EE233 Circuit Theory Lab1

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Abstract—As the solutions to many complex problems can be traced back to the simplest ones, most of the implements of projects in engineering nowadays can date back to a basic circuit–the RC circuit. Therefore, lab1 aims to utilize test bench instruments to build and analyze an RC circuit. There are two parts in this lab, with the first one using step function as input while the second one using sinusoidal function as input. The results will be got by both using the measurement capability of the equipment and mathematical methods. In addition, experimental results should be compared to theoretical ones and conclusions will be drawn on the comparison.

I. INTRODUCTION

The main purpose of lab1 is to enable us to character circuit systems, especially an RC circuit, get familiar with the equipment in the laboratory and use the equipment to implement the analysis of some fundamental response trends of step and sinusoidal input functions for an RC circuit. The characteristics of an RC circuit system can be represented by its input and output which can be measured as well. In this lab, the voltages of both the input and output of an RC circuit need to be measured. In addition, any changes of parameters in the input signal (e.g. magnitude, frequency, and phase) will cause changes in the output signal.

In this lab, two of the three parameters of the input signal, the magnitude and the frequency, may be changed, which will make a difference in the output signal. We may finally gain knowledge of the basic ways to observe an RC circuit and analyze it by using the equipment to measure some variables in this lab.

II. LAB PROCEDURE

A. The RC Response to a Step Function

In part 1, we use a resistor R=10kΩ, a capacitor C=0.01μF and a function generator which provides square wave as input to construct a RC circuit. As for measurement, we use the oscilloscope. Channel 1 is used to measure the input voltage while Channel 2 is used to measure the output voltage. For the generator and the oscilloscope, we should connect the negative port to the ground.

Initially, we set the period of input to make it more than 3ms and record its value. The voltage over the capacitor is regarded as the output voltage and we use the oscilloscope to display the input and output voltage. Then we enlarge the wave display of output signal to be convenient for recording the time value of 10%-point, 50%-point and bench instruments to build and analyze an RC circuit. There are two parts in this lab, with the first one using step function 90%-point of v_{out}.

Last, we measure the rise time, fall time and two delay times of output voltage. After that, we measure the voltage and time values of 10 points in one interval (rise time or fall time) and record them. Then we build the two-stage and three-stage RC circuits and use the same method as above to measure the delay time.

B. The RC Response to a Sinusoidal Function

We use the same equipment and build the same one- stage RC circuit which is used in part1, and the function of them is also the same. In this experiment, we adjust the amplitude and frequency of the input and display the input and output voltage. Then we sweep the frequency from 10Hz to 1MHz and record the amplitude of the output signal. In the last experiment, we change the output to the voltage of resistor, repeat the same procedure as above, adjust the frequency and record the output amplitude.

III. EXPERIMENTAL PROCEDURE AND ANALYSIS

A. The RC Response to a Step Function

1) Testing procedure:
First of all we connect the circuit as Figure 1 shows.

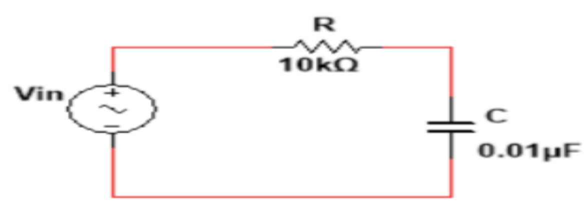

Fig. 1: An RC circuit

We use the color code of the resistor to identify which one's value is 10kΩ. Then we use the equipment in the laboratory to measure the values of all capacitors and finally identify the certain one. As the value of T is required much larger than R*C, we set the period to 4 ms, which means f is 250Hz. For the first part, the input should be square wave. Then we use the two-channel oscilloscope to display the input and output on the screen. (Channel one is for the input, while Channel two is for the output, the voltage value on the capacitor.)

We adjust the time base to display 3 complete cycles of the signals to get a hard copy output from the scope display with both the wave forms and the measured values. And we record the maximum and minimum values of the output signal as well.

Then we use the measurement capability of the oscilloscope to measure the time value of 10%-point 50%-point and 90%-point of output voltage. We also use the measurement capability of the oscilloscope to measure the rise time, fall time and two delay times ($t_{PHL}$and t_{PLH}) of output voltage.

