AC Circuits & Impedance

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(5nd Week Post-Experiment Lab Report)

I. EXPERIMENT DATA & ANALYSIS

A. Capacitors and Capacitive Reactance

For the **first measurement of the first experiment**, the circuit shown in the figure below was constructed. Switches were not available, so the switches S_1 and S_2 were simulated by connecting and disconnecting the wires between the respective components. Initially, the "switches" were both put as open. The first measurement was on closing the S_1 switch and observing the LED. When this was done, LED1's light was turned on and slowly turned off.

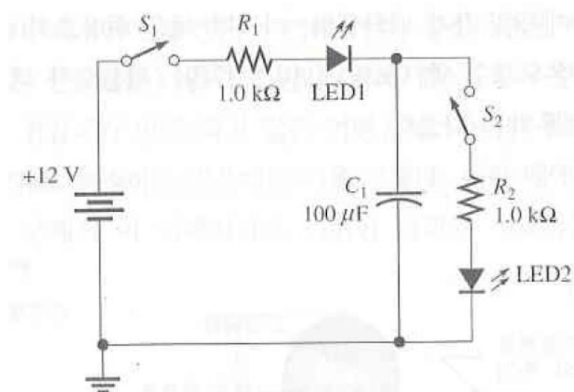

FIG. 1. Capacitor circuit.

The reasons for this result can be attributed to the behaviour of the capacitor. In a DC (direct current) circuit, while the capacitor was charging, current would have passed through LED1, causing it to turn on. However, as the capacitor was charged to it's maximum charge, it can be deduced that the capacitive reactance would have increased, with the frequency f going to 0 in the limit. This would have caused near-infinite resistance to occur at the capacitor's position, leading no current to flow through LED1. A formal mathematical description could be expressed as the following.

$$\limsup_{t\to\infty} \frac{1}{2\pi f C} = \infty$$

The **second measurement set of the first experiment** was on observing what happens after S_1 is opened and S_2 is closed. When this was done, LED2 showed similar behaviour to LED1; LED2 was turned on, and after the capacitor was fully discharged, it was turned off. After this qualitative observation was finished, the voltage across the capacitor dependent on the capacitance C of capacitor was recorded, as seen in table I below. With this voltage data, the charge of the capacitor was also calculated and compared with theoretical values.

In the **third measurement set of the first experiment**, the 12 V DC power source was taken away and a function generator was connected to the circuit. The frequency was set as 10 Hz, and the amplitude was set as 10 V to observe what behaviours the LEDs would show. After both switches were closed, both LEDs showed blinking behaviour, indicating a clear AC flow.

C of capacitor (µF)	V of capacitor (V) (experimental)	V of capacitor (V) (theoretical)	% diff.
0.001	10.78	12.00	10.17
0.01	10.78	12.00	10.17
0.1	12.00	12.00	0
0.47	10.78	12.00	10.17
1	10.77	12.00	10.25
4.7	10.75	12.00	10.42
47	10.74	12.00	10.50
100	8.78	12.00	26.83

TABLE I. Voltage across the capacitor depending on the capacitance.

C of capacitor (µF)	q of capacitor (µC) (experimental)	q of capacitor (µC) (theoretical)	% diff.
0.001	0.01078	0.01200	10.17
0.01	0.1078	0.1200	10.17
0.1	1.200	1.200	0
0.47	5.067	5.640	10.17
1	10.77	12.00	10.25
4.7	50.53	56.40	10.42
47	504.8	564.0	10.50
100	878.0	1200	26.83

TABLE II. Charge of the capacitor depending on the capacitance.

In the **fourth measurement set of the first experiment**, the following figure was first constructed.

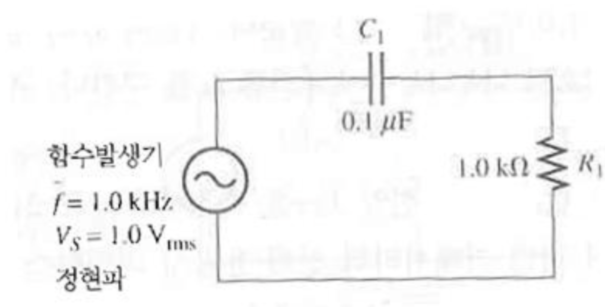

FIG. 2. Capacitor circuit.

