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**Lab 6**

*Figure 1. Circuit diagram.*

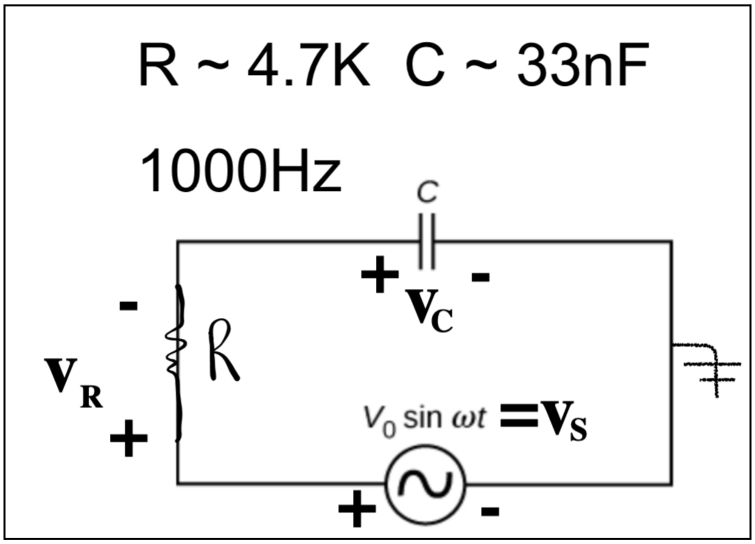



*Figure 2. Built circuit with Scopy probes.*

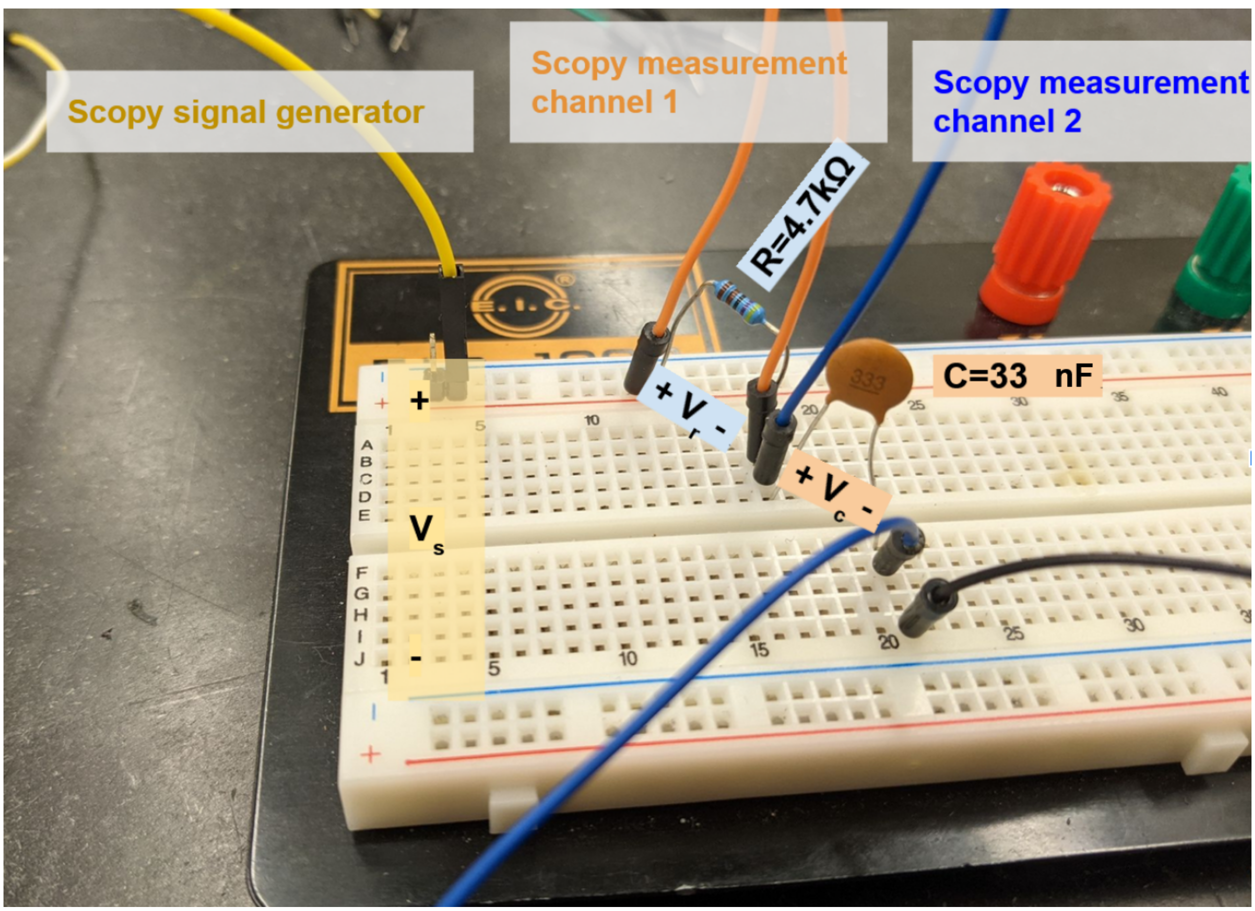
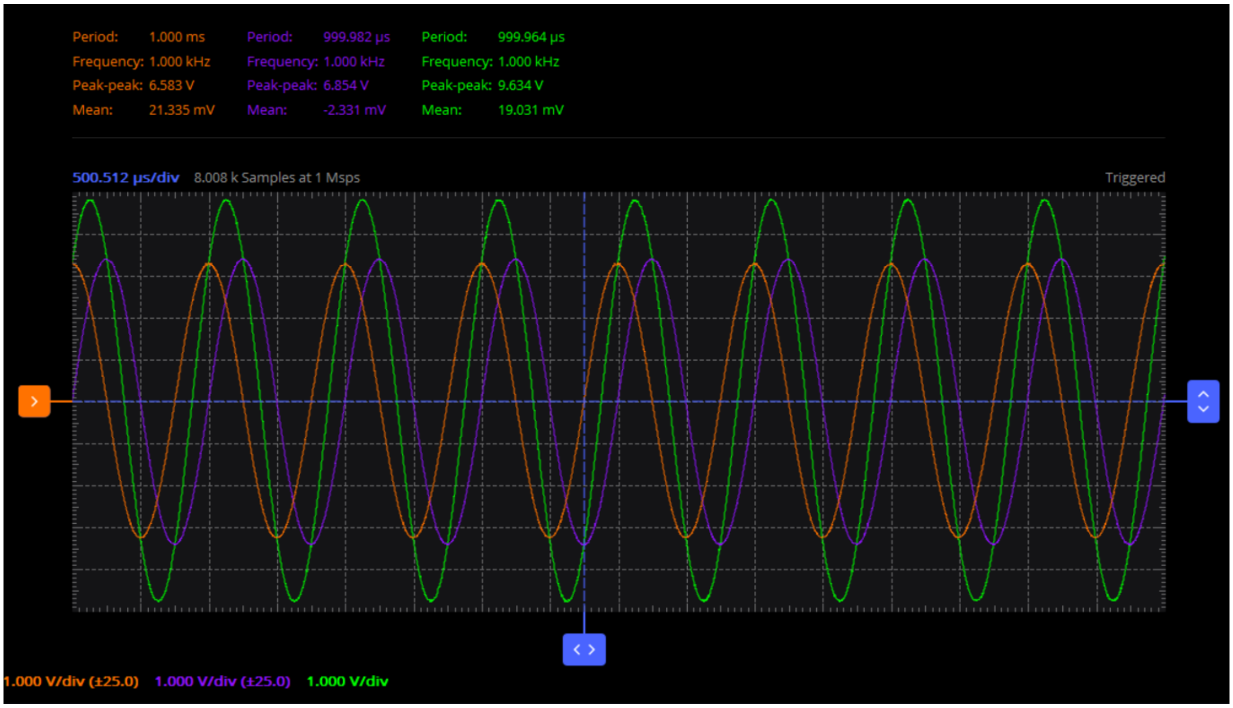


*Figure 3. Using Scopy oscilloscope to measure peak-to-peak voltage. Frequency = 1kHz.*




To determine the gain, Scopy's oscilloscope function was used to measure the peak-to-peak voltages across the resistor and the capacitor. $V_r$ is shown in orange in the figure above, while $V_c$ is shown in purple. By Kirchhoff's Voltage Law, $V_s$=$V_r$+$V_c$, so a math channel was used to calculate $V_s$ based on measured $V_r$ and $V_c$. $V_s$ is shown in green in the figure above.