To measure the time constant τ=R*C, we use the paired measurement capability of the oscilloscope to measure the voltage and time values at 10 points on the output voltage waveform during one interval (rise time or fall time) Note that the time values should be referred to time t= 0 at the point where the input signal rises from 0 V to 5 V or falls from 5 V to 0 V. Record the 10 measurements.

Last, we build two-stage and three-stage RC circuits and measure time constant τ of two stages and three stages, using the same method as the last task. The circuits of two- stage and three-stage RC are shown in Figure 2 and Figure 3

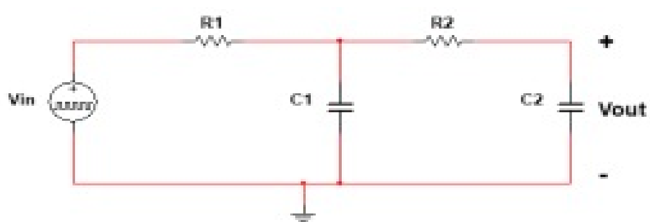

Fig. 2: The diagram of two-stage RC circuit

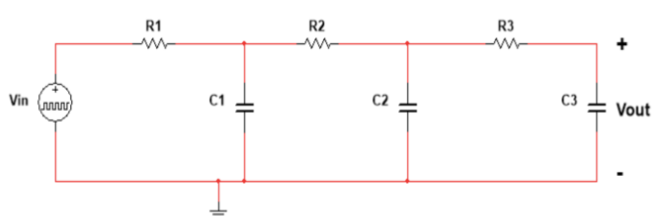

Fig. 3: The diagram of three-stage RC circuit

2) Analysis of the results: 1. According to figure 1, we find that V_{in} displayed on Channel 1 is a step wave, which verifies that our input is correctly selected. Then on Channel 2, we figure out that in an interval, the slope of the output voltage wave gradually decreases to zero, keep zero for some time and continues decreasing to negative values. This reflects the charging and discharging process of the capacitor. In the charging process, voltage over the capacitor increases while the speed of increasing decreases over time. Similarly, in the discharging process, the output voltage decreases sharply at first, but the speed of decreasing become slower and slower until it is zero. The measured values are displayed in the image and they are all close to the theoretical values. The oscilloscope displays the expected waveform, but when it comes to the parameters, errors cannot be avoided completely and our measurement is not absolutely precise. This is probably the effect of the internal error of the equipment.

Figure 4 shows the waveforms of input and output we got

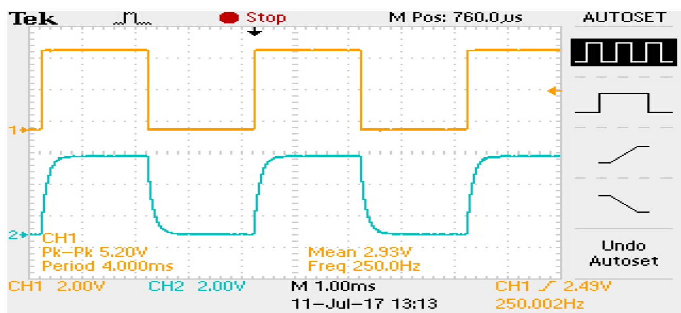

Fig. 4: The wavaforms of input and output

2.The data we measured is listed below.

$$T_{in} = 4ms, u_{min} = 0V, u_{max} = 5.40V$$

$$t_{10\%-rise} = 12\mu s, t_{50\%-rise} = 80\mu s, t_{90\%-rise} = 240\mu s$$

$$t_{10\%-fall} = 16\mu s, t_{50\%-rise} = 68\mu s, t_{90\%-rise} = 268\mu s$$

We calculate the values. We use both the values when the wave rises and falls to calculate the delay time and they are different to each other. $t_{rise} = 218\mu s$ $t_{fall} = 252\mu s$ $\tau_{rise} = 80\mu s$ $\tau_{fall} = 68\mu s$ The theoretical values is $\tau_{th} = 70\mu s$

Obviously, errors exist in our measurement. One possible reason causing the error is the internal error of the equipment such as the oscilloscope and the function generator. When we read and record the data, the values on the oscilloscope are not always steady, which may cause a deviation of $12\mu s$ at most. The function generator, in practice, cannot precisely generate the voltage we select. Hence, the error of the output voltage can be explained.

