Lab 1 RC Circuit

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EE233 Circuit Theory

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***Abstract*—**

I. Introduction

II. Lab Procedure

III. Experimental Procedure and Analysis

A. The RC Response to a DC Input

1) Square Wave Input Analysis: We built the circuit in figure[1] with a resistor of $10\text{k}\Omega$ and a capacitor of 0.01μF. However, the actual resistance and capacitance we got are $R_1 = 10.1\text{k}\Omega$ and $C_1 = 0.0183\mu$F. Thus, $\tau_1 = R_1C_1 = 0.185\mu$s.

We set the function generator to provide a square wave input with the period $T = 4.00000000$ms and the voltage of $V_{pp} = 5$V with offset $+2.5$V, which generates a square wave of maximum voltage 5V and minimum 0V.

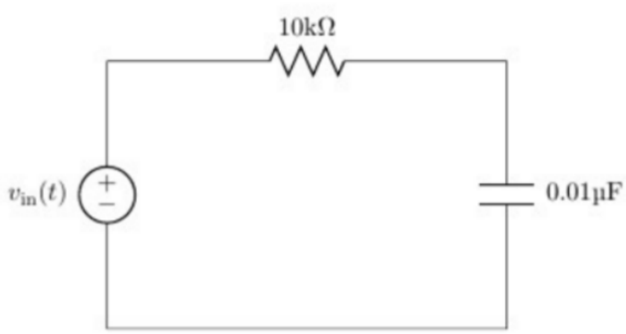

Fig. 1. RC circuit for square wave input analysis

We used channel 1 of the oscilloscope to verify the input and measured the output voltage of the capacitor by channel 2. Figure[2] is the screen output of two and half cycles.

Analyze #1:
The oscilloscope did display the same waveform plotted in Prelab#7. They are of the same shape, and both of their peaks and valleys reach the input waveform. Meanwhile, no obvious difference is found.

Using the *Cursor* menu, we recorded the period T, as well as the range of the output signal. Then we measured the time value of the 10%, 90%, and 50% point of V_{out}. The results are shown in table[I].

After calculating the rise time, fall time, and delay time of the RC circuit, we got table[II]. Using the results we've calculated in prelab, both rise time and fall time are 2.2τ, and delay times are 0.69τ.

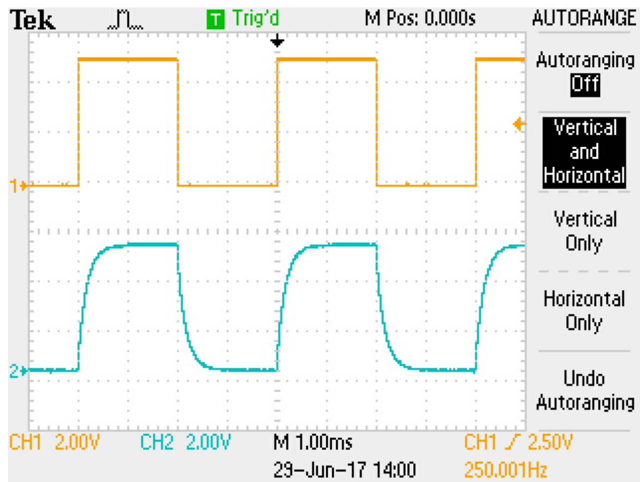

Fig. 2. The waveform of input and measure

TABLE I
Measurements of the output signal

name	value
period	4.000ms
max voltage	5.120V
min voltage	0.000V
time of $10\%V_{out}$ (LH)	20μs
time of $90\%V_{out}$ (LH)	480μs
time of $50\%V_{out}$ (LH)	124μs
time of $10\%V_{out}$ (HL)	12μs
time of $90\%V_{out}$ (HL)	394μs
time of $50\%V_{out}$ (HL)	106μs

TABLE II
Comparing actual values with theoretical values I

name	actual value (calculated)	theoretical value	PE
rise time	460μs	$407\mu s$	13.0%
fall time	382μs	$407\mu s$	6.1%
delay time (LH)	124μs	$128\mu s$	3.1%
delay time (HL)	106μs	$128\mu s$	17.2%

Analysis #2:
There are a few reasons that can lead to the error. First, the 10%, 90%, and 50% points we measured on the oscilloscope were not precise. We could not set the cursor the exactly the points. Second, their might be error with the capacitance measured by *Digit Multimeter*. The capacitance may be lower than it is measured, for the reason that most actual values

are lower than their theoretical value. Finally, the oscilloscope itself might interfere with the circuit, causing minor systematic error.

