ELCT 201 – EE LABORATORY 1

MEASURING A TRANSFER FUNCTION

CARSON MURRAY

14 SEPTEMBER 2022

DEPARTMENT OF ELECTRICAL ENGINEERING

UNIVERSITY OF SOUTH CAROLINA

COLUMBIA, SC 29208

ABSTRACT

For this lab, a circuit consisting of a 10 kΩ resistor and a 0.01 μf capacitor are connected in series with a $2V_P$ voltage source. This circuits output voltage response to a sine wave voltage source was recorded at many frequencies ranging from 10Hz – 100kHz. Circuit theory concepts such as phase response, impedance, transient response, and transfer functions were present throughout the experiment. The data collected on the circuits response to different frequencies explicitly showed that the increase in frequency resulted in a decrease in output voltage and an increase in phase shift between the input and output voltage.

CIRCUIT APARATUS

The RC circuit shown in Figure 1 was used to collect data for the input and output voltages during this experiment. Probes were connected along before R1 and in between R1 and C1 to measure these voltages.

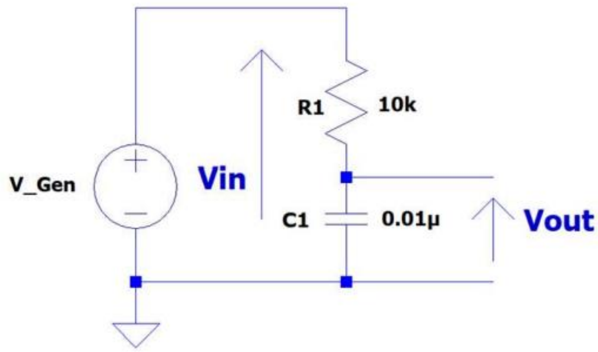

Figure 1. Circuit diagram of the RC circuit utilized in the experiment

COLLECTION OF DATA

A set of 13 different frequencies ranging from 10 Hz to 100 kHz along with their corresponding input and output voltage were recorded during this project. These voltages were calculated with RMS (Root Mean Square) and maximum voltage amplitude. RMS is used to compare the AC voltage to DC voltage, as RMS voltage is equivalent to the amount of DC voltage that causes an equal amount of power dissipation. Along with voltage measurements, phase shift (in degrees) of the output voltage was measured using Equation 1:

$$\varphi^{\circ} = -\arctan(2\pi f RC) \qquad \text{(Eq 1)}$$

This measurement was utilized to calculate the time delay of the output voltage given by the following equation:

$$\Delta t = \frac{\varphi^{\circ}}{360 * f} \qquad \text{(Eq 2)}$$

The measurements mentioned above were organized into the following table:

Frequency (Hz)	Vin (Vrms)	Vout (Vrms)	Vin (Vp)	Vout (Vp)	Time shift of Vo (s)	Phase of Vo (deg)
10	1.35	1.332	1.92	1.92	-1.75E-06	-0.00628
20	1.382	1.365	1.92	1.92	-1.75E-06	-0.01257
60	1.389	1.37	1.96	1.92	-1.74E-06	-0.03768
100	1.386	1.364	1.96	1.92	-1.74E-06	-0.06275
200	1.384	1.355	1.96	1.88	-1.74E-06	-0.12501
600	1.413	1.306	1.96	1.76	-1.67E-06	-0.36052
1000	1.407	1.192	1.96	1.6	-1.56E-06	-0.56098
2000	1.42	0.913	2	1.2	-1.25E-06	-0.89864
6000	1.43	0.415	2	0.44	-6.07E-07	-1.31151
10000	1.349	0.243	2	0.22	-3.92E-07	-1.41297
20000	1.42	0.173	2	0.08	-2.07E-07	-1.49139
60000	1.43	0.128	2	-0.04	-7.15E-08	-1.54428
100000	1.434	0.12	2	-0.08	-4.32E-08	-1.55488

