Lab 2: Frequency Response

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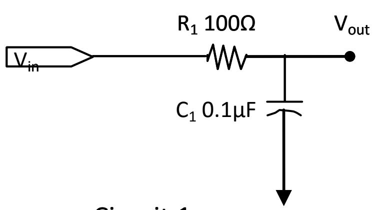
Purpose:

1) Get familiar with and be able to use oscilloscope to measure some characters of waves of input and output voltage, such as frequency, Peak-Peak voltage, phase etc, and compare the waves of input voltage and output voltage.
2) Understand the characters of capacitor, be able to theoretically analyze the frequency response of capacitor-resistor circuit;

Content:

1) Build the following circuit on breadboard



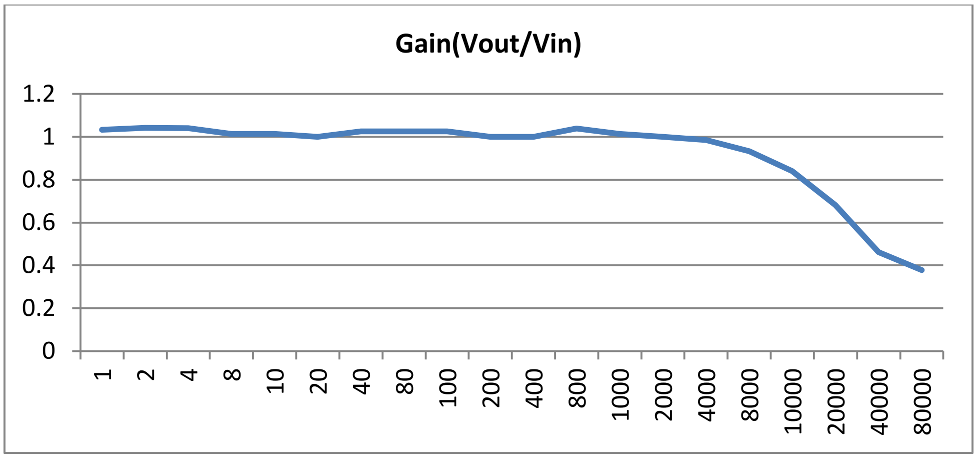
Circuit 1

In the left circuit, V_{in} is sin wave, fed by power supply, the measured values (frequency of Vin, frequency of V_{out}, Input Voltage, output voltage, and phase of V_{out}) are show in following table

