75	3.97×10^{-4}
1374	0.1	3.56×10^{-4}

Table 4. Time constant τ (Fall time) – Two stage RC circuit (4.9V peak)

Time (us)	Voltage (V)	τ (s) Calculations
16.0	4.5	2.96×10^{-4}
30	4.25	2.70×10^{-4}
64	3.75	2.71×10^{-4}
108	3.25	2.85×10^{-4}
168	2.75	3.07×10^{-4}
242	2.25	3.24×10^{-4}
338	1.75	3.38×10^{-4}
470	1.25	3.52×10^{-4}
658	.75	3.56×10^{-4}
1330	0.1	3.44×10^{-4}

Table 5. Time constant τ (Fall time) – Three stage RC circuit (4.9V peak)

- After analyzing the values from tables 4 and 5, it was discovered that tau calculations were quite close to the theoretical time constants for the two-stage circuit but not as much for the three-stage circuit. The theoretical equation for the two-stage circuit $\tau = (R1)C1 + (R1 + R2)C2$ yielded 0.0003s as the time constant and though the calculations matched up, the individual values for each time were slightly off. The theoretical equation for the three-stage circuit $\tau = (R1)C1 + (R1 + R2)C2 + (R1 + R2 + R3)C3$ yielded 0.0006s as the time constant but calculations did not quite align with this value. This can be contributed to how time values were recorded by moving the X cursor until it intersected with the Y which was placed at the voltage.

The next part of this lab used the circuit in Figure 1. The waveform generator was then set up to run the sinusoidal wave from the lab procedure. The oscilloscope was then set up to use Channel 1 and 2 to measure the input voltage and voltage over the capacitor. The image of the waveforms and measured values can be seen in Figure 7.

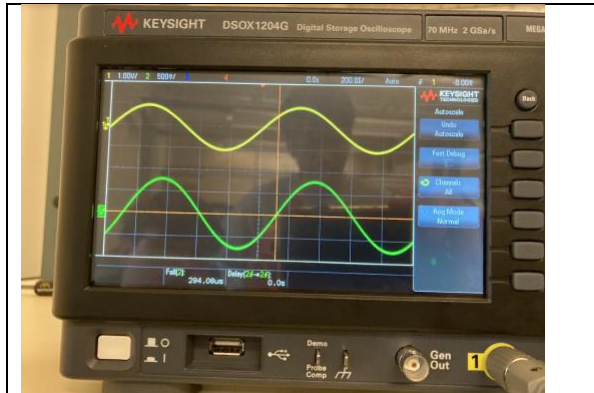


Figure 7. Input voltage (yellow) and output voltage over the capacitor (green) displayed on oscilloscope display

After getting the oscilloscope set up, the RC response of the circuit was measured by adjusting the starting input frequency of the waveform generator, starting from 10 Hz to then ending at 1 MHz to see the changing in amplitude for the output signals. Once that was completed, the probes used to measure over the capacitor were then moved so that the voltage over the resistor could be measured. The same steps of adjusting the starting input frequency were conducted to measure the amplitude of the output signals.

From measuring the amplitude of the voltage across the capacitor, it was found that as frequency increased, and the amplitude peak-to-peak voltage was decreasing. The table is shown in **Error! Reference source not found.** The plot for these measurements can be seen in Figure 8.

Table 6. Voltage over the capacitor		Table 7. Voltage over the resistor	
Frequ ncy (Hz)	Amplit ude Peak to Peak (V)	Frequ ncy (Hz)	Amplit ude Peak to Peak (V)
10	2.09	10	0
20	2.09	20	0
50	2.09	50	0
100	2.09	100	0

200	2.09	200	0
500	1.87	500	0.13
1000	1.59	1000	0.41
2000	1.13	2000	0.87
5000	0.53	5000	1.47
10000	0.28	10000	1.72
20000	0.15	20000	1.85
50000	0.06	50000	1.94
100000	0.03	100000	1.97
200000	0.02	200000	1.98
500000	0.00	500000	2
1000000	0.00	1000000	2
0		0	

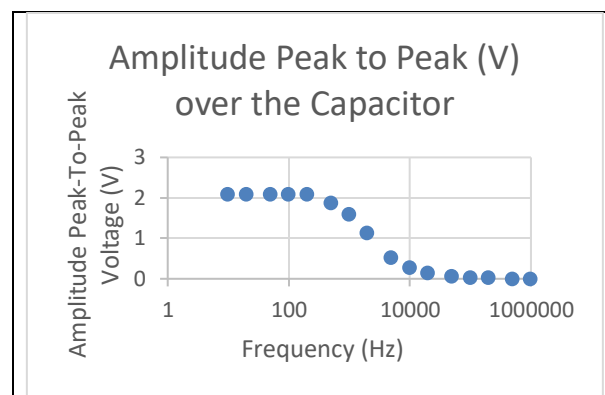


Figure 8. Amplitude peak-to-peak voltage versus frequency over the capacitor.