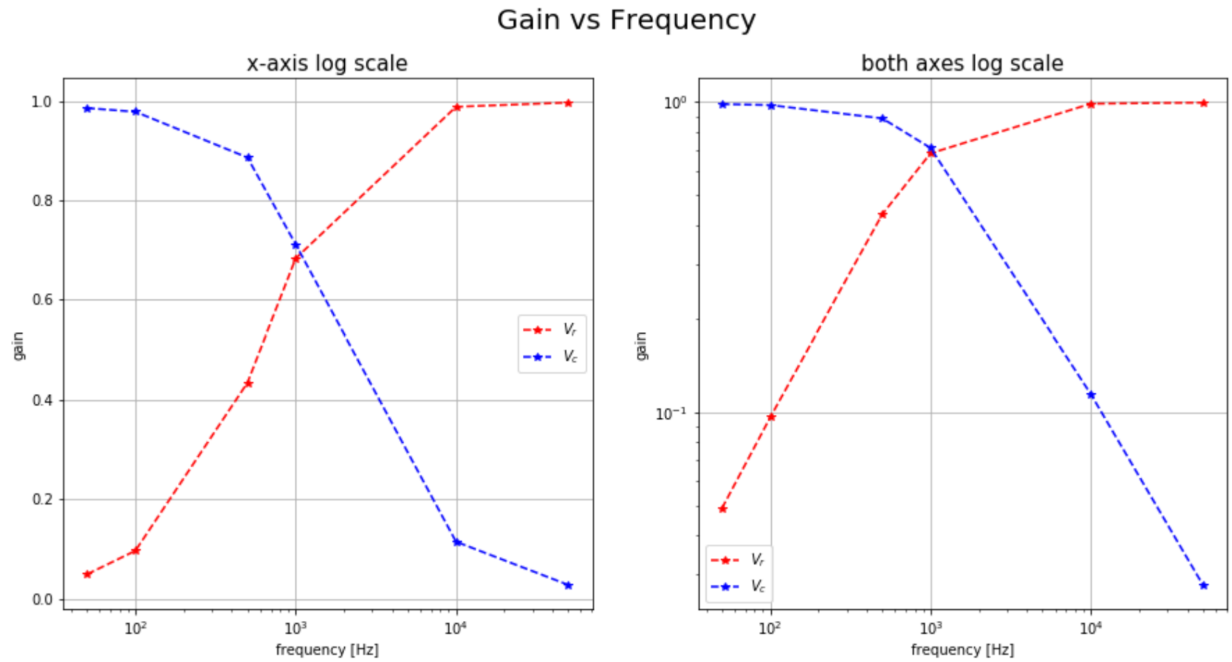
Gain is the ratio of the output voltage to the input voltage. It was calculated for two cases, one treating $V_r$ as the output and one treating $V_c$ as the output. In both cases, $V_s$ was the input. Python was used to organize the peak-to-peak voltages for different frequencies, then calculate and plot the gains at different frequencies.

*Figure 4. Collected data and gain calculations in Python.*

```python
# collected peak-to-peak voltage data from low frequency to high frequency
freq = np.array([50, 100, 500, 1000, 10000, 50000]) #Hz
Vr = np.array([0.47,0.92,4.19,6.58,9.06,8.62]) #v
Vc = np.array([9.45,9.34,8.55,6.85,1.05,0.24]) #v
Vs = np.array([9.59,9.55,9.65,9.63,9.17,8.65]) #v
```

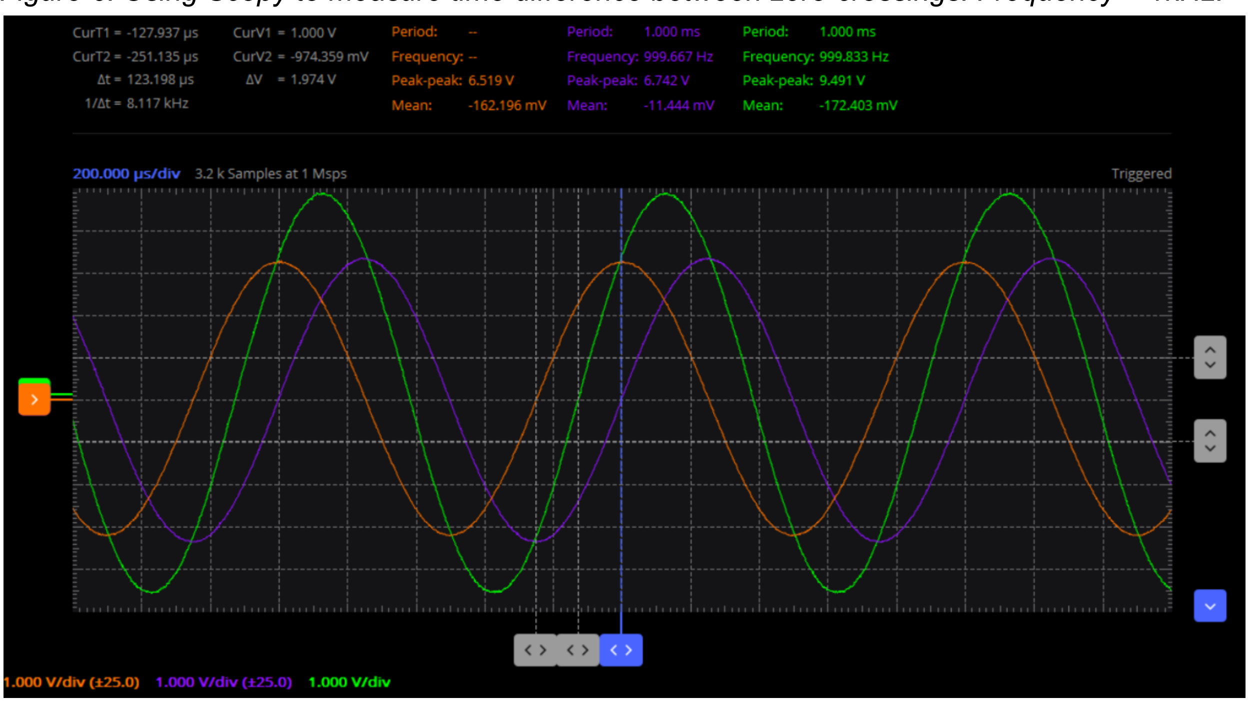
```python
# calculating gain
gain_vr = Vr / Vs
gain_vc = Vc / Vs
```