Table 1. Voltage and phase measurements at selected frequencies

DATA REPRESENTATION

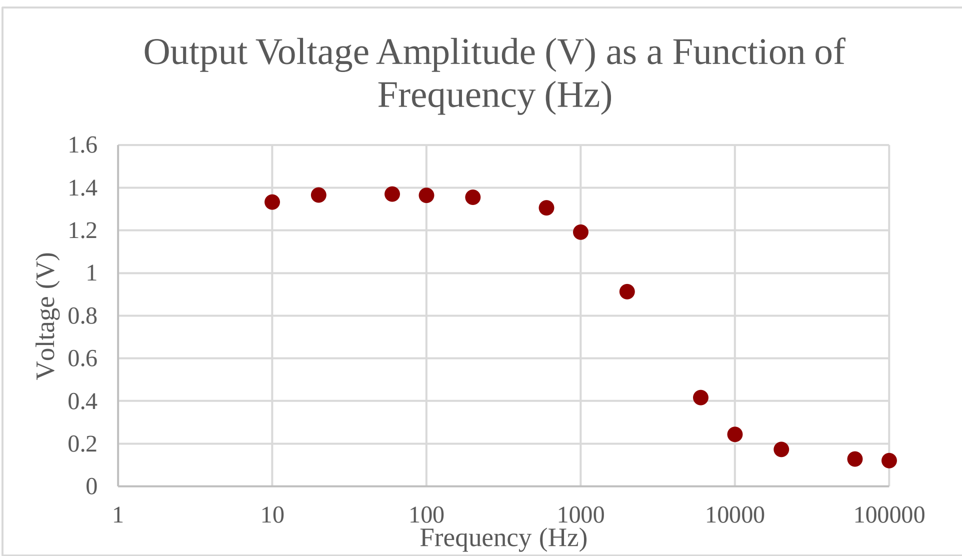

Figure 2. Output voltage amplitude as a function of frequency from 10 Hz to 100 kHz, with a linear voltage axis and a logarithmic frequency axis.

Figure 2 illustrates how output voltage varies when frequency changes. It shows an eventually decrease in voltage around 1000 Hz.

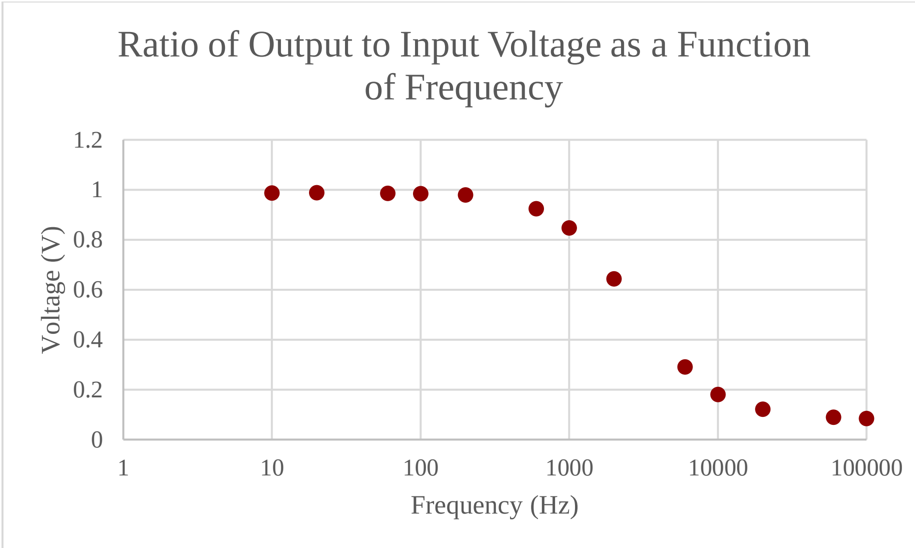

Figure 3. Ratio of output voltage to input voltage, as a function of frequency from 10 Hz to 100 kHz, with a linear voltage axis and a logarithmic frequency axis.

Figure 3 shows how the ratio of output voltage to input voltage changes as frequency changes. Similarly to Figure 2, the voltage ratio decreases as frequencies increase.