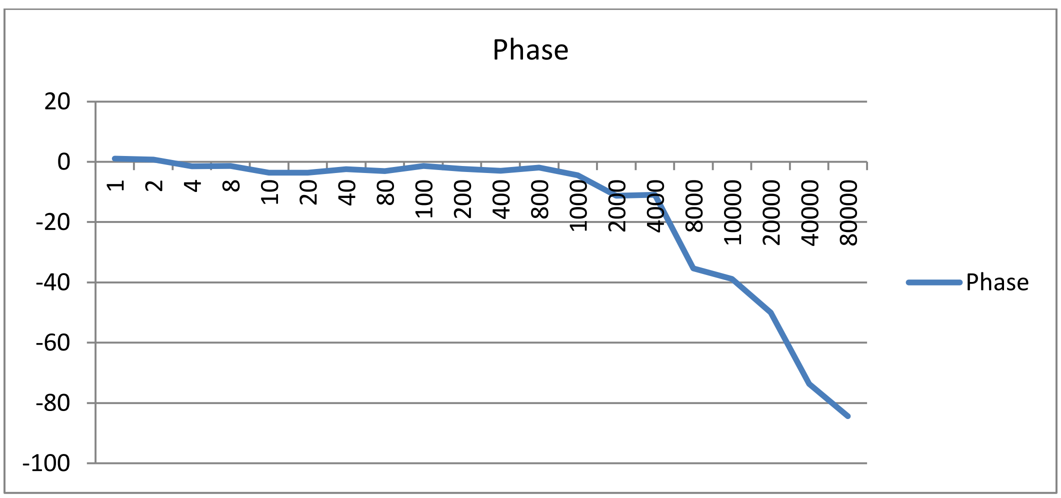
R_1=99.2 Ω C=0.104μF

Frequency	Frequency (V_{in}) Hz	Frequency (V_{out}) Hz	V_{in} (Volt)	V_{out} (Volt)	Gain (V_{out}/V_{in})	Phase of V_{out}
1	0.964	0.970	2.4	2.48	1.033333	1.04
2	2.101	2.11	2.84	2.96	1.042254	0.759
4	3.215	4.0	3	3.12	1.04	-1.45
8	7.74	7.81	3.08	3.12	1.012987	-1.4
10	9.91	9.95	3.08	3.12	1.012987	-3.6
20	18.59	18.6	3.12	3.12	1	-3.58
40	40.34	40.54	3.12	3.2	1.025641	-2.4
80	79.38	79.95	3.12	3.2	1.025641	-3.04
100	116.3	116.1	3.12	3.2	1.025641	-1.4
200	216.2	215.4	3.12	3.12	1	-2.36
400	400	403.2	3.12	3.12	1	-2.98
800	799.5	802.7	3.08	3.2	1.038961	-1.92
1000	114.9	1140	3.08	3.12	1.012987	-4.45
2000	2240	2230	3.04	3.04	1	-11.2
4000	4000	4018	2.84	2.8	0.985915	-10.9
8000	7910	8000	2.4	2.24	0.933333	-35.3
10000	14020	14000	2	1.68	0.84	-38.9
20000	24110	23500	1.76	1.2	0.681818	-50
40000	9480	9090	1.56	0.72	0.461538	-73.7
80000	24760	25000	1.48	0.56	0.378378	-84.2

The Gain(V_{out}/V_{in}) frequency response is shown as following



The phase frequency response is shown as following



In the previous two pictures, the frequency response curves are not very smooth, that is partly because the amount of measure points are relatively low, the trend of curves, however, can demonstrate the characters of Low-Frequency filter circuits, namely the value of gain(V_{out}/V_{in}) decreases with increase of frequency of input voltage, the phase of output voltage lags more behind with the increase of frequency of input voltage.

Theoretical analysis:

In the circuit 1:

$$V_{out}=V_c=I*Rc=(V_{in}/(R_1+R_c))*R_c$$

$$\Longrightarrow Gain=V_{out}/V_{in}=R_c/(R_1+R_c)=1/(R_1/R_c+1)$$

$$R_c=1/j\omega C_1 \Longrightarrow \text{Gain}=1/(R_1{*}j\omega C_1+1) \xrightarrow{\omega=2\pi f} \begin{cases} \omega \approx 0, & \text{Gain} \approx 1 \\ \omega \to \infty, & \text{Gain} \approx 0 \\ \omega: 0 \to \infty, & \text{Gain}: 1 \to 0 \end{cases}$$

because $$|\text{Gain}| = {}^{1}\Big/\sqrt{\omega^2 * R_1^2 * C_1^2 + 1} = {}^{1}\Big/\sqrt{(2\pi f)^2 * R_1^2 * C_1^2 + 1} \qquad \text{(a)}$$

When Gain is 3dB down, the frequency is calculated as following:

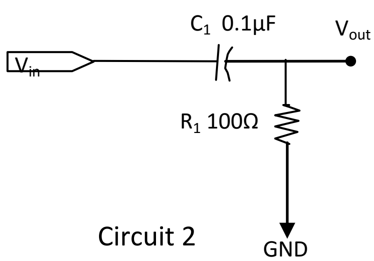
$${}^{1}\Big/\sqrt{(2\pi f)^2 * R_1^2 * C_1^2 + 1} = 0.707 \Longrightarrow 2 * \pi * f * 100\Omega * 0.1 * 10^{-6} = 1 \Longrightarrow f \approx 16000\text{Hz}$$

According to the graph of frequency response of Gain, this frequency corresponding to 3dB down of Gain is almost equal to 16000Hz, so the measured value agrees with its theoretical value. According to equation (a), several points of frequency are calculated as following table

Frequency(Hz)	Calculated Value of Gain	Measured Value of Gain
1000	0.998	1.013
10000	0.847	0.84
20000	0.623	0.681

From the table above, it can be seen that the conservations of lab are valid and the theoretical analysis is also correct.

