Lab 5: RC Frequency Response

Purpose:

a) To investigate the variations in circuit impedance, generator current, and phase angle caused by changing frequency in a series RC circuit.
b) To become proficient at measuring and graphing circuit response as a function of frequency.

To be submitted:

1. **Deadline**: At the end of the lab session, submit on LEA the word document and the excel document zipped.
2. **No formal report required**.
    a. Fill in results of all tables (clearly labelled). If calculation is involved, clearly indicate formula used for the calculation.
    b. Attach all the 4 plots as required in step 6.
    c. Answer all the questions in the lab (clearly numbered), and include a final discussion and conclusion session.

Theory:

In series RC circuit, as frequency is increased, there is no change to the resistance, but the capacitive reactance will decrease. The effect on impedance is illustrated in figure below. It can be observed that the magnitude of phase angle of impedance also decreases. Also, it is obvious that the phase angle must always be between -90° and 0°.

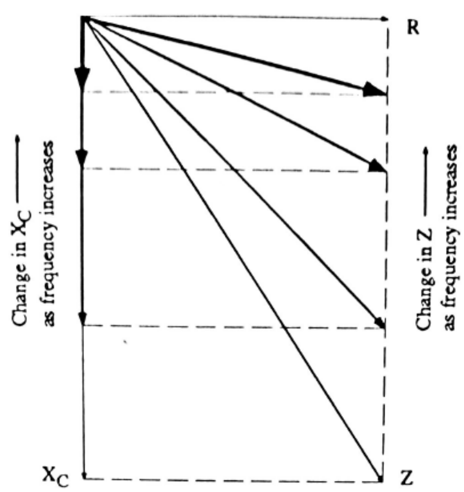

Figure 1: Series RC impedance variation with frequency

For a series circuit, it can be shown that the phase angle between generator voltage and generator current will always be the same as the angle of impedance. If generator voltage lags generator current, the phase angle will be negative, indicating a circuit that is acting capacitive. Therefore, the magnitude and the sign of the impedance phase angle is always the same as the phase angle between generator voltage and generator current.

It is helpful to visualize the variation in circuit phase angle versus frequency, which is shown in the figure below.

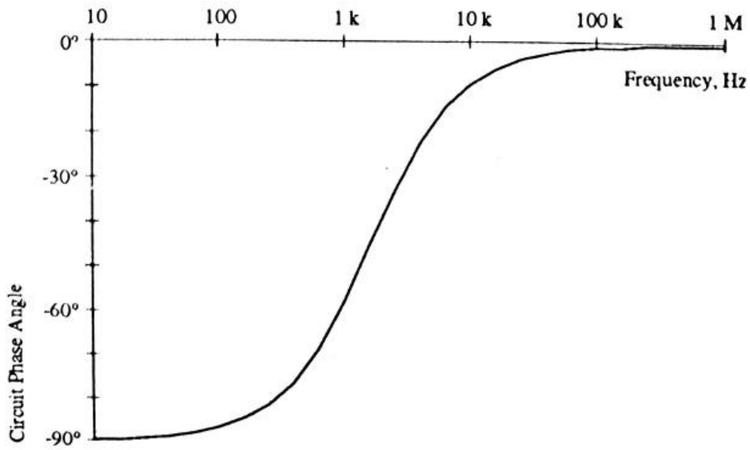

Figure 2 : Series RC circuit phase response versus frequency

Lab Work:

1. Put numbers in from lab report

Frequency	Calculations					
	X_C	Z	I_g	V_C	V_R	Phase
3 kHz	530.5Ω	1.1kΩ	1.27mA	673mV	1.27V	-28°
7 kHz	227.4Ω	1kΩ	1.4mA	318mV	1.4V	-16°

Table 1: Series RC circuit calculation

2. Connect the circuit of Figure 3.

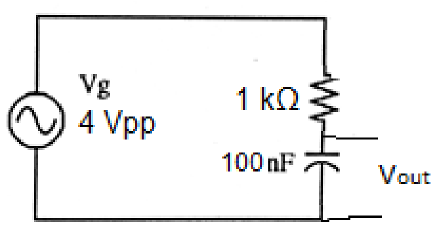

Figure 3 : Series RC measurement circuit

3. Set the generator frequency to 10 Hz. Measure the Vg and Vc voltage (rms) and enter the measurement into Table 2.

4. Repeat step 3 for the remaining frequencies listed in Table 2. Be sure to keep your generator voltage constant.

5. Complete the calculations required for `Table 2` using the following relationships.

$$I_g = \frac{V_R}{R}$$

$$Z = \frac{V_g}{I_g}$$

$$Phase = -\cos^{-1}\frac{V_R}{V_g}$$

6. Use the data from this table to plot graphs of **V_c, I_g, Z** and **phase** angle versus **frequency** (logarithmic scale). 4 Graphs required here.