3.The data we measured is listed below.

$$t_{rise} = 225\mu s, t_{fall} = 240.7\mu s$$

In practice, the oscilloscope cannot figure out the time t_{PLH} and t_{PHL}.The relative error of the rise time and the fall time is 2.2% and 4.7%. Because of the restriction of the minimum value of oscilloscope, we cannot figure out the accurate value when the voltage is 10% of the maximum. This accounts for the error. The inaccuracy of the resistor and capacitor will also affect the values we measured.

4.The t we calculated from experiment data is nearly 102 μs, 2. while the theoretical value should be 100 μs. We think the two values are close to each other. (The error is less than 2%.) The reasons to the deviations are as follows: on one hand, when we get data from the oscilloscope, it keeps jumping from one number to another, which makes us hard to record the correct data. On the other hand, the resistor has been connected to the circuit for a long time that can be heated , making its value larger than former and leading t to be larger.

The original data is shown in the following table :

TABLE I: Original data of one-stage RC circuit

t/μs	52	80	116	148	160
V_{out}/V	2.1	2.88	3.36	3.8	3.84
t/μs	188	200	240	288	336
V_{out}/V	4.2	4.24	4.52	4.66	4.84

After processing the data, we get the following image:

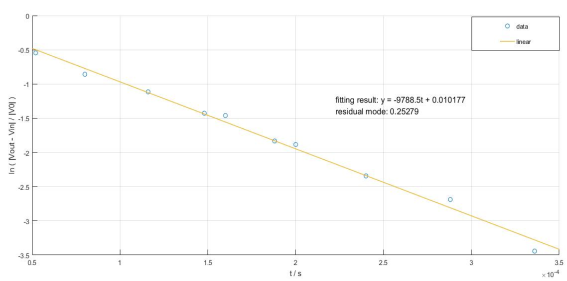

Fig. 5: Data processing result of RC circuit

5.The data is shown below.

$$\tau_{two-stage} = 321.9\mu s, \tau_{three-stage} = 624.0\mu s$$

Thetheoretical values are

$$\tau_{two-stage} = 300\mu s, \tau_{three-stage} = 600\mu s$$

Correspondingly, the relative errors are 7.3% and 4%. We attribute the existence error to the internal error of equipment and the random error caused by recording data from the oscilloscope. Another possible reason is that the capacitance is larger than theoretical one, and the resistance becomes higher when connect it to a source, causing the systematic error.

The original data is shown in the following table:

TABLE II: Original data of two-stage RC circuit

t/μs	110	220	340	450	540
V_{out}/V	1.22	2.36	3.14	3.62	3.88
t/μs	670	790	900	1060	1230
V_{out}/V	4.12	4.28	4.40	4.50	4.52

After processing the data, we get the following image:

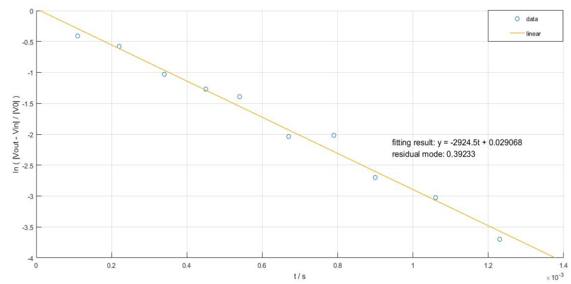

Fig. 6: Data processing result of two-stage RC circuit

The original data is shown in the following table :

TABLE III: Original data of three-stage RC circuit

t/μs	220	300	420	500	600
V_{out}/V	0.962	1.82	2	2.43	2.98
t/μs	720	800	1000	1200	1420
V_{out}/V	3.24	3.57	3.93	4.19	4.35

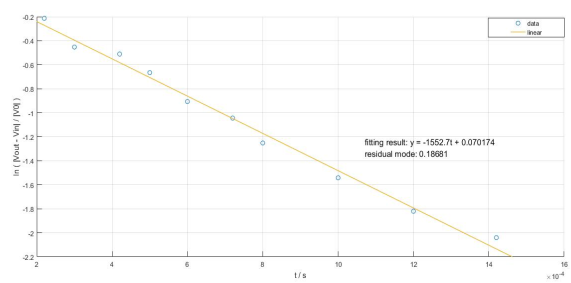

Fig. 7: Data processing result of three-stage RC circuit

B. The RC Response to a Sinusoidal Function

1) Testing procedure:

The second part uses a sinusoidal wave as the input. During the experiment, we change the amplitude into 1 V, which means the peak-to-peak voltage is 2 V. What's more, we connect channel1 to the input voltage and Channel2 to the voltage over the capacitor as the output. Then we display the input and output voltages simultaneously on the oscilloscope in 3 complete cycles to get the hard copy of both wave forms and the measured values. After that, we keep the input amplitude at 1 V, sweep the frequency from the starting input frequency of 10 Hz and vary it using a 1-2-5 sequence up to 1 MHz. When doing this, we also record the amplitudes of the output signals with various frequencies.