TABLE III
COMPARING ACTUAL VALUES WITH THEORETICAL VALUES II

name	actual value (measured)	theoretical value	PE
rise time	348μs	407μs	14.5%
fall time	369μs	407μs	9.3%
delay time (LH)	124μs	128μs	3.1%
delay time (HL)	106μs	128μs	17.2%

Analysis #3:

As is shown in table[III], the automatically measured figures are all lower than the theoretical ones. The final two reasons of Analyze #2 can also cause the error here. Compare those with quantities in table[II], we can learn that the first reason mentioned in Analyze #2 is not the major problem. Although we cannot make sure that the point we measured is precise, the oscilloscope's automatically measurement did not improve the PE result greatly.

2) Time Constant Measurement:

After we connected the circuit in Graph[1] in the lab instruction, we detected a waveform on our oscilloscope. To calculate its time constant accurately, we need as many data as possible. According to the instruction, we recorded 10 points separately for the original circuit, two-stage and three-stage. When we were selecting our testing points, we tried to pick more where the voltage rose(or fell) more rapidly with time. Also, we noticed that the measurements were not stable on the oscilloscope if its value was too small, so we paused the screen on random to record a relatively accurate number.

When we were measuring the voltages and their according time, we used the Cursor whose type was time and took Channel 2 as its source. We settle one of the cursor at start point of a rising or falling action, and moved the other cursor slightly. We also scaled the width of the waveform to get a more accurate move.

Our recordings for the original circuit are shown in the table below.

Analyze #4:

Then we apply the data in Excel, we get a plot[3].

After we tried to conduct the formula under the Analysis #4 in the instruction file, we found that we need to adjust the value of y-axis from $V_{out}(t)$ to $\frac{V_0 - V_{out}(t)}{V_0}$ so that the unit of voltage is unrelated to the final result, also leaving the exponential part alone on the right side of the equality mark. Also, it is the y-axis(ratio) that needs to be logarithmic, not x-axis(time). After making y-axis logarithmic, it is equivalent to applying the ln operation to both side of the equation and taking the left side as y. Thus making the right side become $-\frac{t}{\tau}$. Then we can fit the current plot to a linear line and calculate the time constant from the inverse of the line's slope as shown in the graph[4].

Then we fit a linear line to this plot, and we get a slope of -4970. we get its inverse $2.012 \times 10^{-4} s$.

TABLE IV
EXPERIMENT RECORD IN THE ORIGINAL CIRCUIT

No	Voltage(V)	time(μs)
1	0.64	24.0
2	1.32	56.0
3	1.96	88.0
4	2.16	100
5	2.76	140
6	3.14	176
7	3.76	248
8	4.20	340
9	4.40	412
10	4.60	512

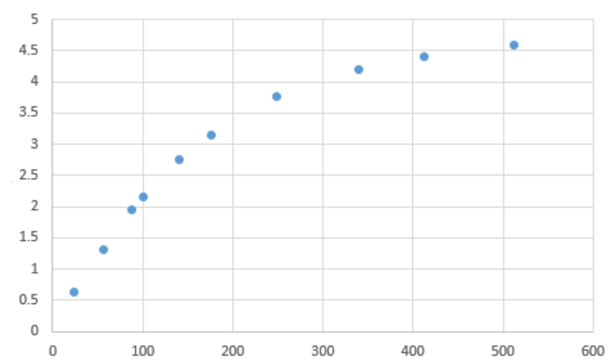

Fig. 3. Plot on the Voltage of capacitor in the original circuit with time.

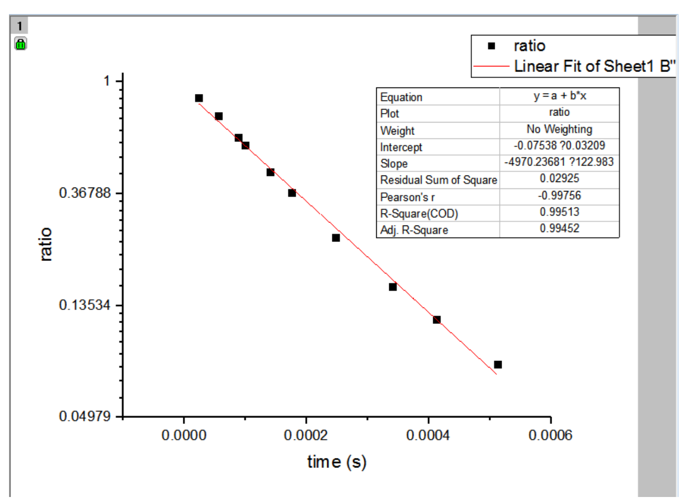

Fig. 4. plot on the logarithmic ratio () in the original circuit with time.