In this measurement set, the goal was in trying to deduce the capacitance value of the capacitor using the deducible impedance of the circuit. The impedance is the equivalent resistance that the circuit experiences, and thus is analogous to Ohm's law.

$$I = \frac{V}{Z}$$

Here, the impedance Z can again be dissected into influences by the resistor, capacitor, and the inductor like the following.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Here, the X_{L} and X_{C} are the inductive and capacitive reactance respectively. Through this set of formulae, along with the capacitive reactance formula, namely

$$X_C = \frac{1}{2\pi f C},$$

the capacitor's capacitance was deduced using purely current and voltage measurements. The following tables show what variables and physical quantities were sought to deduce the final capacitance value, which was compared with the capacitance value written on the capacitor. Each capacitor had a value of 0.1 µF, and the V_{PP} of the function generator was set as 2.828 V, as this was equivalent to the 1.0 V_{RMS} of the diagram.

single			series			parallel		
V_{R} experimental	V_{R} theoretical	% diff.	V_{R} experimental	V_{R} theoretical	% diff.	V_{R} experimental	V_{R} theoretical	% diff.
0.5202	0.5323	2.326	0.2926	0.3000	2.495	0.7433	0.7829	3.929

TABLE III. Voltage of the resistors when the capacitor was a single, put in series, and put in parallel.

single			series			parallel		
I_{R} experimental	I_{R} theoretical	% diff.	I_{R} experimental	I_{R} theoretical	% diff.	I_{R} experimental	I_{R} theoretical	% diff.
0.5202	0.5323	2.326	0.2926	0.3000	2.495	0.7533	0.7829	3.929

TABLE IV. Current of the resistors when the capacitor was a single, put in series, and put in parallel.

single			series			parallel		
V_{C} experimental	V_{C} theoretical	% diff.	V_{C} experimental	V_{C} theoretical	% diff.	V_{C} experimental	V_{C} theoretical	% diff.
0.8380	0.8472	1.098	0.4776	0.4773	0.06281	0.6122	0.6230	1.764

TABLE V. Voltage across a single capacitor when the capacitor was a single, put in series, and put in parallel.

single			series			parallel		
X_{C} experimental	X_{C} theoretical	% diff.	X_{C} experimental	X_{C} theoretical	% diff.	X_{C} experimental	X_{C} theoretical	% diff.
1.611	1.592	1.179	3.265	3.183	2.511	0.8127	0.7958	2.079

TABLE VI. Capacitive reactance when the capacitor was a single, put in series, and put in parallel.

single			series			parallel		
C experimental	C theoretical	% diff.	C experimental	C theoretical	% diff.	C experimental	C theoretical	% diff.
0.09879	0.1	1.225	0.04875	0.05	2.564	0.1958	0.2	1.145

TABLE VII. Total capacitance when the capacitor was a single, put in series, and put in parallel.

In the **fifth measurement set of the first experiment**, the following figure was first constructed. The voltage and currents across each component (additionally, the capacitive reactance of the capacitor) for both AC and DC components were separately measured and recorded in the tables below.

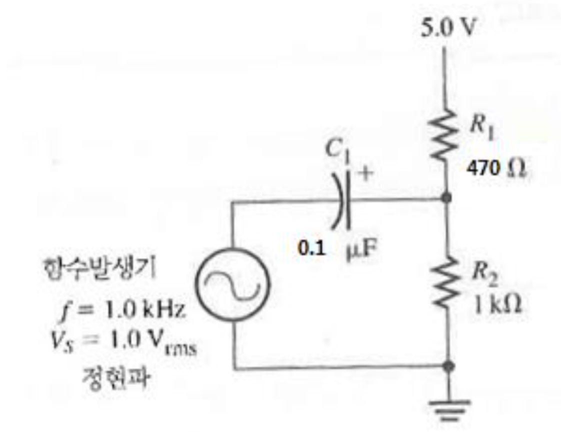

FIG. 3. Capacitor circuit.

V_{R_1} (V)			V_{R_2} (V)			V_C (V)		
V experimental	V theoretical	% diff.	V experimental	V theoretical	% diff.	V experimental	V theoretical	% diff.
1.580	1.598	1.202	3.352	3.401	1.474	3.555	3.401	4.321

TABLE VIII. Voltage across each component when only the DC power source was applied.

I_1 (mA)			I_2 (mA)			X_C (kΩ)		
I experimental	I theoretical	% diff.	I experimental	I theoretical	% diff.	I experimental	I theoretical	% diff.
3.361	3.401	1.205	3.352	3.401	1.474	null	null	null

TABLE IX. Current and capacitive reactance across each component when only the DC power source was applied.