2) Build the circuit 2 on breadboard

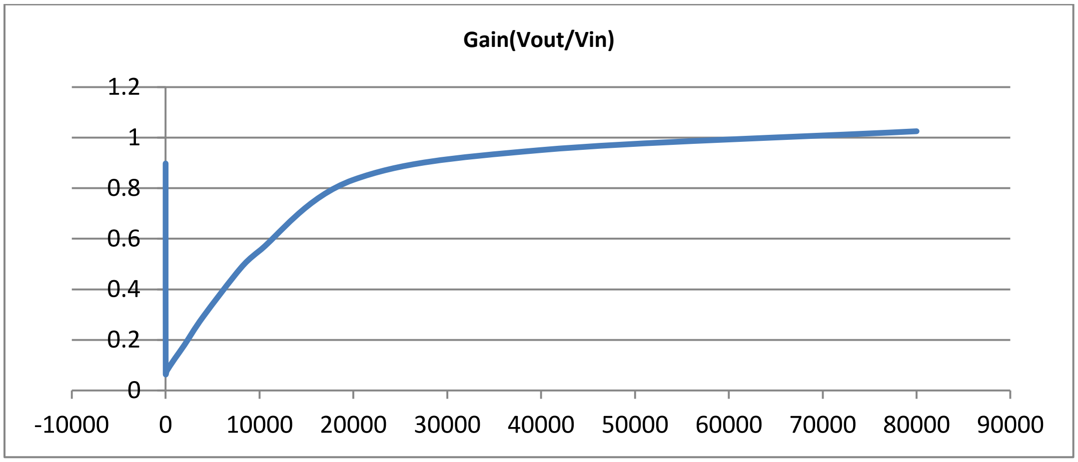


Circuit 2

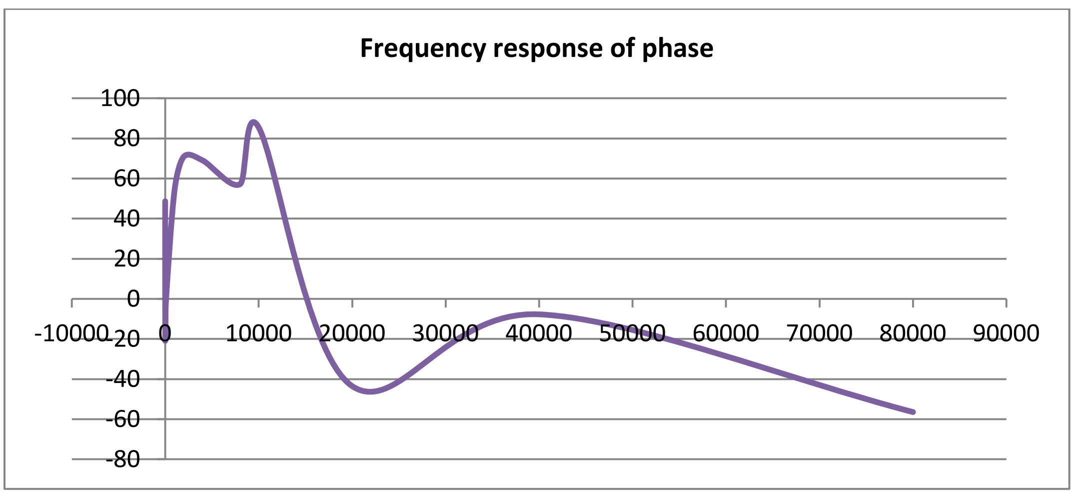
In the left circuit, V_{in} is sin wave, fed by power supply, the measured values (frequency of Vin, frequency of V_{out}, Input Voltage, output voltage, and phase of V_{out}) from oscilloscope are show in following table