In the last section, we change the output to the voltage over the resistor and vary the frequency the same way as mentioned above. The amplitudes of the output signals with various frequencies also need to be recorded in the meanwhile.

2) Analysis of the results:

1. According to the circuit in section 4.1, we set the function generator to provide a sinusoidal wave with amplitude of 1 V and frequency of 1 kHz. Then, we connect channel 1 to the input voltage and channel 2 to the voltage over the capacitor as the output. Figure 8 shows the waveform of both input and output voltage.

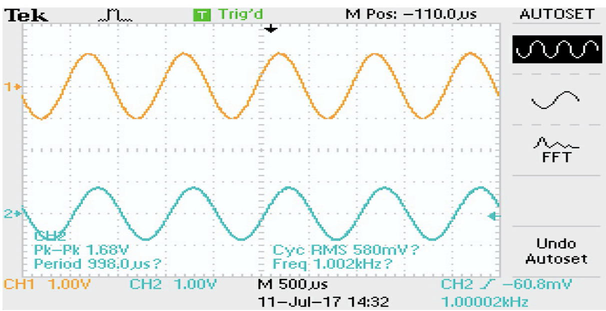

Fig. 8: The waveforms of both input and output voltage

Meanwhile, the measured values we got are as follows:

TABLE IV: Measured values of variables

Variable	Measrued values
Rise time/μs	270
Fall time/μs	280
Pk-Pk/V	1.68

2. In order to measure the RC response to sinusoidal signals with various frequencies, we keep the input amplitude at 1 V, then we sweep the frequency from the starting input frequency of 10 Hz and varying it using a 1-2-5 sequence up to 1 MHz (i.e. set input frequency to 10 Hz, 20 Hz, 50 Hz, 100 Hz, 200 Hz ... up to 10MHz. What we need to record is amplitudes of the output signals. The original datas of the experiment are as follows.

f/Hz	10	20	50	100	200
Amplitude/V	2.08	2.04	2.04	2.04	2.00
f/Hz	500	1k	2k	5k	10k
Amplitude/Hz	1.92	1.68	1.2	0.6	0.32
f/Hz	20k	50k	100k	200k	500k
Amplitude/Hz	0.156	0.072	0.0384	0.0248	0.0136
f/Hz	1M				
Amplitude/Hz	0.0096				

Therefore, we plot the amplitude of the output voltage in terms of frequency in Figure 9.

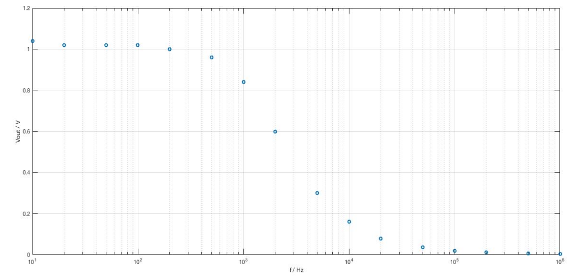

Fig. 9: The amplitude of the output voltage in terms of frequency

To make the results more obvious, we plot both the theoretical values and measured values in terms of frequency in Figure 10.

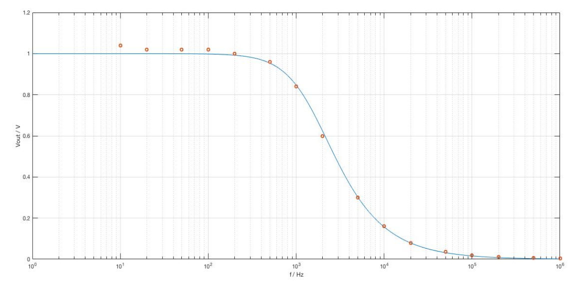

Fig. 10: Comparison of theoretical and measured values

According to Figure 10, the experimental results are in good agreement with the theoretical results. With the increase of frequency, the amplitude of voltage decreases constantly, and the gradient of the curve is slow, then urgent, and finally tends to slow down.