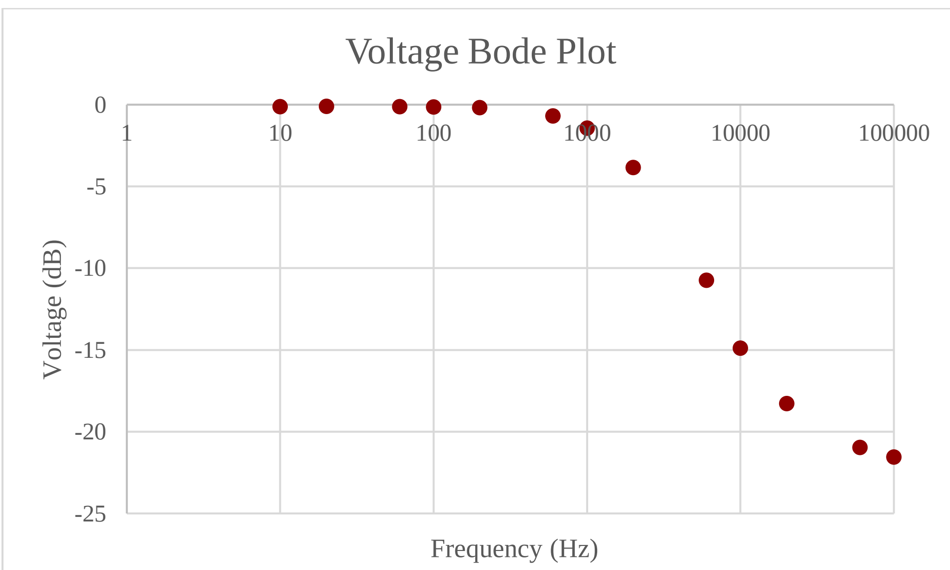

Figure 4. Ratio of output voltage to input voltage, as a function of frequency from 10 Hz to 100 kHz, with the voltage ratio expressed in dB, and a logarithmic frequency axis

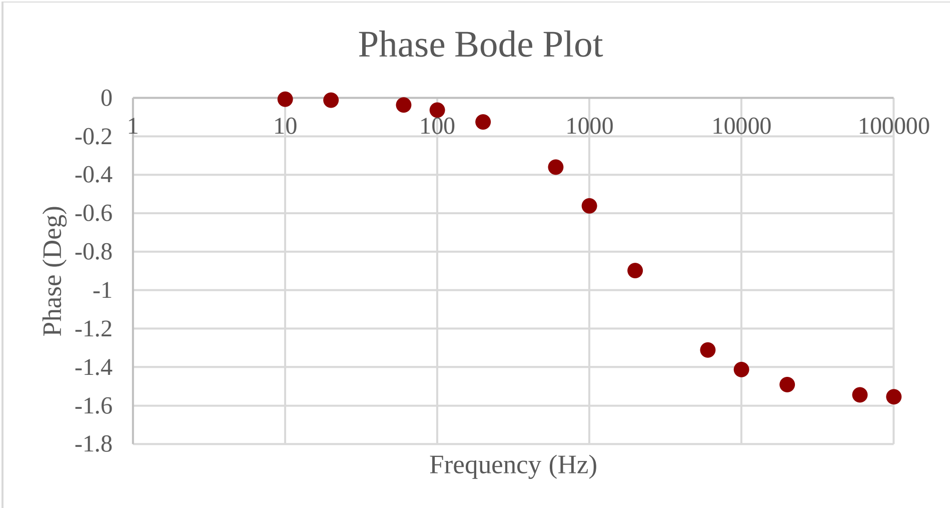

Figure 5. Phase of output voltage, relative to input voltage, as a function of frequency from 10 Hz to 100 kHz, with a logarithmic frequency axis

Figures 4 and 5 represent the voltage and phase Bode plots for the circuit studied during this experiment. It can be concluded from these Bode plots that the circuit shown in Figure 1 is a low pass circuit. Low pass circuits allow lower frequencies to pass a signal until the cutoff frequency is reached. The equation for the cutoff frequency is given as:

$$f_c = \frac{1}{2\pi RC} \qquad \text{(Eq 3)}$$

Plugging in the values from the circuit shown in Figure 1 (10 kΩ resistor and a 0.01 µf capacitor) the cutoff frequency is ≈ 1591.55 Hz. Both the voltage and phase Bode plots begin to decrease at this frequency.

MEASUREMENT OF WAVEFORMS ON OSCILLISCOPE

The oscilloscope was utilized to visualize the circuit's response to the different frequencies that were being applied to it. At first, a sinusoidal voltage wave was created by the voltage generator and applied to the circuit. The following screenshot of the oscilloscope illustrates how the circuit responded to this voltage input.