Also, we calculated the theoretic value for τ and got $\tau = RC = 10k\Omega \times 0.01\mu F = 1 \times 10^{-4}s$, which led to a 101% error.
We think it was pretty strange, so we used the multimeter to measure the actual value of the resistor and capacitor we used in our circuit. From measurement, we found that the real value of resistor was 10.1kΩ, which was quite near to its printed value 10kΩ. However, the capacitor's real value had a great error with its printed value. The capacitor we used had an actual capacity of 18.3nF. After we put the real value of our elements into the calculation of theoretical value of time constant, we got
$\tau = RC = 10.1k\Omega \times 18.3nF = 1.85 \times 10^{-4}$, which led to a percent error of 8.76%, a quite better result than before.
But there are still some difference. We discussed and think that the possible resource of difference may among the list below:
1. The oscilloscope had a measure error on the output signal.(May caused by the interference of the current in the circuit and other reasons)
2. The resistor in the cables and experimental boards were not taken into account.
3. The capacitor showed an unstable value for its capacity when we measured it, so its capacity may be easily influenced by some factors in the environment(such as temperature).
4. The capacitor may act like a resistor or an inductor at extreme frequencies.

Analyze #5:

To finish this analysis, we built a two-stage circuit and then a three-stage circuit. Our two-stage circuit is built according to graph[5].

In the same way as in the original circuit, we measure 10 points to compute its time constant. Like in the original circuit, we plot two figures to show the relative of our measures in two-stage. We then get the time constant of two-stage $\tau = -\frac{1}{slope} = -\frac{1}{-1825} = 5.479 \times 10^{-4}$.
And according to the circuit graph and some prelab exercise and the result of our measurement in analysis 4, we can easily compute the theoretical value of time constant in this case:
$\tau = 3RC = 3 \times 1.85 \times 10^{-4} = 5.55 \times 10^{-4}$ and the percent error $error = 1.28\%$.

Our three-stage circuit was built based on graph[8].

And our measure points are listed below:

Like in the original circuit, we plot two figures

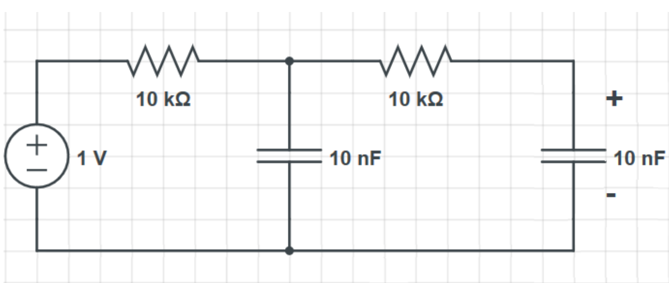

Fig. 5. The circuit graph of two-stage circuit

TABLE V
EXPERIMENT RECORD IN THE TWO-STAGE CIRCUIT

No	Voltage(V)	time(μs)
1	0.04	20.0
2	0.08	30.0
3	0.16	50.0
4	0.48	90.0
5	0.80	130
6	1.68	250
7	2.40	360
8	3.04	500
9	4.28	1000
10	4.72	1650

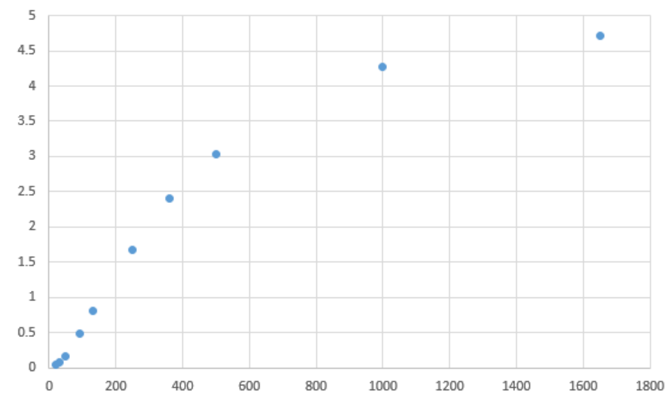

Fig. 6. Plot on the Voltage of capacitor in the two-stage circuit with time.