V_{R_1} (V)			V_{R_2} (V)			V_C (V)		
V experimental	V theoretical	% diff.	V experimental	V theoretical	% diff.	V experimental	V theoretical	% diff.
0.201	0.197	1.794	0.203	0.197	3.401	0.977	0.981	0.440

TABLE X. Voltage across each component when only the AC power source was applied.

I_1 (mA)			I_2 (mA)			X_C (kΩ)		
I experimental	I theoretical	% diff.	I experimental	I theoretical	% diff.	I experimental	I theoretical	% diff.
0.427	0.419	1.803	0.203	0.197	2.763	1.551	1.592	2.643

TABLE XI. Current and capacitive reactance across each component when only the AC power source was applied.

B. Inductors and Inductive Reactance

In the **first measurement set of the second experiment**, the following figure was first constructed. Through the oscilloscope, the voltage across each component was sought, and the derived inductive reactance was used to calculate a experimental inductance value. This experimental inductance value was compared with the inductor's actual inductance value, as seen in tables below.

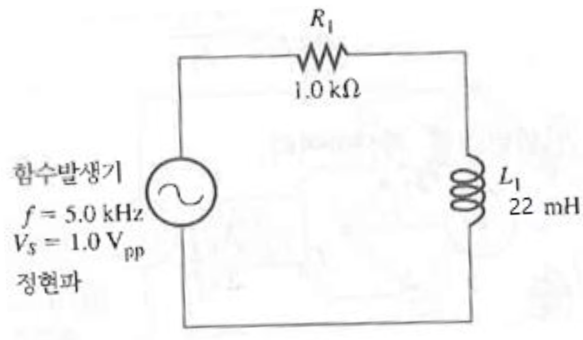

FIG. 4. Inductor circuit.

single			series			parallel		
V_R experimental	V_R theoretical	% diff.	V_R experimental	V_R theoretical	% diff.	V_R experimental	V_R theoretical	% diff.
0.255	0.291	13.91	0.187	0.207	10.92	0.296	0.334	12.91

TABLE XII. Voltage of the resistors when the inductor was a single, put in series, and put in parallel.

single			series			parallel		
I_R experimental	I_R theoretical	% diff.	I_R experimental	I_R theoretical	% diff.	I_R experimental	I_R theoretical	% diff.
0.255	0.291	13.91	0.187	0.207	10.92	0.296	0.334	12.91

TABLE XIII. Current of the resistors when the inductor was a single, put in series, and put in parallel.

single			series			parallel		
V_I experimental	V_I theoretical	% diff.	V_I experimental	V_I theoretical	% diff.	V_I experimental	V_I theoretical	% diff.
0.182	0.201	10.32	0.132	0.143	8.157	0.0959	0.116	20.40

TABLE XIV. Voltage of a single inductor when the inductor was a single, put in series, and put in parallel.

single			series			parallel		
X_I experimental	X_I theoretical	% diff.	X_I experimental	X_I theoretical	% diff.	X_I experimental	X_I theoretical	% diff.
0.714	0.691	3.153	1.418	1.382	2.539	0.324	0.346	6.667

TABLE XV. Inductive reactance of the inductors when the inductor was a single, put in series, and put in parallel.

single			series			parallel		
I experimental	I theoretical	% diff.	I experimental	I theoretical	% diff.	I experimental	I theoretical	% diff.
22.72	0.1	1.225	0.04875	0.05	2.564	0.1958	0.2	1.145

TABLE XVI. Total inductance when the inductor was a single, put in series, and put in parallel.

C. Impedance and Phase Angles

In the **first measurement of the third experiment**, the following circuit was first constructed. Along with this circuit and the circuit shown in figure 4, the difference in phase between the voltage signal of the inductor (capacitor) and the voltage signal of the function generator was sought and compared.

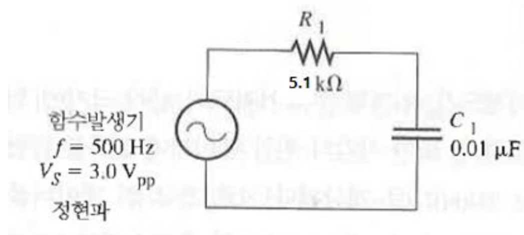

FIG. 5. Series DC Circuit.

frequency (kHz)	t_1 (µs)	t_2 (µs)	$t_2 - t_1$ (µs)	phase difference experimental (degrees)	phase difference theoretical (degrees)	% diff.
5	18.00	50.00	32.00	57.60	55.35	3.906
10	8.000	20.00	12.00	43.20	35.88	16.94

TABLE XVII. RL Circuit, phase difference.

frequency (kHz)	t_1 (µs)	t_2 (µs)	$t_2 - t_1$ (µs)	phase difference experimental (degrees)	phase difference theoretical (degrees)	% diff.
0.5	320.0	720.0	400.0	72.00	80.90	12.36

TABLE XVIII. RC Circuit, phase difference.