*Figure 5. Plotted gain vs frequency.*




The figure above shows that the gain of the capacitor and the gain of the resistor are inversely proportional. The gain of the capacitor increases with frequency, while the gain of the resistor decreases with frequency. At a very low frequency, $V_r$ is almost equal to $V_s$, and $V_c$ is much smaller than $V_s$. The gain of the resistor is almost one and the gain of the capacitor is almost zero. At a very high frequency, the reverse is true. At a frequency of 1kHz, both gains are approximately equal.

*Figure 6. Using Scopy to measure time difference between zero-crossings. Frequency = 1kHz.*



To determine the phase difference, the cursor feature in Scopy's oscilloscope function was used to determine the different times at which $V_r$, $V_c$, and $V_s$ crossed the x-axis (were equal to zero volts). The difference in time is displayed, and the sign of the difference was determined by visual inspection of the plotted sinusoidal voltages to determine which voltages led and which voltages lagged. In all cases, $V_s$ was used as the reference voltage. As in previous figures, $V_r$ is indicated in orange, $V_c$ is indicated in purples, and $V_s$ is indicated in green in the figure above. The two cursors are gray. In the above figure, they are being used to measure the time difference between $V_r$ and $V_s$.

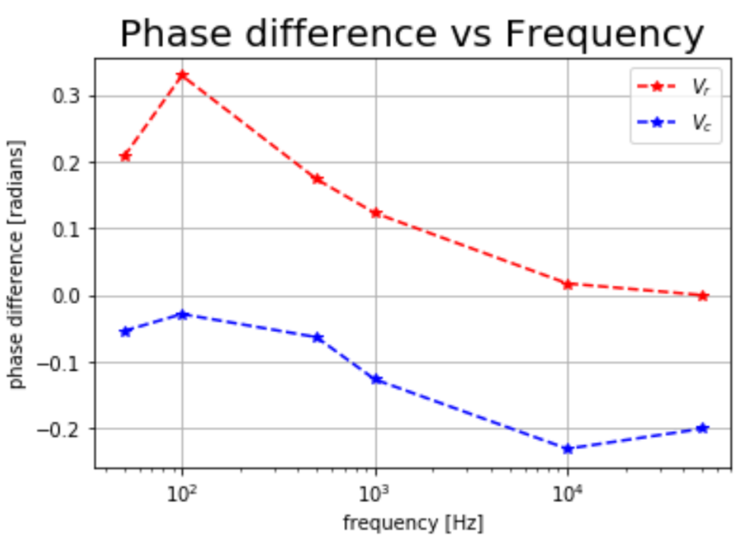
The difference in phase between two sinusoids is equal to the frequency multiplied by the time offset of their zero-crossings. The phase differences between the source voltage and the resistor voltage as well as between the source voltage and the capacitor voltage were calculated and plotted in Python for different frequencies.

*Figure 7. Collected data and phase difference calculations in Python.*

```
# collected time difference data from low frequency to high frequency
tdiff_vr = np.array([0.004138, 0.003285, 0.000347, 0.000123, 0.00000174, 0]) #s
tdiff_vc = np.array([-0.001074, -0.000284, -0.000126, -0.000126, -0.000023, -0.000004]) #s
```

```
# calculating phase difference
phase_diff_vr = freq * tdiff_vr
phase_diff_vc = freq * tdiff_vc
```

*Figure 8. Plotted phase difference vs frequency.*




The figure above shows that the phase difference decreases with frequency. However, the phase difference between $V_r$ and $V_s$ is positive, so as the frequency increases, it approaches zero and the two voltages are closer to being in phase with each other. The phase difference between $V_r$ and $V_s$ is negative, so as the frequency increases, it gets farther from zero in the negative direction and the two voltages are farther from being in phase with each other. Both trends have the same general shape, displaying an increase to a peak, then a decrease with decreasing slope.