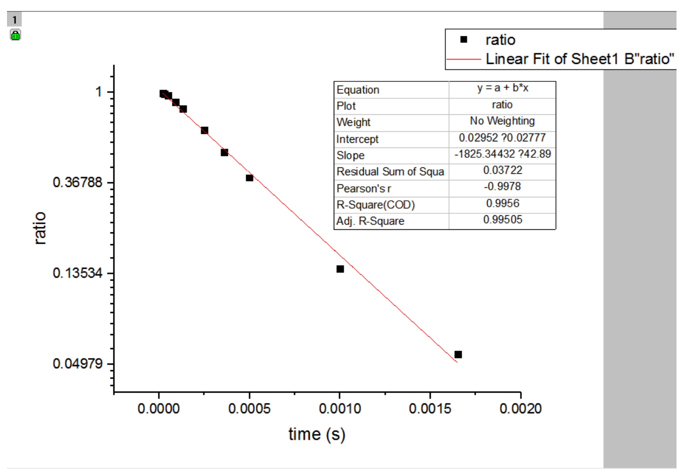

Fig. 7. Plot on the Voltage of capacitor in the two-stage circuit with time.

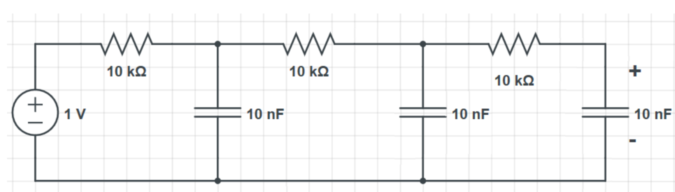

Fig. 8. The circuit graph of three-stage circuit

TABLE VI
EXPERIMENT RECORD IN THE THREE-STAGE CIRCUIT

No	Voltage(V)	time(ms)
1	0.04	100
2	0.24	180
3	0.52	250
4	0.82	330
5	1.28	450
6	1.80	600
7	2.40	810
8	3.00	1110
9	3.60	1550
10	3.92	1930

to show the relative of our measures in three-stage. We then get the time constant of three-stage

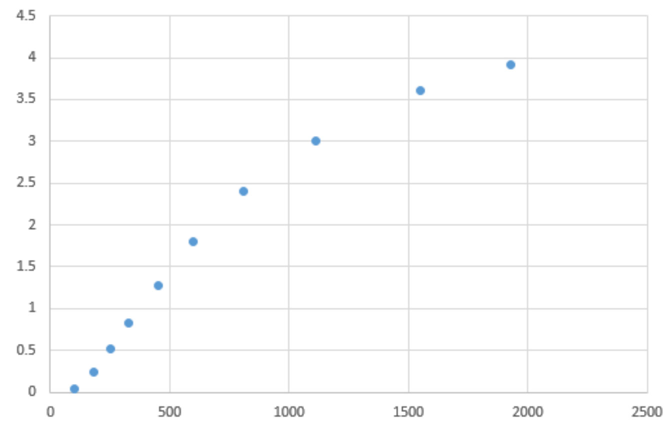

Fig. 9. Plot on the Voltage of capacitor in the three-stage circuit with time.

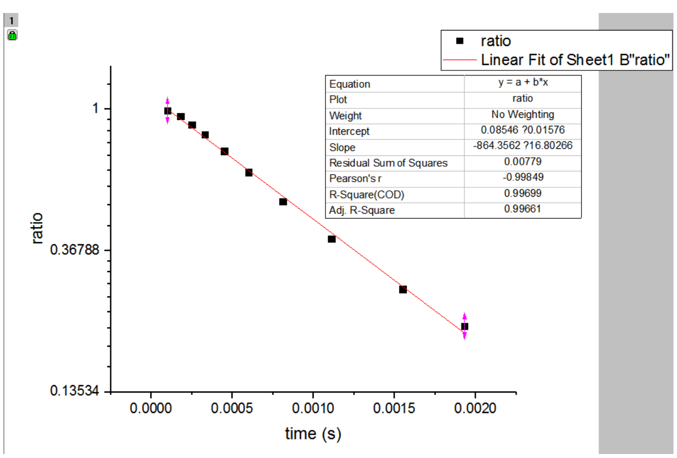

Fig. 10. Plot on the Voltage of capacitor in the three-stage circuit with time.

$\tau = -\frac{1}{slope} = -\frac{1}{-864.4} = 1.157 \times 10^{-3}$.
And according to the circuit graph and some prelab exercise, we can easily compute the theoretical value of time constant in this case:

$\tau = 6RC = 6 \times 1.85 \times 10^{-4} = 1.11 \times 10^{-3}$ and the percent error $error = 4.23\%$.
We thought the reason for the difference may among these reasons:
1. Some existing reasons that we have already mentioned in Analysis 4.
2. The resistors and capacitors we used to build two-stage and three-stage circuit may be different from those in the original circuit, thus causing some difference.
3. Other equipment errors caused by adding more elements and wires in our circuit.

B. *The RC Response to a Sinusoidal Input*

IV. CONCLUSIONS

V. APPENDIX