Frequency	Frequency in number	Measurements			Calculations		
		V_g	V_C	V_R	I_g	Z (in Ω)	Phase
10 Hz	10	1.40Vrms	1.37Vrms	9.0mVrms	9uA	155.555k	-89°
30 Hz	30	1.40Vrms	1.40Vrms	27.5mVrms	27.5uA	50.909k	-89°
100 Hz	100	1.40Vrms	1.39Vrms	91.0mVrms	91uA	15.384k	-86°
200 Hz	200	1.40Vrms	1.38Vrms	180mVrms	180uA	7.777k	-82°
400 Hz	400	1.40Vrms	1.35Vrms	349mVrms	349uA	4.011k	-75°
700 Hz	700	1.40Vrms	1.27Vrms	576mVrms	576uA	2.430k	-66°
1 kHz	1000	1.40Vrms	1.17Vrms	758mVrms	758uA	1.846k	-57°
1.5 kHz	1500	1.40Vrms	1.00Vrms	965mVrms	965uA	1.450k	-46°
2 kHz	2000	1.40Vrms	861mVrms	1.10Vrms	1.1mA	1.272k	-38°
3 kHz	3000	1.40Vrms	650mVrms	1.24Vrms	1.24mA	1.129k	-28°
4.5 kHz	4500	1.40Vrms	461mVrms	1.31Vrms	1.31mA	1.068k	-21°
7 kHz	7000	1.40Vrms	308mVrms	1.36Vrms	1.36mA	1.029k	-14°
10 kHz	10000	1.40Vrms	219mVrms	1.38Vrms	1.38mA	1.014k	-10°
30 kHz	30000	1.40Vrms	74.80mVrms	1.39Vrms	1.39mA	1.007k	-7°
50 kHz	50000	1.40Vrms	45.19mVrms	1.39Vrms	1.39mA	1.007k	-7°
100 kHz	100000	1.40Vrms	22.82mVrms	1.40Vrms	1.4mA	1k	-1°
200 kHz	200000	1.40Vrms	11.50mVrms	1.40Vrms	1.4mA	1k	-1°
300 kHz	300000	1.40Vrms	7.70mVrms	1.40Vrms	1.4mA	1k	-1°

`Table 2 : Series RC circuit measurements`

Questions:

1. Compare and comment on your calculations in Table 1 with the data in Table 2, for 3 kHz and 7 kHz frequencies.

   My results from table 1 match closely to what I got in table 2. For the 3 kHz: 1.1kΩ (for Z), 1.27mA (for I_G), 673mV (for V_C), 1.27V (for V_R), -28° (for phase) and for the 7 kHz: 1KΩ (for Z), 1.4mA (for I_G), 318mV (for V_C), 1.4V (for V_R), -16° (for phase). If you compare these results in Table 2, you'll see they are very close.

2. Based on the results of your measurement, is this a high-pass or low-pass filter? Explain.

   Based on the results, this is a low-pass filter. The graph in my excel spreadsheet ("Graph of V_C versus frequency") shows that when a higher frequency is applied, there is no charge in the capacitor and when a lower frequency is applied, there is a charge stored in the capacitor. Moreover, the circuit above Table 1 shows the measurement is coming from the output of the capacitor, therefore this is automatically a low-pass filter.

3. Refer to Table 2. For frequency of 1 kHz, do your values of resistor voltage and capacitor voltage add up to the generator voltage? Show your calculation.

   The result, when calculated, doesn't add up to the exact waveform generator output voltage. Here is my calculation below. You'll see that the calculated (from measurement) value differs from the measured value of V_G.

   $V_G = V_C + V_R$
   $= 1.17V_{RMS} + 758mV_{RMS}$
   (Calculated) $V_G = 1.928V_{RMS}$
   (Measured) $V_G = 1.40V_{RMS}$

4. Refer to your graph of Phase angle vs Frequency. Indicate, from your graph, the frequency at which the circuit phase angle is -45°. Compare this frequency to the cutoff frequency that is calculated with the following relationship:

   Calculated cutoff frequency:

   $$f = \frac{1}{2 \times \pi \times R \times C}$$
   $$f = \frac{1}{2 \times \pi \times 1k\Omega \times 100nF}$$
   $$f = 1.6kHz$$

   Looking at my graph, it has come to my attention that my calculated cutoff frequency matches closely to what appears in my graph (when looking at around -45°, the frequency yields around 1.5 kHz-close to what I had calculated).

5. Explain why the current Ig reached an almost constant high value at high frequency.

   As, the value of X_C of the capacitor decreases, the value of I_G reaches a high value when high frequencies are achieved.

Discussion and conclusion:

Recalling the events from today's lab, I was able to learn one of few things. I was able view the behavior of a low-pass filter as this was the circuit that was built and measured. Also, I was able to practice how to calculate certain parameters (ex: phase) using my calculator then change the notation to engineering notation. I was also able to input my measurements into an excel spreadsheet then graph certain parameters versus the frequency applied in the circuit. Finally, I was able to identify and understand specific characteristics of a low-pass filter circuit (ex: question 5 above).