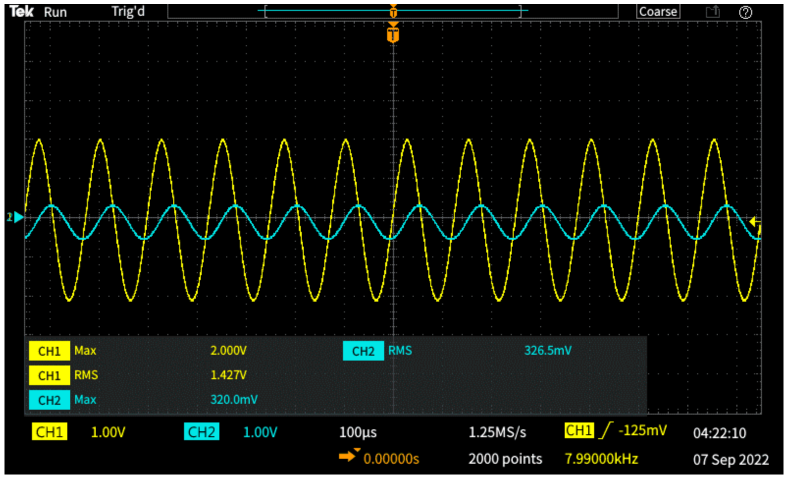

Figure 6. Oscilloscope screenshot of a sinusoidal input voltage with 2V_p *amplitude and 8kHz frequency (Channel 1) and the sinusoidal output voltage (Channel 2)*

The yellow sinusoidal wave illustrates the input voltage (Vin), and the blue sinusoidal wave represents the output voltage (Vout). It is apparent that the amplitude of the output voltage decreased significantly, and a phase shift has occurred because of the capacitor present in the circuit.

The pulse voltage waveform was also measured during the project and is shown in the following screenshot of the oscilloscope.

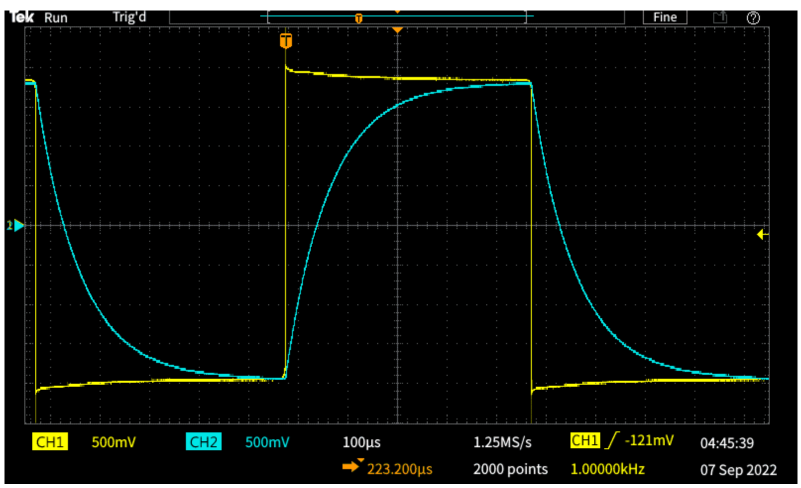

Figure 7. Oscilloscope screenshot of a pulse input voltage with a +2V high voltage and a -2V low voltage and 10kHz frequency (Channel 1) and the resulting transient response of the circuit (Channel 2)

This waveform provides a visual representation of the transient response present in the circuit. This is shown by Channel 2's exponential curves, representing the time delay that occurs for a capacitor, as voltage cannot charge or discharge a capacitor instantly.

ESTIMATING AN UNKOWN COMPONENT

Utilizing relationships between different aspects of a circuit can be helpful in estimating the value of an unknown component. For example, if there is a capacitor within your circuit with an unknown value, it is possible to arrange equations to solve for it. In this case, the reactance capacitance (Equation 4), total impedance (Equation 5), and voltage divider equations can be utilized to solve for capacitance.

$$X_c = \frac{1}{2\pi f C} \qquad \text{(Eq 4)}$$

$$Z = \sqrt{R^2 + X_c^2} \qquad \text{(Eq 5)}$$

Rearranging Equation 5 to solve for X_c:

$$X_c = \sqrt{Z^2 - R^2} \qquad \text{(Eq 6)}$$

Plugging in Equation 4 into Equation 6 and solving for C:

$$C = \frac{1}{2\pi f * \sqrt{Z^2 - R^2}} \qquad \text{(Eq 7)}$$

You can now utilize these variables to solve for the unknown capacitor by plugging in for the values in Equation 7. The function generator and the oscilloscope can be used to determine and/or create the values needed to satisfy the equation.

CONCLUSIONS

This project succeeded in representing how the output voltage was affected by the combination of a 10 kΩ resistor and a 0.01 μf capacitor. A conclusion that was drawn from this experiment was that when the frequency was increased, the output voltage decreased, and the phase increased. This can be seen throughout the data collected in Table 1 and in graphical form in Figures 1-4. Also, the transient response illustrated in Figure 7 is significant as it shows that capacitors take time to charge and discharge.