Frequency	**Frequency of V_{in} (Hz)**	**Frequency of V_{out} (Hz)**	**V_{in} (Volt)**	**V_{out} (Volt)**	**Gain (V_{out}/V_{in})**	**Phase of V_{out}**
1	0.3464	0.3202	1.96	1.76	0.897959	48.7
10	12.3	9.95	3.12	0.2	0.064103	-18.97
100	124.2	130	3.16	0.24	0.075949	-0.002
1000	1046	1220	3.16	0.4	0.126582	54.1
2000	2050	1939	3.12	0.56	0.179487	71.0
4000	4092	4280	2.88	0.84	0.291667	69.1
8000	8098	8136	2.48	1.2	0.483871	57.2
10000	11450	11590	2.28	1.26	0.552632	85.6
20000	4020	3990	1.80	1.5	0.833333	-43.5
40000	8940	10580	1.64	1.56	0.95122	-7.7
80000	1885	1910	1.56	1.6	1.025641	-56.46

The frequency response of Gain(V_{out}/V_{in})is shown as following graph:



The frequency response of phase is shown as following



From the previous graphs, it can be seen that the gain of circuit increases with the increase of frequency of input voltage (from 0 up to 1), while the phase of output voltage decreases with the increase of frequency of input voltage (the curve in the graph of phase frequency response looks weird, that means that something wrong with the measured values of phase of output voltage); both features demonstrated the characters of high-pass filter .

Theoretical analysis:

In the circuit 2:

$$V_{out}=V_R=I*R1=(V_{in}/(R_1+R_c))*R_1$$

$$\Longrightarrow \text{Gain}=V_{out}/V_{in}=R_1/(R_1+R_c)=1/(1+R_c/R_1)$$

$$R_c = 1/j\omega C_1 \Longrightarrow \text{Gain} = 1/(1/(j\omega C_1 * R_1)+1) \xRightarrow{\omega = 2\pi f} \begin{cases} \omega \approx 0, \quad \text{Gain} \approx 0 \\ \omega \to \infty, \text{Gain} \approx 1 \\ \omega: 0 \to \infty, \text{Gain}: 0 \to \infty \end{cases}$$

$$|\text{Gain}| = {(\omega * R_1 * C_1)} \Big/ {\sqrt{\omega^2 * R_1^2 * C_1^2 + 1}} = {(2\pi f * R_1 * C_1)} \Big/ {\sqrt{(2\pi f)^2 * R_1^2 * C_1^2 + 1}} \qquad (b)$$

According to equation (a), several points of frequency are calculated as following table

Frequency(Hz)	Calculated Value of Gain	Measured Value of Gain
1000	0.063	0.126
10000	0.532	0.553
20000	0.782	0.833

From the table above, though there are deviations between calculated values and observed ones (the deviation maybe caused by the facts that the resistance of R_1 is not exactly 100Ω, the capacitance of $C_1$is not exactly 0.1µf and oscilloscope also has measure error), the observed values of lab largely agree with the theoretical values. So the observations of lab are valid (except the phase measurements) and theoretical analysis is also correct.

Conclusions:

From the lab 2, I understand characters of gain frequency response and phase frequency response for two types of RC filters, namely low-pass filter and high-pass filter, and am able to use circuit theory to analyze the observed the values.

What I did in Lab 2

1)build the circuit according to lab direction;
2)adjust the oscilloscope;
3)take measures;
4)analyze the problem and try to solve the problem

What my lab partner did:

1) Cooperate me with building the circuit;
2) Select the resistor and capacitor and measure then with multimeter;
3) Check the circuit and record the measurements;
4) Analyze the problem encountered during lab with me and try to solve the problem