3. In this part, we change the output to the voltage over the resistor. Other conditions remain same as section 4.2.2. The original datas we obtained are as follows.

f/Hz	10	20	50	100	200
Amplitude/V	0	0.0034	0.076	0.148	0.284
f/Hz	500	1k	2k	5k	10k
Amplitude/Hz	0.664	1.18	1.64	2.04	2.12
f/Hz	20k	50k	100k	200k	500k
Amplitude/Hz	2.12	2.12	2.12	2.12	2.12
f/Hz	1M				
Amplitude/Hz	2.12				

According to the data obtained, we plot the amplitude of the output voltage in terms of frequency in Figure 11.

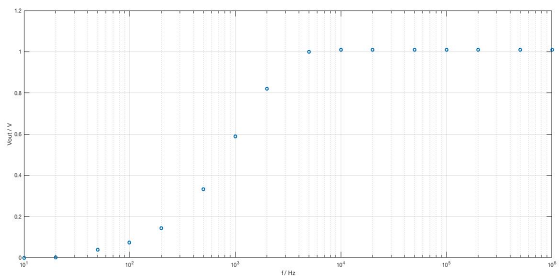

Fig. 11: The amplitude of the output voltage in terms of frequency

In order to compare the difference between the theoretical situation and the real situation we plot both the theoretical values and measured values in terms of frequency in Figure 12.

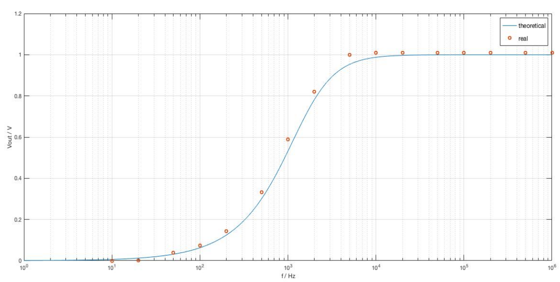

Fig. 12: Comparison of theoretical and measured values

According to the images we get, the experimental results are in good agreement with the theoretical results. With the increase of frequency, the amplitude of voltage increases constantly, and the gradient of the curve is slow, then urgent, and finally tends to slow down. When the frequency is large enough, even if the frequency continues to increase, the voltage amplitude tends to be a constant.

IV. CONCLUSIONS

The RC Response to a Step Function

After building the RC circuit and setting relevant parameters, we got the waveforms and data of the experiment, which are shown in section III. As the figures shown above, the waveform displayed by the oscilloscope is very similar to the theoretical results, indicating the correctness of the circuit connection. Then, after recording values of some parameters, such as the period of the input signal, the 10%-point, 50%-point, and 90%-point of output voltage and comparing them to theoretical ones, we can conclude that there are some factors that cause the error: internal error of experimental apparatus, accidental error when recording data.

Time constant is also an important characteristic of an RC circuit, and its value can be extracted from measured data. We finally got the values of time constant of different RC circuits, which are shown in the table below.

	one-stage	two-stage	three-stage
$\tau/\mu s$	102	321.9	624.0

The RC Response to a Sinusoidal Function

After building the RC circuit and setting relevant parameters, we got the waveforms and data of the experiment, which are shown in section III. Then we changed the frequency of input in the RC circuit and recorded the amplitudes of output signals, which are shown above. From the figure, we can conclude that with the increase of frequency, the amplitude of voltage decreases constantly, and the gradient of the curve is slow, then urgent, and finally tends to slow down.

Also, from the figures, we can conclude that with the increase of frequency, the amplitude of voltage increases constantly, and the gradient of the curve is slow, then urgent, and finally tends to slow down. When the frequency is large enough, even if the frequency continues to increase, the voltage amplitude tends to be a constant..

During this lab, we do gain knowledge on using the equipment to build an RC circuit and learn the procedures of analyzing the circuit by changing the input magnitude or frequency. From the results, we can draw a conclusion that our experimental results are within error tolerance, indicating the success of our first lab. In addition, we also make innovations that we put forward some new ideas when calculating the time constant, stating them in section III.

V. APPENDIX

In the second experiment we found that the result in rise time of the graph is always less precise than the fall time. At the rise time, the error is about 5% while in the fall time the error is about 3%. We think the reason is that maybe when we got data in the rise time we recorded more data from the two sides of the graph and less from the center of the graph. And when goes to fall time, we did the opposite. The data in the center of the graph is more precise because the slope is smoother there. Next time when we do experiment, we should get data from the center where the slope is smoother, leading the data to be more precise.