II. DISCUSSION

A. Goals and Recapitulation of Experiments

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A. Goals and Recapitulation of Experiments

For the whole experiment, there were three sub-experiments, aimed at obtaining a total of two goals. The two goals were:

a. Understand basic components such as resistors, capacitors, and inductors, and thereby construct an alternating current circuit.

b. Through the concept of impedance, broaden understanding of alternating current circuits.

Consequently, in total, there were 5 different sets of measurements made for the first experiment, 1 set of measurements made for the second experiment, and 1 set of measurement for the third experiment. The 7 measurement sets can be seen in the list below.

1. The first measurement (set) of the first experiment was on quantitatively observing what happens to the LEDs in the circuit shown in figure 1 after only S_1 was closed. Switches were not available, so the switches S_1 and S_2 were simulated by connecting and disconnecting the wires between the respective components. Initially, the "switches" were both put as open. The first measurement was on closing the S_1 switch and observing the LED. When this was done, LED1's light was turned on and slowly turned off.

2. The second measurement (set) of the first experiment was on quantitatively observing what would happen to the LEDs in the circuit shown in figure 1 after only S_2 was closed after the capacitor was charged. When this was done, LED2 showed similar behaviour to LED1; LED2 was turned on, and after the capacitor was fully discharged, it was turned off. After this qualitative observation was finished, the voltage across the capacitor dependent on the capacitance C of capacitor was recorded, as seen in table I. With this voltage data, the charge of the capacitor was also calculated and compared with theoretical values.

3. The third measurement (set) of the first experiment was on observing what would happen to the circuit when an AC power source was supplied. A 12 V DC power source was taken away and a function generator was connected to the circuit. The frequency was set as 10 Hz, and the amplitude was set as 10 V to observe what behaviours the LEDs would show. After both switches were closed, both LEDs showed blinking behaviour, indicating a clear AC flow.

4. The fourth measurement (set) of the first experiment

was on experimentally deducing the capacitance of the capacitor through finding the capacitive reactance.

5. The fifth measurement (set) of the first experiment was on verifying the superposition theorem, by supplying both an AC current and DC current on a circuit and observing its behaviour.
6. The first measurement (set) of the second experiment was on experimentally deducing the inductance of the inductor through finding the inductive reactance.
7. The first measurement (set) of the third experiment was on finding the phase difference between voltages through components and the AC source in various circuits.

B. Evaluation and Error Assessment

Throughout the experiment, the errors were minimal, showing a successful verification of our theory. However, there were deviations in the third measurement set of the first experiment, along with errors ranging from 0 to 10 % throughout the whole three experiments. Some sources of these errors can be summed up like the following.

Load effects happen when adding something like an LED to a circuit changes how other parts of the circuit work. For instance, when you put an LED in a circuit, it can change how much voltage or current flows through other components like resistors or capacitors. This change can make measurements or predictions less accurate. To deal with load effects, it's important to think about how the new part (like the LED) will affect the rest of the circuit. You might need to adjust things or use special techniques to make sure the circuit works as expected and gives accurate results.

Temperature effects occur when changes in temperature affect how components in a circuit work. For example, when the temperature rises or falls, it can cause components like resistors, capacitors, or inductors to behave differently than expected. This change in behavior can lead to variations in electrical properties such as resistance, capacitance, or inductance, which can affect the overall performance of the circuit. To deal with temperature effects, it's important to consider how temperature changes might impact the components in the circuit. Using components that are designed to withstand a range of temperatures or implementing temperature compensation techniques can help minimize the impact of temperature variations and ensure the reliability of the circuit's operation.

A faulty connection between terminals causes increased resistance at the connection spot. This extra resistance can cause a drop in voltage across the circuit, making the reading inaccurate. Also, things like electromagnetic interference or changes in power supply can add unwanted signals to the measurement, making the true voltage harder to see. Making sure the measurement tools are calibrated correctly and reducing outside interference are important to fix these problems and get accurate voltage readings.

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