6. Comparing Figure 8 plot to the graph in section 3.2 item 4 yields a similar trend for both. At lower frequencies, the amplitude remains high, but as frequency increases, the amplitude starts to get smaller. The plot for section 3.2 item 4 can be seen in Figure 9.

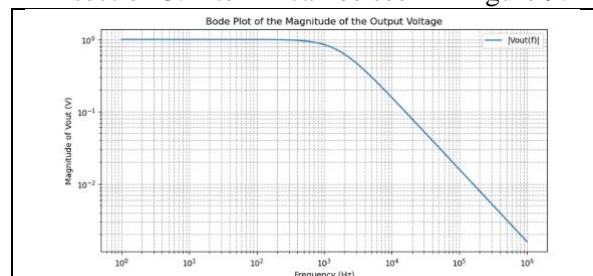


Figure 9. Section 3.2 item 4, output voltage versus frequency.

Upon switching the output to over the resistor, it was found that the relationship between output voltage and frequency was flipped compared to over the capacitor. As the frequency gets higher, so does the voltage over the resistor. The table is

shown in **Error! Reference source not found..** The plot for these measurements can be seen in Figure 10.

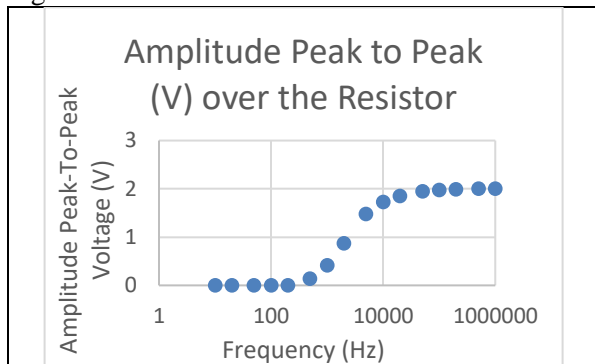


Figure 10. Amplitude output peak-to-peak voltage versus frequency over the resistor.

7. Similarly, comparing the results from the measurements and the plot in section 3.2 item 6 yielded a similar trend for both. At lower frequencies, the voltage amplitude was very low, but as frequency increased, so did the resulting output voltage. The plot for section 3.2 item 6 can be seen in Figure 11.

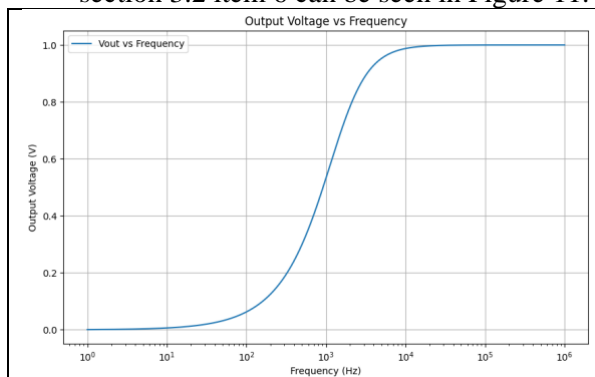


Figure 11. Section 3.2 item 6, output voltage vs. frequency.

IV. CONCLUSIONS

In this laboratory, we investigated the behaviors and characteristics of an RC circuit in response to both step-function and sinusoidal input voltages. By constructing and analyzing 1, 2, and 3-stage RC circuits, we gain a better understanding of how RC circuits reacts to various frequencies and voltages and reinforce theoretical concepts such as time constant(τ) and the influence of input signals on the output signal.

Experimental results from oscilloscope readings indicated a distinct relationship between input frequency and the amplitude of the output voltage

across the capacitor and resistor. As the frequency increased, the capacitor's voltage amplitude decreased, while the resistor's voltage amplitude increased, illustrating the fundamental frequency-dependent behavior of RC circuits.

The discrepancies between theoretical and observational values were noted, with potential sources of error stemming from the precision of the oscilloscope and the human factor in reading and positioning cursors. These errors highlighted the limitations of measurement tools and human factors.

Ultimately, the experiment succeeded in demonstrating the expected outcomes of RC circuit behaviors and provided practical experience in circuit analysis.

Team Roles

Activity	Student(s) Name
Prelab: Circuit Analysis	Travis, Ethan, Junhan
Prelab: Simulations and Graphs	Travis, Ethan, Junhan
Prelab: Questions	Travis, Ethan, Junhan
Lab: Circuit Construction	Travis, Ethan, Junhan
Lab: Data Collection	Travis, Ethan, Junhan
Lab: Data Analysis	Travis, Ethan, Junhan
Report: Procedure	Travis, Ethan, Junhan
Report: Analysis and Graphs	Travis, Ethan, Junhan
Report: Questions	Travis, Ethan, Junhan

V. APPENDIX